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The South African Hydrogen Economy: A TVET-Industry Skills Gap Analysis

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A report produced by Bambili Advisory for submission to UK PACT Output 2.1: TVET-Industry Gaps Analysis Report to assess the structural skills training capacity constraints within the TVET college system and lack of alignment with industry skills needs.

Research consortium partners:

Key stakeholders and primary beneficiaries represented on the steering committee:

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Executive Summary

The purpose of this assignment was to attempt to identify the gaps between the supply of essential technical and vocational skills for the hydrogen and green hydrogen economies from the current South African technical, vocational education and training (TVET) college system, and the current and future demand for those skills in South Africa. Because the green hydrogen economy is nascent globally and in South Africa, an approach was taken which consisted of a literature and document review, supported by interviews with key stakeholders in the current and future industry.

International literature provided a useful overview of the viability of a green hydrogen option (and blue hydrogen) for the world, including South Africa. It seems clear from the wealth of information available globally, that i) policy linked to climate change which requires significant reduction in greenhouse emissions, has become entrenched in almost all global economies via the Paris Agreement and specific national policy commitments and targets have been agreed and ii) this means that the production of clean energy, where green hydrogen[1] plays a major role, will continue to grow exponentially so that national and global targets to reduce greenhouse emissions can be met. The cost effectiveness of green hydrogen as a source of clean fuel and the scale requirement for production have been well documented and it is thus possible to conclude that the production of green hydrogen is likely to achieve commercial scale in the near future.

Domestic literature and documentation is more scant. Although South Africa currently produces, uses and exports grey hydrogen[2] currently, it has yet to begin production of green hydrogen or blue hydrogen.[3] Nonetheless, important policy, scientific and technical work, as well as the exploration of commercial realities, has been and is being undertaken along the hydrogen value chain, from renewable energy (RE) inputs to fuel cell (FC) storage and utilisation of FCs to supply clean energy in a number of applications. The data so far indicate that there is (currently at least) an excellent opportunity and potentially viable commercial logic for the production of green hydrogen to scale in South Africa for domestic consumption and for export.

The review of the TVET system internationally indicates that nations and regions are highly variable in their planning and execution of the delivery of so-called green skills (including hydrogen value chain skills) to the green economy. In some cases, additional content and training has been added to existing highly functional TVET systems, while in others, new green skills categorisations have been developed and are driving additional elements in TVET curricula. In South Africa however, there is an extensive body of literature, and supporting statistical data, that suggest that overall, the TVET system is not strong enough to support the development of skills for the green economy, or the hydrogen economy. Apart from some few excellent TVET individual colleges, the system is unable to meet the current and future needs

[1] Green hydrogen (GH) - where hydrogen is produced using renewable energy (RE).
[2] Grey hydrogen- where hydrogen is produced using non-renewable energy, such as fossil fuels, which contribute to greenhouse emissions
[3] Blue hydrogen- where hydrogen is produced using non-renewable energy such as fossil fuels, but the carbon emissions are captured and stored instead of entering the atmosphere.

of industry as it is constituted. This conclusion is supported by stakeholders in the South African hydrogen economy and post school education and training (PSET) domain.

The TVET system cannot provide adequate quality of graduates with solid and reliable work experience to the hydrogen value chain and industry. This is linked to lack of relevant content in curricula, highly variable lecturer quality, low levels of student entry with science, technical, engineering and mathematics (STEM) qualifications and poor industry/TVET working relationships. This latter means that the TVETs cannot meet industry skills needs as they simply do not know what they will be or are. Nor can they estimate the need for the quantity of skills that are or will be needed, by type. Industry copes with this by generating the necessary skills through the use of private TVET colleges, internal training systems, and specific outsourced service providers which work directly with the company concerned.

Recommendations arising from this report include i) immediately and significantly improving the working relationship between TVET colleges and firms which are and will continue to be involved in the hydrogen economy (and potentially the RE industry as it is the key catalyst for moving from grey to green hydrogen production); ii) significantly improving alignment, budgeting, management and governance of the TVET system with particular attention to aligning policy and budget and to high levels of involvement of industry in all planning activities; iii) immediate focus on improving the quality of lecturers and governance at TVET colleges which are likely to serve hydrogen industry value chain needs and iv)the setting up of a Centre of Specialisation (CoS) in terms of the current programme to focus on the essential skills required by the hydrogen economy going forward.

The development of a Green Skills Master plan for South Africa is highly recommended.

1. Introduction

1.1 Context

Successful and aligned Technical and Vocational Education and Training (TVET) is central to South Africa's economic growth and thus the creation of decent work for South Africans. If TVET skills supply is not aligned to industry needs in terms of type, quality and content, employability is reduced, and industry lacks the resources needed to grow.[4] Creating employment in the Green Hydrogen Economy (GHE) is part of South Africa's Just Transition (JT) strategy as well as a socio-economic imperative. In 2018, those people in South Africa who only received secondary education experienced an unemployment rate between 25.4 and 27 percent, but those who completed tertiary education showed an unemployment rate of 6.2 percent (OECD, 2019).

The Green Hydrogen Economy (GHE) globally comprises industries ranging from firms producing Hydrogen (such as Sasol), to those storing, distributing, and selling/trading Hydrogen, or adding value to Hydrogen as an energy source by manufacturing storage solutions. The required skills for the GHE are typically similar to general industry requirements in manufacturing, logistics and energy storage and utilisation. These are, artisanal skills, technical and digital skills, and others related to the stages of the value chain involved. The dominant means of storage and dissemination of hydrogen derived energy is currently fuel cells (FCs) and of these, the dominant technology is currently Proton Exchange Membrane (PEM) FCs. In South and southern Africa, the industry is essentially pre-commercial. It has not yet begun the growth associated with a viable industry. However, there is a need to ensure that as it progresses along the product life cycle, the TVET system will be in place to ensure a supply of appropriate, sufficient, and quality skills.

The TVET system as it stands is not considered ideal for general industry needs and a number of challenges need to be addressed. Current challenges for industry overall and thus in future for the GHE in South Africa are linked to a lack of skilled persons available in some regions for some industries;[5] curricula, especially with regard to technology, are outdated;[6] the National Certificate (Vocational) NC(V) system does not require work training; many lecturers lack industry knowledge, experience, and training; and NC(V) graduates lack practical know-how.[7] Field (2014) for the Department of Higher Education (DHE) further recorded South African TVET challenges to be as follows:

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[4] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Employment for sustainable development in Africa (E4D). 2018

[5] Martin Kühn. The South African Technical and Vocational Education and Training System from a German Perspective. 2019.

[6] Organisation for Economic Co-operation and Development (OECD). OECD skills outlook 2017: skills and global value chains. 2017. http://hdl.voced.edu.au/10707/429058.

[7] Kühn. The South African Technical and Vocational Education and Training System from a German Perspective.

- Current architecture of the South African TVET system poses a confusing mix of overlapping and competing programmes and qualifications and inadequately developed programmes;
- Current TVET programmes are insufficiently responsive to the current labour market;
- Inadequate skills and qualifications of lecturers and the need to improve professional preparation of college leaders; and
- TVET colleges currently offer limited support for students in academic difficulties, and this reflects insufficient incentives at colleges to encourage completion.

If this is the current reality for industry at large in South Africa, then interventions will be required to ensure GHE readiness in the TVET system.

1.2 Research problem

Because demand in the GHE in South Africa is pre-commercial, there is little known about skills supply and demand. The skills – type and content – which will be required are not well researched at this time. A preliminary assessment is needed so that the South African TVET system can adequately prepare to deliver skills needed by the industries comprising the GHE even if demand may be some years away.

1.3 Research questions

- Is the TVET system adequate to provide the quality, quantum, and capability to ensure a supply of essential skills into the current hydrogen economy (HE) in South Africa and the future GHE?
- What type of skills will be in demand in the future HE and GHE in South Africa?
- In terms of an "ideal state", what are the gaps in full alignment between future GHE industry needs and current TVET ability to supply?
- What if any recommendations can be made at a high level around essential interventions to align future skills supply and demand at the TVET level?

1.4 Aim and objectives of the study

To develop a profile of what the current nature of skills required is for the South African HE overall, with special focus on GHE for the future; the current ability and capacity of the TVET system to supply these, assess the gap and provide high level recommendations for intervention where required.

1.5 Key concepts and terminology

The following are key concepts and terms in the context of this research.

Table 1- Concepts & Terminology

Term/Concept	Definition
4IR	Fourth Industrial Revolution. Also referred to as 4IR or Industry 4.0, describes the age of intelligence and encompasses technologies like artificial intelligence, augmented reality, 3D printing and cloud computing, machine learning and others.
ATR	Auto Thermal Reforming. This is a process for producing syngas, composed of hydrogen and carbon monoxide, by partially oxidizing a hydrocarbon feed with oxygen and steam and subsequent catalytic reforming.
CCS	Carbon Capture and Storage. This is the process of capturing waste carbon dioxide, transporting it to a storage site, and depositing it where it will not enter the atmosphere.
CCUS	Carbon Capture, Utilisation and Storage. As above but some of the carbon is used for applications such as inputs to plastics, growing greenhouse plants, or carbonate fizzy drinks.
CSP	Concentrating Solar Power. Concentrated solar power systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight onto a receiver. Electricity is generated when the concentrated light is converted to heat, which drives a heat engine connected to an electrical power generator or powers a thermochemical reaction.
FC	Fuel Cell. This is an electrochemical cell that converts the chemical energy of a fuel and an oxidizing agent into electricity through a pair of redox reactions.
GE	Green Economy. UNEP defines this as a low carbon, resource efficient and socially inclusive economy. Growth in employment and income are driven by public and private investment into such economic activities, infrastructure and assets that allow reduced carbon emissions and pollution, enhanced energy and resource

Term/Concept	Definition
	efficiency, and prevention of the loss of biodiversity and ecosystem services.
GH	Green Hydrogen. *Green* hydrogen is produced using renewable energy and electrolysis to split water and is distinct from *grey* hydrogen, which is produced from methane and releases greenhouse gases into the atmosphere, and *blue* hydrogen, which captures those emissions and stores them underground to prevent them causing climate change.
GHG	Greenhouse gases are gases in Earth's atmosphere that trap heat. They let sunlight pass through the atmosphere, but they prevent the heat that the sunlight brings from leaving the atmosphere. Two main greenhouse gases are carbon dioxide and methane.
INDC/NDC	Intended Nationally Determined Contribution or nationally determined contribution are non-binding national plans highlighting climate actions, including climate related targets for greenhouse gas emission reductions, policies and measures governments aim to implement in response to climate change and as a contribution to achieving the global targets set out in the Paris Agreement.
JT	Just Transition. Just Transition is a framework originally developed by the trade union movement to encompass a range of social interventions needed to secure workers' rights and livelihoods when economies are shifting to sustainable production, primarily combating climate change, and protecting biodiversity.
PEM	Polymer Electrolyte Membrane. Polymer electrolyte membrane electrolysis is the electrolysis of water in a cell equipped with a solid polymer electrolyte that is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes. It is used in electrolysers and fuel cells.
P2X or power to X	Power-to-X conversion technologies allow for the decoupling of power from the electricity sector for use in other sectors (such as transport or chemicals), possibly using power that has been

Term/Concept	Definition
	provided by additional investments in generation.[8]
SDG	Sustainable Development Goals are a collection of 17 interlinked global goals designed to be a "blueprint to achieve a better and more sustainable future for all". The SDGs were set up in 2015 by the United Nations General Assembly and are intended to be achieved by the year 2030. Also known as Agenda 2030.
TVET	Technical and Vocational Education and Training is education and training which provides knowledge and skills for employment. TVET uses formal, non-formal and informal learning. TVET is recognised to be a crucial vehicle for social equity, inclusion, and sustainable development.

1.6 Research approach

A mixed methods approach was used which consisted of a literature review, and two case studies, one local and one international. A review of available statistics, coupled with a series of interviews and discussions with a selection of industry stakeholders were undertaken. 25 interviews were requested and 15 were achieved.

1.7 Anticipated contributions of the study

The study will provide an assessment of the gap between the current capacity of the TVET college system in South Africa to supply current grey hydrogen and future blue and green hydrogen needs for industry. Recommendations for potential solutions based on the research findings offer inputs for more detailed research which seeks to anticipate and build capacity for current and future skills needs within the hydrogen industry in South Africa.

1.8 Structure of the study

This gap assessment is structured in eight sections. Section one (this section) explains the rationale, approach and methodology and defines key terms and concepts. Sections two and three discuss the international and local hydrogen economies and activity chains, and the

[8] Lepoldina; Akademienunion, eds. (2016). Flexibility concepts for the German power supply in 2050: ensuring stability in the age of renewable energies (PDF). Berlin, Germany: National Academy of Science and Engineering.

skills in demand along the green, grey and blue chains. Section four deals with the South African HE. Sections five and six profile international and local TVET systems for the current and future hydrogen economy and the opportunities and challenges these represent for TVET globally and in South Africa. Section seven discusses the current TVET skills gap between the South African TVET supply systems and the current and future demand of skills from hydrogen producers. Section eight provides a summary, discussion and recommendations arising from the findings and section nine outlines the conclusions.

2. International and local hydrogen economy and skills required

2.1 Background and context

When considering the need for technical and vocational level skills in the current grey and future green hydrogen economies, a relevant factor is the structure and growth dynamic of the international HE as well as the international energy transition towards renewable energy (RE) in relation to the HE, the value chain, end user needs, exports, and potential for growth. In particular, the strength of the drivers of the grey and green HEs and their cost structures will determine the growth of the industry and consequently the nature of skills required. The production of grey hydrogen occurs currently in South Africa largely via SASOL production of ammonia, petro-chemicals and fertiliser, but the GHE is entirely pre-commercial. Lessons from international hydrogen economies will therefore be useful in determining the likely skills needed by the future GHE in South Africa and will contribute to an understanding of the blue hydrogen skills requirements which may be needed if there is a transition from grey to blue, before the commercial GHE is achieved. This is a potential transitional option for South African firms as the production cost for green hydrogen is a function of the price of renewable electricity and the capital cost of the electrolyser as well as its operational capacity.[9] In 2020, the International Renewable Energy Agency (IRENA) confirmed that the cost of production of green hydrogen is approximately three times that of blue hydrogen suggesting that the blue hydrogen pathway may precede the sustainable energy transition to green hydrogen in South Africa.[10] The timing of demand growth will determine the timing of the need for skills along the various hydrogen pathways, thus an understanding of the drivers of change, and the stage of evolution of the GHE, are necessary.

2.2 Renewable energy

The world still relies on fossil fuels for just under 84 percent of all energy supply and consumption[11] and many of the renewable and clean technologies of today need more work to get them to scale by reducing costs, as well as to increase reliability. According to Swilling, however, RE is now more affordable than fossil fuels in over 100 countries, and investments in RE exceeded investment in new capacity for fossil fuels from 2009 to 2019.[12] From 2020, 40 percent of all energy investments in G20 countries since the COVID pandemic began were in fossil fuels, representing approximately US$224 billion for 2020 alone. Over the same period, RE

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[9] IRENA. *Making green hydrogen a cost competitive climate solution.* 2020. [Making Green Hydrogen a Cost-Competitive Climate Solution (irena.org)]

[10] IRENA. Making green hydrogen a cost competitive climate solution.

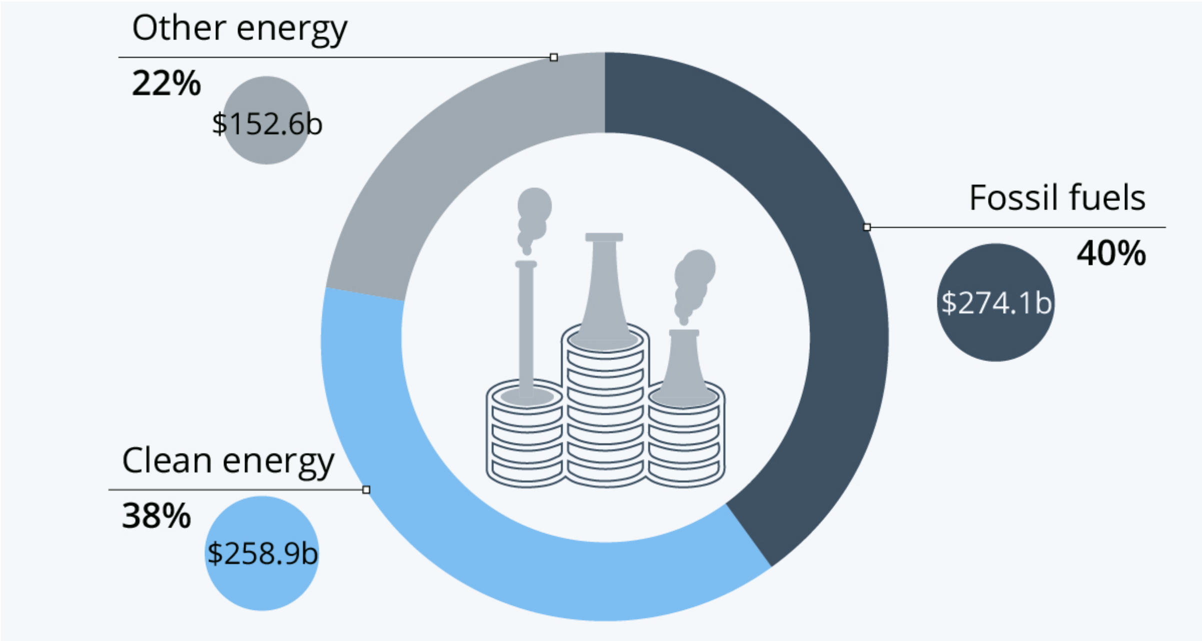
[11]Hannah Ritchie and Max Roser. Renewable Energy. https://ourworldindata.org/renewable-energy

[12] Mark Swilling. The Age of Sustainability: Just Transitions in a Complex World'. Routledge. 2019. https://a.co/d2kMOuW

investments were valued at US$258 billion (38 percent) with the balance allocated to other sources as Figure 1 demonstrates.[13]

[13] Statista. Fossil fuel investment persists. 2021. Energy Policy Tracker - Track funds for energy in recovery packages

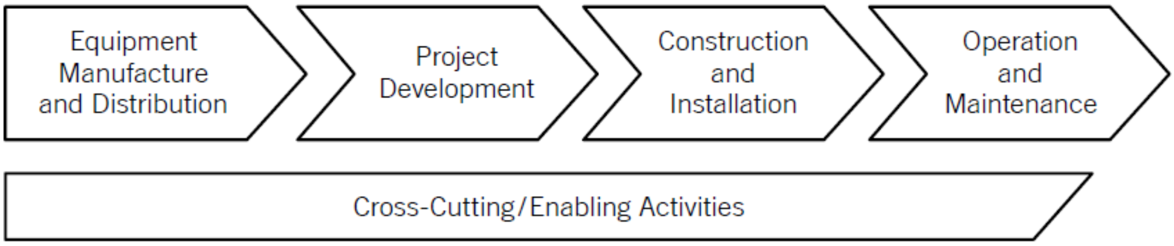
Figure 1- RE vs Fossil fuel investment, G20, 2020



Source: Energy policy tracker, 2021

RE is a critical component in the reduction of greenhouse gases (GHGs) into the future. Energy, whether in the form of electricity, heat, transport or industrial processes, accounts for the majority of GHG emissions. The focus in terms of mitigation is largely on clean energy solutions (renewable or nuclear energy), improvements in energy efficiency, and transition to low-carbon transport. RE and/or energy which generates zero or low GHGs with the most emission generating sectors as primary targets, is a major thrust of the technology drive to get to net zero by 2050. From a sector perspective, in 2019, globally, around ¼ of all electricity generated in 2019 was produced by/from RE.[14]

Figure 2- Renewable energy value chain



[14] Rajendra Pachauri and Leo Meyer. Climate Change. Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri, and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151.
https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_Front_matters.pdf

Source: ILO, 2011

The number of jobs created by the RE sector and the two main sub sectors such as photovoltaic cells and wind energy is significant and growing, and affects the skills required at all levels of the skills supply chain in the manufacture of equipment such a turbines and solar panels, construction, and installation of new RE plants, and operation and maintenance (O&M). Jobs include electricians, heating, ventilation, and air conditioning (HVAC) technicians, plumbers, drilling technicians, construction specialists, manufacturing processes operators, wind farm O&M technicians, Photo Voltaic (PV) modules installers, logistics operators, automation and control technicians, chemical laboratory assistants, etc. to name a few. The majority of the jobs internationally are at the vocational technical level and this represents a significant source of demand in the immediate term.[15] However, the construction and set up phase is particularly vulnerable to a "boom-bust' reality, where once construction has been completed, the skills uptake reduces, while in the construction phase, skills are often in short supply.[16]

Ideally, the rapid growth in demand for skills in the RE field internationally should have been met with a concomitant increase in quality skills supply, but this has not been the case. Problems with demand for skills and labour shortages are occurring due to unanticipated rapid growth and there are widespread skills shortages. This gap occurs largely with engineers and technicians, partly because it is not quick or easy for educational institutions to respond to rapid changes in demand, and partly because the investment needed in the development of new courses can be high and is often only made when growth is evident – thus creating a lag effect between supply and demand.[17] As the RE programme rolls out in South Africa this gap may occur domestically suggesting that skills supply in this area, which is critically important as inputs for GH, should be addressed by the South African TVET system as part of the primary GH supply chain and earlier in the skills development process (refer detailed list of skills required in annex 1).

Many RE technologies available today need more work to bring down costs and accelerate deployment. Reducing approximately half of current emissions, *in ceteris paribus*, depends on four main technology streams: change in technology use (electrification/ hybrid/hydrogen/other) in end use sectors such heating and transport; the application of carbon capture, use and storage; the use of low-carbon hydrogen and hydrogen-based fuels; and the use of bioenergy.[18] The timing of technology innovation can be critical in some

[15] Charalampos Malametenios. Renewable energy sources: Jobs created, skills required (and identified gaps), education and training. *Renewable Energy & Environmental Sustainability*.1, 23. Renewable energy sources: Jobs created, skills required (and identified gaps), education and training | Renewable Energy and Environmental Sustainability (rees-journal.org)

[16] ILO. Skills and occupational needs in renewable energy. 2011. https://www.ilo.org/publication/wcms_166823

[17] Charalampos Malametenios. Renewable energy sources: Jobs created, skills required (and identified gaps), education and training.

[18] International Energy Agency (IEA). 2020. Clean Energy Innovation. https://www.iea.org/reports/clean-energy-innovation

sectors. For example, the next refurbishment cycle in chemicals, cement and steel is due to begin roughly in 2030. If the new energy technology systems are not in place by then, it will likely take at least another full cycle until the processes are adapted. Funding is also an issue. COVID-19 has reduced funds available to most policy makers for funding research and development (R&D) and technology entrepreneurs.[19]

RE as defined above has limitations in specific applications, thus also in certain sectors. Rapid innovation has become crucial – as it seeks to overcome current solution limitations – if the world is to succeed in mitigation. New technologies are being sought and identified, but scaling is typically the barrier to speedy implementation. In some sectors the technology options for emissions reduction are limited such as in shipping, trucks, aviation and heavy industries like steel, cement, and chemicals. Decarbonising these sectors will require the development and scaling of innovative technologies, and green hydrogen is expected to play a significant role in this regard.

For educational institutions to keep abreast, and to some extent anticipate the needs of industry for clean energy skills, it will be essential to have built a full partnership between those institutions supplying the skills and industry. It is only industry which can inform the choices educational institutions make in sufficient time for the skills supply system to respond. This interaction, which will include the voice of organised labour to ensure a just labour transition, is the main means of closing the gap between skills supply and demand for industry.[20] Industry investment decisions are a clear indicator of future skills needs and these decisions are usually taken some considerable time before the actual investment takes place. Early warning via a good working partnership between the hydrogen industry and TVET skills supply entities will provide the education and training institutions time to develop additional curricula as required.

2.3 The just transition

The original concept of a just transition (JT) was tabled by trade unions in the 1980s. It was an attempt to ensure that social interventions needed to secure workers' rights and livelihoods (when economies were shifting to sustainable production, combating climate change, and protecting biodiversity) would be included in decision-making processes. Although there is yet to be a fully accepted definition of what a 'just transition' means, it can be argued that it is essentially a process when societies have decided to move away from CO_2 based economies which ensures that the transition to a clean energy economy takes social and labour justice into account.[21] Considerations of social justice, employment, the reduction of inequality and the inclusion of all stakeholders in decision-making around energy, environment and climate (EEC) shifts, and their impacts, are central to the concept, as is the use of 4IR. To be a truly just

[19] IEA. Clean energy innovation.

[20] Charalampos Malametenios. Renewable energy sources: Jobs created, skills required (and identified gaps), education and training.

[21] Raphael Heffron, Darren McCauley. What is the just transition? McCauley_CriticalReview_JustTransition_AAM.pdf (st-andrews.ac.uk)

transition therefore, economic considerations alone in decision-making will not suffice. A just transition requires an inclusive approach, where all stakeholders and their considerations are part of transition strategies.

The global move to RE arising from the imperative of mitigating and adapting to negative climate change impacts caused by greenhouse gases (GHGs), requires a critical shift in many of the skills required to make the transition. There are impacts on companies, communities and nations which are currently heavily reliant on fossil fuel extraction and utilisation who are likely to lose their livelihoods over time. Not all can adapt to a new energy dispensation and specific plans and programmes need to be put in place to ensure that those who cannot are supported in specific programmes. Adaptation of skills will require fundamental shifts to education systems, including vocational education, as well as upskilling of current workers (especially in digital technologies), and in some cases full reskilling of workers. For workers and the unemployed alike, a range of social interventions are needed to secure rights and livelihoods.

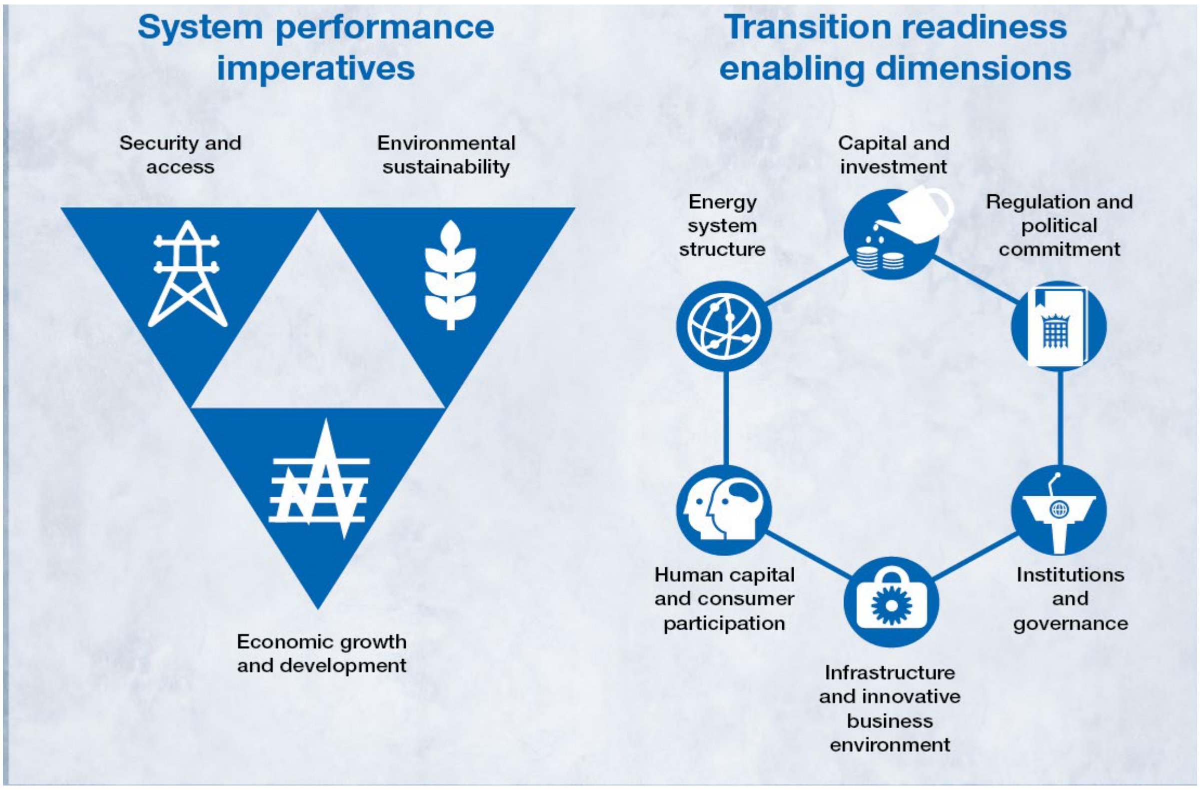
2.3.1 European Union model

A useful model for consideration is the European Community (EC) Just Transition Mechanism (JTM) launched in 2019. This is an element of the overall European Union (EU) Green Deal plan of creating a climate-neutral economy by 2050. Its focus is to overcome the economic and social costs of the climate transition in the most vulnerable coal and carbon-intensive regions of the EU. The JTM consists of three financing pillars, that is, the Just Transition Fund, a dedicated just transition scheme under InvestEU, and a public sector loan facility. All are focussed on mobilising investment in clean energy in vulnerable areas of the EU.[22] The framework below provides a model overview, as well as a view of the systemic elements of readiness for a just energy transition (JET) which include human capital and consumer participation, and the continuation of decent and quality work in the transition context.[23]

[22] European Commission. 'Green Deal: Coal and other carbon-intensive regions and the Commission launch the European Just Transition Platform'. Commission launches the European Just Transition Platform (europa.eu)

[23] Weforum. 'Energy Transition Index 2020'. Energy Transition Index 2020: from crisis to rebound | World Economic Forum (weforum.org)

Figure 3- Just energy transition framework



Source: Weforum. Energy transition index

Of particular relevance in the domain of energy, is the shift, and the timing of the shift, from Oil and Gas (O&G) energy production and consumption to renewables and clean energy, and the impact this will have across a number of spheres. The O&G sector is central in many countries for economic growth and job creation. In some cases, it makes up the bulk of national Gross Domestic Product (GDP) and many O&G companies, especially in the developing world, are owned by the state and are National Oil Companies (NOCs). O&G and coal JLT remain an important topic for countries reliant on fossil fuels.

Consequently, communities and workers in industries which are high carbon reliant, are an important focus of international efforts to ensure a JT which in turn encompasses a Just Labour Transition (JLT) and JET where various mechanisms are considered.[24] Policies and programmes include building conversations with workers and communities who will be negatively affected; ensuring social protections such as skills training, early retirement and potentially relocation; and creating funds to support the redevelopment of affected communities and workers.[25] Swilling argues that for the JET to be truly just, energy democracy is a prerequisite. Viewed through this lens, energy is a commonly shared resource as opposed to a material commodity delivered from a central control, hence power regarding energy production and availability

[24] 'IndustriALL Global Union. A trade union guide to a Just Transition for workers. 2021. Available from A trade union guide to a Just Transition for workers | IndustriALL (industriall-union.org)

[25] Conway, M. 'Developing and Implementing Just Transition Policies'. 2021. Available from Developing and Implementing Just Transition Policies | World Resources Institute (wri.org)

is held at community level.[26] Such an approach in South Africa would require radical changes in policy, new forms of financing and new collaborations in R&D and governance and would have major effects on the nature of production and distribution of GH.

Energy democracy as a tool in the JLT

Swilling notes that in 2016 "*there were 754 energy cooperatives in Germany, of which 431 managed solar energy generation, 47 onshore wind, while the remainder were in bioenergy or provided energy services. These 754 cooperatives had 136,000 members, 125,000 of whom were classified as citizens. Together, these 754 cooperatives raised 416 million Euros in equity and over 800 million Euros in debt, resulting in a total investment by these cooperatives of 1.2 billion Euros in RE by 2012. Half the debt capital was derived from cooperative banks and subsidized loans from DFIs. By 31 December 2015, there were 1,055 registered energy cooperatives of which 933 were involved in RE…. Local governments of various kinds were involved in (co)founding 38% of all cooperatives registered by 2014 and were on the Boards of 26%. Cooperative banks helped (co-)found 36% and were on the Boards of 16%. Municipal energy providers helped (co-)found 11% of the registered cooperatives and were on the Boards of 6%. Other entities involved in the founding and governance of cooperatives included other energy cooperatives, RE project management and consulting companies, RE energy plant providers, RE investment companies*".[27] Such a model may warrant investigation in South Africa. As well as having the potential to democratise energy, it could also create a number of jobs at the community level including for workers in high carbon locations.

The transition to a low-carbon economy will introduce millions of new jobs, reduce employment in high-emitting sectors, and alter most existing occupations in terms of task compositions and skills requirements.[28] The strategy of reskilling and/or upskilling for a JLT in the energy transition is thus strongly linked to the ability of local vocational educational institutions to provide access for communities, the unemployed and workers to new learning to capacitate people to earn in new ways and in new jobs. Emphasis is placed on "boosting skills for green jobs, approaches to green competency standards, qualifications and curricula; financing solutions; and incentives for skills development and lifelong learning to achieve a just transition and climate action".[29] Critical factors are the linking of all national skills strategies to the national climate change strategy and the provision of funding to gear up national TVET systems. Gender equality in all frameworks and strategies should be explicitly included.[30]

[26] Swilling, M. 'The Age of Sustainability: Just Transitions in a Complex World'.

[27] Swilling, M. 'The Age of Sustainability: Just Transitions in a Complex World'.

[28] ILO. 'Boosting Skills for a Just Transition and the Future of Work'. 2019

[29] ILO. 'Boosting Skills for a Just Transition and the Future of Work'. 2019

[30] UNFCC. Introduction to Gender and Climate Change. 2021. Introduction to Gender and Climate Change | UNFCCC

2.4 International hydrogen economy

In 2018, the global production of grey hydrogen was 60 million metric tons and is expected to increase to 300 million metric tons by 2030. Supplying hydrogen to industrial users (ammonia and methanol production, oil refining and steel production) is a major global business. Demand for hydrogen has grown by 300 percent since 1975 and continues to rise. Currently, hydrogen is supplied almost completely from fossil fuels (over 75 percent from natural gas). Six percent of global natural gas and two percent of global coal are consumed by the production of hydrogen and under 0.1 percent of global dedicated hydrogen production currently comes from water electrolysis. The production of hydrogen is responsible for CO_2 emissions of approximately 830 million tonnes per annum. Costs of production are almost entirely due to the input cost of gas (thus higher for those countries which have to import) and the capital cost of the equipment, which is higher as a percentage of total cost of production when carbon capture and storage (CCS) is part of the production process.[31]

Hydrogen (H) is present in all forms of water, animal and vegetable tissue, petroleum and in the atmosphere. The main applications for elementary hydrogen in the industrial arena are the production of ammonia (currently consuming approximately 2/3 of global hydrogen production) and in the hydrogenation of carbon monoxide and organic compounds. It is also used as a primary rocket fuel and a propellant for nuclear-powered rockets and space vehicles.[32] More recently, hydrogen, when RE sources are used in its production instead of fossil fuels, is being used as a clean fuel, and is a very important factor in meeting global decarbonisation goals. The production of hydrogen using fossil fuels is energy intensive and produces undesirable carbon by-products in the form of high CO_2 emissions.

The global market for hydrogen (predominantly grey hydrogen) is expected to grow quickly over the next five years, driven largely by increasing government regulations in desulphurisation of petroleum products and increasing demand for hydrogen as a clean transportation fuel.[33] Predictions suggest that the global hydrogen market could increase to US$33 billion over the next four years, from US$122 billion in 2018 to US $155 billion in 2022, indicating growth of 33 percent over the period. This is a Compound Annual Growth Rate (CAGR) of six percent per annum.[34]

The production of hydrogen in all its forms, and particularly green hydrogen, will continue to grow at increasing rates so that nations can meet their Paris Agreement goals. The pace of change to RE is accelerating and South Africa is no exception. In RE, South Africa currently has a competitive advantage given its easy and cheap access to solar and wind energy, and

[31] IEA. Current policy support for hydrogen deployment. https://www.iea.org/data-and-statistics/charts/current-policy-support-for-hydrogen-deployment-2018

[32] Lee Jolly. Hydrogen. Encyclopaedia Britannica, June 1, 2020. https://www.britannica.com/science/hydrogen

[33] Roger Bezdek. Whatever happened to the hydrogen economy? *World Oil*. 6, 23 (2018)

[34] Research and Markets. Global market for hydrogen fuel cell vehicles report 2017– data & forecasts 2015–2020, 2021–2026, and 2027–2032.

possibly biomass. From a technology perspective, South Africa is a leader in grey hydrogen production and export. As demand increases globally and domestically for RE and GH, skills will be needed at an increasing rate, beginning with those construction related skills required to set up a RE plant, electrolysers and pipelines, *inter alia*. Shortly thereafter, specialised skills needed to operate and maintain the plants will become important. Ensuring the TVET skills are available and of the right quality will be critical to a JT, as jobs and job opportunities in fossil fuel related industries and communities fall away.

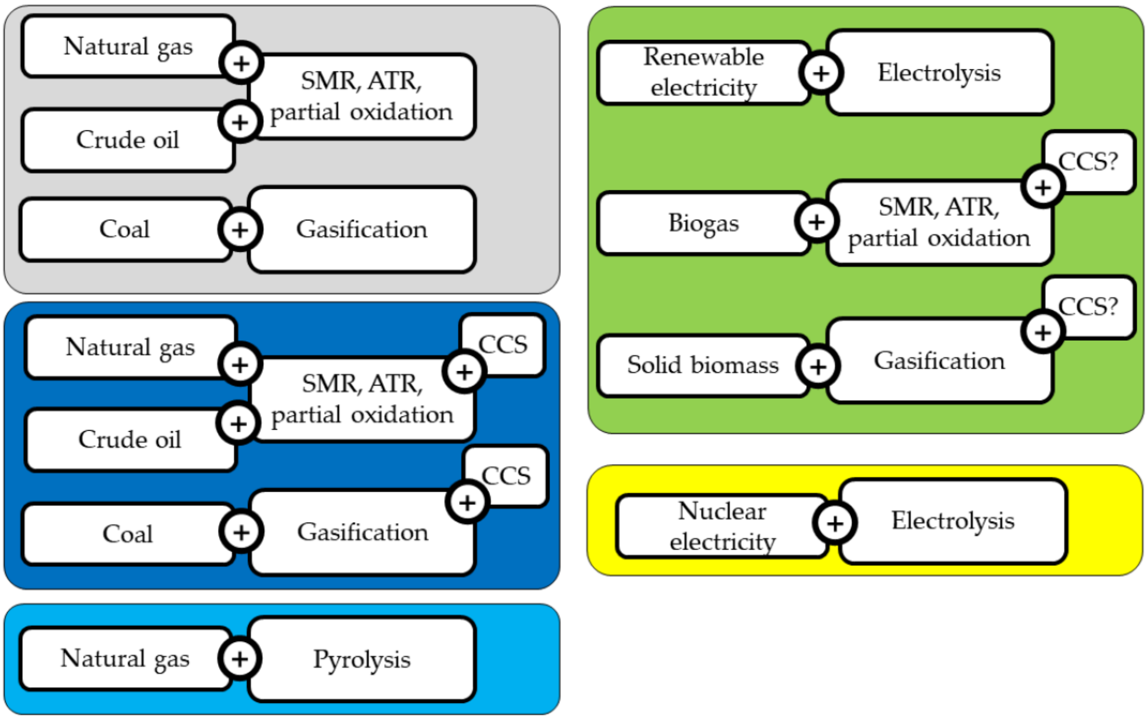
2.4.1 Hydrogen colour classification

Currently, most of the use of hydrogen in oil refining and chemical production is provided by hydrogen derived from fossil fuels, that is, grey hydrogen. The colour classification system in use for hydrogen is linked to the technology used to produce it. *Brown (or black)* hydrogen is generated by means of coal gasification while the production of *grey* hydrogen from natural gas produces carbon waste. *Blue* hydrogen uses CCS to void most GHG emissions, specifically those generated in the production of grey hydrogen. *Turquoise* hydrogen is produced via the pyrolysis of a fossil fuel with a solid carbon by-product, while *yellow or purple* hydrogen is produced by electrolysers from nuclear power plants.[35] *Blue* hydrogen represents the bulk of hydrogen produced currently using natural gas as the feedstock via a process of steam methane reforming (SMR).[36] Finally, *green* hydrogen is produced by electrolysers using renewable energy to create hydrogen fuel. Within each colour classification there is variability of carbon intensity. The main technology pathways linked to colour codes are shown in Figure 4.

[35]Michel Noussan, Pier Raimondi, Rosanna Scita and Manfred Hafner. The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective'. *Sustainability*, 2021. https://www.mdpi.com/2071-1050/13/1/298/pdf

[36] Jill Feblowitz, The Colors of Hydrogen – Brown, Grey, Blue and Green – Think About It' The Colors of Hydrogen – Brown, Grey, Blue and Green – Think About It - Utility Analytics Institute

Figure 4- Hydrogen production pathways (colour coded)



Source: Sustainability, 2021

In 2020 over 95 percent of all industrial hydrogen was produced via methane reforming with fossil fuels as the source, ie largely natural gas but also coal and oil. Transport and storage require equipment and health and safety protocols designed for hazardous materials and are similar to those applied in the chemicals industry. The production of hydrogen from electrolysis, however, is more expensive, and energy intensive. The optimum solution is to be able to use RE to generate GH via electrolysis.[37] Some experimental methods currently under examination are bio-hydrogen production, renewable electrolysis, solar high-temperature thermocycles and others. Recently, there is interest in the production of GH using scrap aluminium (the Cavendish process) which may be able to produce GH cost effectively and which is scalable.[38]

Because grey hydrogen is generated from fossil fuels, blue hydrogen provides a cleaner option which is up to three times less expensive than GH.[39] While grey hydrogen is largely derived from natural gas resulting in nine units of CO_2 for every unit of hydrogen, blue hydrogen captures

[37] California Air Resources Board. *Factsheet, 2030 renewables*. https://www.arb.ca.gov/html/factsheets/2030_renewables.pdf and https://www.arb.ca.gov/msprog/zevprog/zevprog.html

[38] Cavendish Energy. The Cavendish Process will change the way the world generates hydrogen. https://www.cavendish-e.com

[39] IRENA. Making green hydrogen a cost competitive climate solution.

the CO_2 and disposes of it in some manner, such as deep underground (although this can be problematic as there is no way of knowing if leakage will occur), or using it in advanced oil recovery. The production of blue hydrogen can reach scale more rapidly and some view it – largely in the US – as a transitional means of hydrogen production before full GH production is implemented. Lowering costs for carbon capture technology is an essential factor for blue hydrogen.[40] Blue hydrogen production uses a specific technique for separating hydrogen from gas mixtures, ie the use of polymeric separation membranes where PEM is the base technology. This approach can lower energy consumption, reduce maintenance requirements, and increase selectivity in separation which reduces CO_2 emissions. Gas separation, a critical post-gasification processing stage of syngas production, allows hydrogen to be isolated from syngas and used as a clean fuel or feedstock. The leftover CO_2 can then be captured and sequestered rather than released into the atmosphere using CCS.[41]

Some developed and developing nations are moving directly into GH without taking a transitional step via blue hydrogen. The hydrogen strategy of the EU commits to the installation of six gigawatts of renewable hydrogen electrolysers by 2024, and some countries in Asia, such as China and Japan are moving directly to GH.[42] The need to invest in blue hydrogen infrastructure and technology, is viewed by some industry actors as an additional and possibly unnecessary cost in the journey to clean energy.[43] GH is the ideal state, where no carbon emissions occur but the costs of production are still high, and specific issues have to be overcome in order to scale GH commercially as Figure 5 indicates.

[40] IRENA. Making green hydrogen a cost competitive climate solution.

[41] US Department of Energy. Robust Polymer Composite Membranes for Hydrogen Separation. Robust Polymer Composite Membranes for Hydrogen Separation (energy.gov)

[42] Jim Magill. Blue vs green hydrogen -which will the market choose? Blue Vs. Green Hydrogen: Which Will the Market Choose? (forbes.com)

[43] MISTRA. Dr. Nqobile Xaba and Dr. Zamanzima Mazibuko-Makena. Interview by Josie Rowe-Setz. Online. Johannesburg, May 2021.

Figure 5-Reducing green hydrogen costs.

Source: IRENA, 2020

The capital cost of electrolysis however, reduced by 60 percent between 2010 and 2019.[44] The logistics, distribution, and refuelling infrastructure (for consumers) will need to be built on existing gas or fuel pipelines or installed as Greenfields infrastructure.[45]

Skills needed in the green and blue hydrogen chains are linked to differing technology (RE inputs and CCS respectively) but are essentially similar, requiring technology knowledgeable engineers and technicians in RE in the first instance, as well as technical capability in CCS technology for blue hydrogen. However, the availability of skilled workforces to build and operate hydrogen energy technologies for both blue and green hydrogen is limited and largely insufficient in both developed and developing economies.[46]

2.4.2 Sectors in the hydrogen economy

Hydrogen is required by the refining industry (25 percent) for use in hydrocracking and desulphurisation. This sector is growing rapidly as global governments increase regulations to limit sulphur in final petroleum products. Hydrogen is also extensively used in the synthesis of chemical products, mostly in the production of methanol (10 percent) and ammonia (55

[44] Hydrogen Council. Path to Hydrogen Competitiveness- a Cost Perspective. Path to Hydrogen Competitiveness: A Cost Perspective - Hydrogen Council

[45] IEA. The Future of Hydrogen. https://www.iea.org/reports/the-future-of-hydrogen

[46] Drax. Jobs, skills, zero emissions – the economic need for carbon capture. 2020. Jobs, skills, zero emissions – the economic need for carbon capture by Drax - Drax

percent), and as a fertiliser in agriculture. Other applications (10 percent) include metals production, electronics, fuel cells, energy storage and food processing, *inter alia*.[47]

There are two main categories of hydrogen demand. The first category is termed *merchant hydrogen*. Merchant hydrogen is generated for the most part from SMR or natural gas (95 percent) with electrolysis making up only five percent. This is hydrogen produced on site and distributed to customers from there via truck, tanker or pipeline and demand is currently growing at approximately seven percent per annum. Growth is driven by manufacturers using electrolysis (water) and reformation (methane). The merchant hydrogen industry provides hydrogen to industrial processes such as the manufacture of automotive fuels, jet fuel, diesel, plastics, metals, agricultural fertilizer, pharmaceuticals, and food oil products. Food and semiconductor manufacturing and emerging energy or fuel applications for transportation are also supplied but are currently small. The power generation segment is expected to grow at the highest CAGR.[48] The second category is called *captive hydrogen* and is consumed on premises by the producer for its own use. This is by far the dominant category and represents approximately 95 percent of demand.[49]

2.5 Trade, logistics and distribution

In 2019, world trade in hydrogen was valued at US$ 9.97 billion. China was the main exporter, at a value of US$1.52 billion, followed by the US at US$1.38 billion, and Germany at US$1.04 billion. China was also the world's largest importer in 2019, at US$1.65 billion, followed by Japan at US$1.18 billion, and Germany at US$995 million. Trade in 2019 experienced a very significant drop over 2018 of -17.4 percent.[50]

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[47] Markets and markets. Hydrogen generation market worth 154.74 billion USD by 2022. www.marketsandmarkets.com/Market-Reports/hydrogen-generation-market-494.html

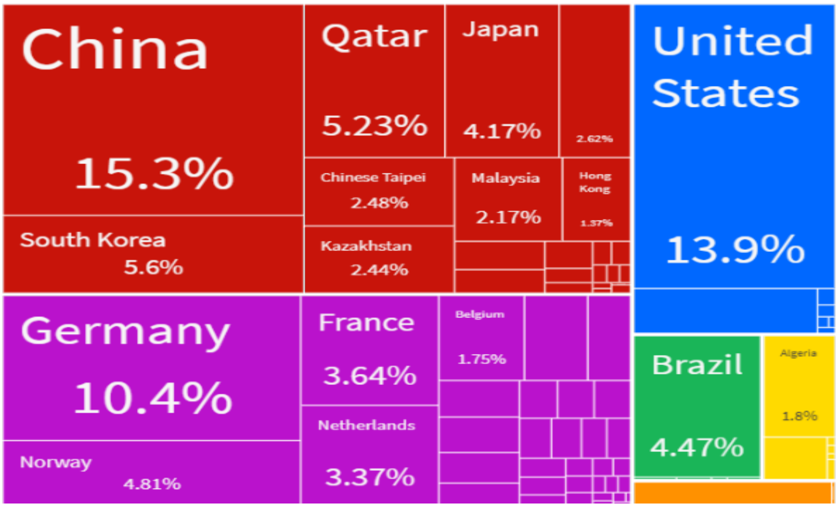
[48] Research and markets. Hydrogen generation market- 2021 and forecast to 2025. 2021. Hydrogen Generation Market by Application (Petroleum Refinery, Ammonia & Methanol Production, Transportation, Power Generation), Generation & Delivery Mode (Captive, Merchant), Source (Blue, Green & Grey Hydrogen), Technology, and Region-Forecast to 2025 (researchandmarkets.com)

[49] Markets and markets. Hydrogen generation market worth 154.74 billion USD by 2022.

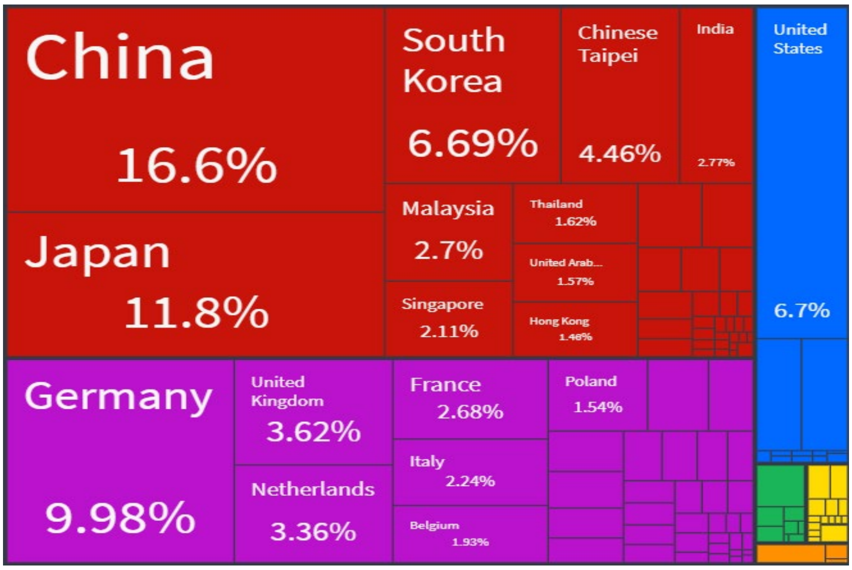
[50] Observatory of Economic Complexity (OEC). Hydrogen. Hydrogen (HS: 2804) Product Trade, Exporters, and Importers | OEC - The Observatory of Economic Complexity

Figure 6- Hydrogen exporters & importers (2019)

Export



Import



Source: OEC. Hydrogen., 2019

National production of grey hydrogen in China grew by 6.8 percent annually from 2010 to 2018 inclusive. By 2018, Chinese production represented 18 percent of global production and it was the leading producer globally. Within China, national demand is dominated by ammonia production, using coal as feedstock via a partial oxidation process. Hydrogen is also used in the production of methanol which can be produced using coal. China intends to expand green hydrogen production, especially into emerging applications such as in transport (one million fuel cell electric vehicles (FCEVs) and one thousand fuel stations, by 2030); in electricity storage and in cement and steel production, and similarly difficult to abate applications.[51]

The logistics of moving hydrogen to market are very similar to those for natural gas. Delivery technology and infrastructure for hydrogen is available commercially as a result of the movement of industrial hydrogen to users. Hydrogen is taken from the producer to end user via pipeline, on road in cryogenic liquid tanker trucks or gaseous tube trailers, or by rail or barge. At sea, specialised containers are used on board. Dedicated hydrogen pipelines are an important distribution route, either via new pipelines or by repurposing other pipelines such as gas and petroleum for hydrogen use. Where a country has a network of natural gas pipelines, hydrogen can be blended into the existing network.[52]

Hydrogen used in portable or stationary applications can be delivered by truck to a storage facility or in cylinders. Hydrogen used in FCEVs is provided the same way as petroleum fuel is, via a filling station. On-site hydrogen storage options include insulated liquid tanks and gaseous storage tanks. The four types of common high pressure gaseous storage vessels are shown in Table 2 below.

Table 2-Types of gaseous storage vessels

Type	**Description**
I	All-metal cylinder
II	Load-bearing metal liner hoop wrapped with resin-impregnated continuous filament
III	Non-load-bearing metal liner axial and hoop wrapped with resin-impregnated continuous filament
IV	Non-load bearing, non-metal liner axial and hoop wrapped with resin-impregnated continuous filament

Source: [On-Site and Bulk Hydrogen Storage | Department of Energy]

Cryogenic liquid storage tanks (also referred to as dewars) are the usual way to store large quantities of hydrogen. Super-insulated low-pressure vessels are needed to store liquid hydrogen at -253°C (-423°F). A national hydrogen infrastructure could require Geologic (underground) bulk storage – and at ports – to handle variations in demand throughout the

[51] Kevin Jianjun Tu. Prospects of a Hydrogen Economy with Chinese Characteristics. Étude de L'Ifri. 2020

[52] Hydrogen Europe. Hydrogen transport and distribution. https://hydrogeneurope.eu

year. Geologic bulk storage is common practice in the natural gas industry.[53] In marine transportation, due to various physical characteristics of hydrogen and the effect on the ship, as well as capacity considerations, specialised design in areas such as cargo containment facilities is required. Vessels have been designed which carry only hydrogen and whose engines burn pure hydrogen as the source of energy resulting in a net-zero hydrogen transport solution.[54]

The costs of hydrogen production vary by location, and consequently as the market demand for GH expands, there is potential for global supply chains to develop along cost-efficient routes. Global supply chains for export are likely to consist of long-distance pipelines (such as from Russia to Norway) and shipping routes (such as from South Korea into Japan). Existing technology options for shipping hydrogen globally are liquid hydrogen (LH), ammonia (NH3), and technologies based on liquid organic hydrogen carriers (LOHCs).

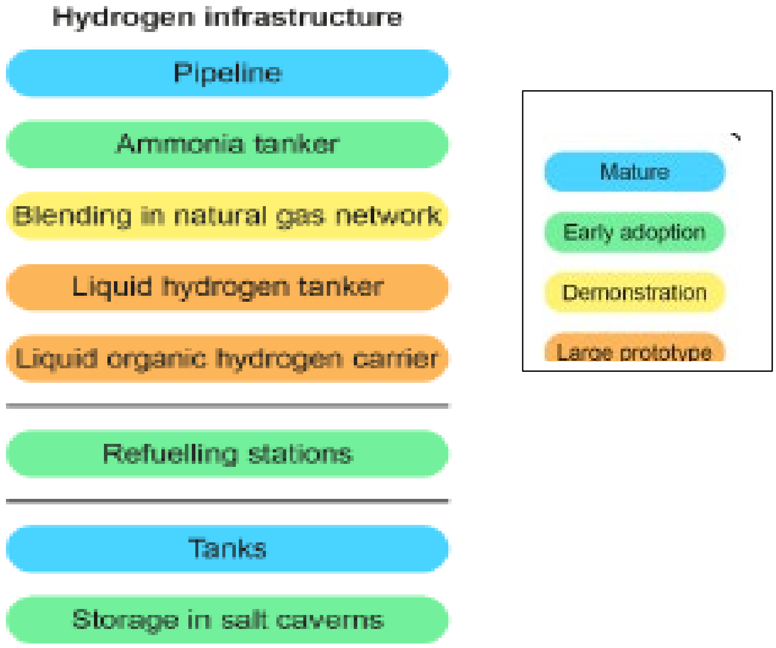
The landed cost of hydrogen via LH is very sensitive to scaling, and thus depends heavily on the level of demand. Ammonia is more easily shipped, and routes and facilities are already established, but safety considerations are significant due to its toxicity and it would require reconversion at the point of delivery.[55] From a GH perspective, technology for infrastructure is at various stages of development as Figure 7 indicates.

[53] Sandia National Laboratories. A Life Cycle Cost Analysis Framework for Geologic Storage of Hydrogen: A User's Tool. A life cycle cost analysis framework for geologic storage of hydrogen: a user's tool. (Technical Report) | OSTI.GOV

[54] Hydrogen Europe. Hydrogen transport and distribution.

[55] IEA. Path to Hydrogen Competitiveness. 2020

Figure 7- Technology readiness: Green hydrogen infrastructure



Source: International Energy Agency. Energy Technology Perspectives, 2020.

The skills required at each stage are engineering and technical and include cross-cutting skills such as materials handling, occupational safety, driving, refuelling personnel, and storage workers, *inter alia*. Many existing skills for grey hydrogen and industrial gas and hazardous chemicals logistics are viewed as identical to those needed for GH and require reskilling largely in equipment and storage management, suggesting the need is for re-orientation of existing skills for workers, rather than a complete upskilling or reskilling process.[56]

2.6 Green and blue hydrogen production growth

The rate of growth in GH production, and its ability to substitute for grey hydrogen, is an important factor in determining the need for GH related skills. The rate of growth is in part driven by agreed international decarbonisation goals. GH production will make a significant impact on national abilities to meet the Paris Agreement[57] goal of abating more than 10 gigatons of carbon dioxide a year from the most challenging industrial sectors. These include mining, construction, and chemicals.[58] Substitution of GH for grey – as a decarbonisation strategy – is significantly affected by costs of production and related technologies. Distribution, storage,

[56] SASOL. Interview by Andisa Sibukhwana.

[57] UNFCC, The Paris Agreement. 2015. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[58] World Economic Forum. Top ten emerging technologies of 2020. www.weforum.org

and logistics costs are equally important and over time are more likely to determine competitiveness as GH commodifies.

Added to this are issues of global geopolitics. As the world steadily becomes more dependent on hydrogen for energy, various regions are adopting strategies consistent with national plans, made up of a mix of local production, importation, and exports – the selection influences investment.[59] Middle East and North Africa (MENA) countries seek to in part mitigate revenue losses from fossil fuels and are considering production for local consumption and export, Europe and Japan are considering a mix of local production and import, while Russia and Australia, *inter alia*, are working on major export strategies.[60] However, using current technologies with CCS or carbon capture, utilisation and storage (CCUS) is still the main route for low-carbon hydrogen production because production costs are lower than for other low-carbon technologies such as electrolysis.[61]

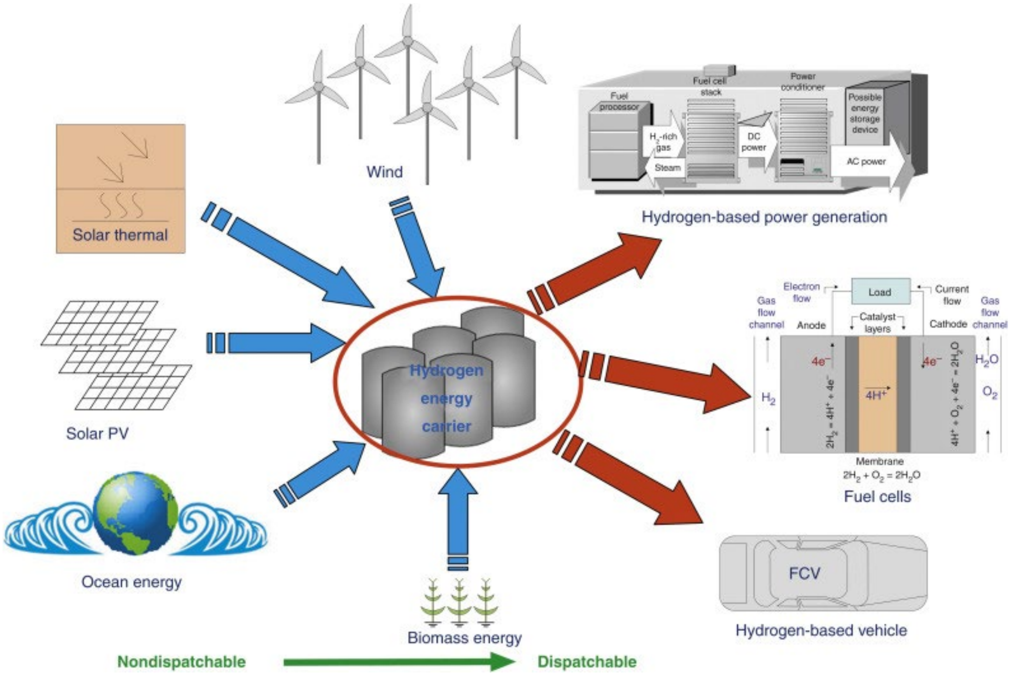
GH can improve air quality in cities and support energy security. It is also able to facilitate the integration of RE in an electricity system, as it can be used to store electricity for months and is potentially an ideal fuel from an environmental perspective. The current challenge for GH at scale is manufacturing it into useable forms for various major applications such as electrolysers, fuel cells and hydrogen production with CCS or CCUS as shown in Figure 8.

[59] UNFCC. The Paris Agreement, 2015

[60] Thijs Van de Graaf, Indra Overland, Daniel Scholten and Kirsten Westphal. The new oil? The geopolitics and international governance of hydrogen. *Energy Res. Soc. Sci*. 2020, 70, 101667.

[61] IEA. Hydrogen. Hydrogen - Fuels & Technologies - IEA

Figure 8- Potential green hydrogen energy eco-system



Source: Nehrir, Wang, in Electric Renewable Energy Systems, 2016

2.6.1 Renewable energy and electrolysers

2019 saw major electrolysis capacity become operational and over 20 announcements were made regarding significant investments in the next five years, mainly in countries near the North Sea. Alkaline electrolysers dominate the market currently, but many new projects require PEM designs as they are more flexible and more compatible with variable renewable electricity generation. Some projects making use of high-efficiency solid oxide electrolyser cells (SOECs) are beginning to be announced, nearly all of them in Europe, to produce synthetic hydrocarbons. Furthermore, the FCEV market almost doubled in 2019 due to expansion in China, Japan, and Korea. The growth in demand for FCEVs, driven by China and Japan, caused global FCEV stock to double to 25 210 units at the end of 2019, over 2018.[62]

An important factor in the building of electrolysers to process GH is the reality that for every unit of GH produced, four units of renewable energy is required as input. This needs large tracts of land.[63] This suggests that the skills required initially will be more linked to the design and construction of large renewables facilities to service electrolysers, with engineering design and drafting skills required in the early stages and thereafter construction and operational skills for

[62] IEA. Hydrogen

[63] MISTRA. Dr. Nqobile Xaba and Dr. Zamanzima Mazibuko-Makena. Interview by Josie Rowe-Setz. Online. Johannesburg, May 2021.; BUSA/Nedlac/SAREM/. Mike Levington. Interview by Josie Rowe-Setz. Online. Johannesburg, May 2021.

the facilities. At the same time, inbound logistics and storage skills for renewable inputs will be required once the construction stage is complete.

3. International hydrogen economy skills

3.1 Green skills

There is as yet no agreed definition of what constitutes green skills. In early definitions, the UN defined green jobs as "sectors and jobs in which waste creation and pollution is minimised" while the ILO defined it similarly but included "any sector that has a lower-than-average environmental footprint".[64] Statistical assessments focus heavily on the environmental goods and services sector. The European Centre for the Development of Vocational Training (Cedefop) subsequently defined green skills as "the knowledge, abilities, values and attitudes needed to live in, develop and support a sustainable and resource-efficient society".[65] Across occupations and industries, this means upgrading, reskilling, repurposing and redeployment so that workers can enter and or transition from industries in decline to new and growth industries. It is estimated that 50 percent of all employees will need reskilling by 2025, and that a significant percentage of worker core skills will need to change over the next five years through upskilling, reskilling, and ongoing learning.[66] Skills and training needs are likely to involve the following:

- Upgrade skill sets in industries experiencing only minor adjustments;
- Gearing up educational institutions and firms to provide the new skills for new occupations and sectors that will emerge from the GE; and
- Retraining and realigning skills in sectors that will decline as a result of the shift.[67]

Mapping possible future jobs is not an easy task and has not yet been achieved. However, the World Economic Forum (WEF) has made inroads into broad mapping and quantitative prediction using innovative metrics in collaboration with partners, ie the New Metrics CoLab initiative and data scientists at three partner companies: Burning Glass Technologies, Coursera, and LinkedIn. The WEF predicts the following emerging jobs and essential skills which will be required in the GE as outlined in Table 3. Notably, jobs related to FCs and RE, both critical for the GHE, are included.[68]

[64] OECD. Greener skills and jobs.

[65] Cedefop. 'Skills for green jobs: European synthesis report'. 2010. http://www.cedefop.europa.eu/EN/Files/3057_en.pdf

[66] World Economic Forum. Building a common language for skills at work- a global taxonomy. 2021. https://www.reskillingrevolution2030.org/

[67] OECD. Greener skills and jobs.

[68] World Economic Forum. Jobs of tomorrow: Mapping opportunity in the new economy. https://www.weforum.org/reports/jobs-of-tomorrow-mapping-opportunity-in-the-new-economy

Table 3- Emerging jobs and essential skills in the green economy

Emerging Jobs		Top 10 Skills	
1	Methane/Landfill Gas Generation System Technicians	1	Digital Marketing
2	Wind Turbine Service Technicians	2	Wind Turbines
2	Green Marketers	3	Landfill Gas Collection
4	Biofuels Processing Technicians	4	Social Media
4	Solar Energy Installation Managers	5	Equipment Inventory
6	Water Resource Specialists	6	Solar Installation
7	Wind Energy Project Managers	7	Health and Safety Standards
8	Chief Sustainability Officers	8	Microsoft Power BI
9	Refuse and Recyclable Material Collectors	9	Electrical Diagrams / Schematics
9	Sustainability Specialists	10	Email Marketing
11	Solar Photovoltaic Installers		
12	Water/Wastewater Engineers		
13	Forest Fire Inspectors and Prevention Specialists		
14	Fuel Cell Engineers		
14	Nuclear Power Reactor Operators		

(N) Rank **Scale of Opportunity:** Small-scale Large-scale
Skill Type: Industry Specialized Tech Baseline Business

Source: WEF, 2020

It is probable that dramatic increases in GE job opportunities will occur as government regulation changes and climate change goals are actioned. Skills sets are likely to become more cluster and content specific for green skills going forward, with tech baseline skills (in on-the-job experience) and industry content knowledge becoming progressively more important.[69]

Skills related to battery storage, metal casing work, and inter alia the manufacturing of membranes and fuel cell stacks as components, will grow concomitantly with the demand for renewables and GH, requiring significant content adjustment in TVET systems globally to ensure graduates understand the industry. It will require ongoing conversation between industry and TVETs to ensure that skills offered by TVETs remain relevant in a dynamic and fast changing global environment, in particular with 4IR implications for how jobs are done. Finally, TVETs need to be geared for increasing access to experiential on-the-job learning.

[69] World Economic Forum. Jobs of tomorrow: Mapping opportunity in the new economy.

3.2 Hydrogen Economy skills

While growth in the HE, in particular the GHE and linked applications, is expected to lead to significant new employment opportunities, the issues researchers, and educationalists grapple with are categorisation and timing. Employment opportunities are expected to occur across industry at large, and not just in the production and delivery of hydrogen and GH, as industries aim for net zero. Some potential GE jobs are likely to require different skills requiring a review of current education and training offerings and requirements.[70]

3.2.1 US approach

In 2008, the US Department of Energy (DOE) assessed the potential impact on employment of a transition to a hydrogen economy in the US between 2020 and 2050. It determined that training for new skills would be required, across a large range of industries similar in breadth and scope to the process of retraining and skilling for 4IR.[71] A subsequent DOE study focussed entirely on FCs and predicted that demand for related skills would grow significantly, in particular for installers, qualified maintenance technicians, manufacturing professionals, educators and others.[72] Another study conducted by the American Solar Energy Association and Management Information Services, Inc. (ASEA/MISI) suggested that if FCs and hydrogen energy use took hold in the US economy, potentially nearly one million new jobs might be created by 2030, predominantly for highly skilled workers.[73] After these earlier attempts to define, categorise and predict the nature and quantum of potential jobs in the HE, the DOE developed models for assessing the potential jobs which could be created by the FC and hydrogen industries. The first model, JOBS FC, provides the ability to assess potential economic impacts from the manufacture of specific FCs only, while the second, JOHBS H2, provides the same ability but for hydrogen fuelling stations.[74]

Based entirely on the US models and US data, Bezdek suggests first that the hydrogen and FC industries will require a wide range of occupations at all skills levels, even though many are likely to need either degrees, long-term on-the-job training or trade certifications. As a result of

[70] Roger Bezdek. The hydrogen economy and jobs of the future. The hydrogen economy and jobs of the future (rees-journal.org)

[71] US Department of Energy. Effects of a transition to a hydrogen economy on employment in the United States. http://hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf

[72] US Department of Energy, Fuel Cell Technologies Office. Careers in fuel cell technologies. https://www1.

eere.energy.gov/hydrogenandfuelcells/pdfs/green_jobs_factsheet.pdf

[73] American Solar Energy Association and Management Information Services, Inc., Defining, estimating, and forecasting the renewable energy and energy efficiency industries in the USA and in Colorado. *America Solar Energy Society*, 12, 2008.

[74] US Department of Energy, Argonne National Laboratory, JOBS FC model, 12, 2012. https://jobsmodels.

es.anl.gov/index.php?content=fc; US Department of Energy, Argonne National Laboratory, JOBS H2 and JOBSNG model, 6, 2014. https://jobsmodels.es.anl.gov/index.php?content=h2 the diversity of value chain constituents, it will be possible to cluster within communities around specific elements and specialise in some way. However, many of these jobs do not currently exist and do not have defined occupational titles and training needs are yet to be established.[75] From the US perspective, most of the skills needed can only be acquired at the university level. Most technician and transport jobs, as well as plant operators and maintenance and repair personnel can acquire the relevant qualifications at the vocational level. An initial list of 42 hydrogen economy jobs/occupations and skills is shown in annex 3 and flags the importance of content in skilling for the GH pathway. For example, while there are plant operators in every manufacturing plant in every industrial sector, what equipment they use and what they do with it differs, and often requires specific on-the-job training.

3.2.2 The EU approach

A different approach is taken by the EU, where the assessment of jobs and employability in the hydrogen economy is more focussed on using the Science, Technology, Engineering and Mathematics (STEM) skills available. The EU views reskilling and upskilling from a general skilling system as the starting point. According to the EU hydrogen roadmap, the larger percentage of value creation in the HE will take place in advanced industries (machinery and equipment, automotive, electricity, and gas supply) and will create more employment than the value chains of fossil fuels. They estimated the number of jobs (additional) to be created by the hydrogen industry in the EU as ten to thirteen new jobs per €1 million in revenues. In aftermarket services, this increases to 15 jobs per €1 million in revenues. Using this means of calculation the study determined that by 2030, the EU hydrogen industry would employ approximately one million people, with 500,000 additional jobs in the manufacturing of hydrogen, distribution equipment and infrastructure setup for end use applications. A further 350,000 additional jobs could be generated for fuel cells, components, and end use applications.[76]

The sustainable development goals (SDGs), as agreed in 2015 by the United Nations General Assembly include SDG7 which focuses on achieving 'affordable and clean energy for all' by 2030.[77] Opportunities exist to shift from current fossil fuel-based production methods to blue (using CCS) and GH (with RE as inputs) which will have significant impact on the mitigation of GHGs. However, the cost of hydrogen production from low carbon energy is still high in relative terms – as is transportation and storage – and this is likely to remain the case until both the cost of RE and the production of GH scale up. Important costs include the cost of FCs, electrolysers, and refuelling equipment.

There is no standard international approach to the development of skills either for the GE or the GHE and different options are being considered. However, new knowledge and

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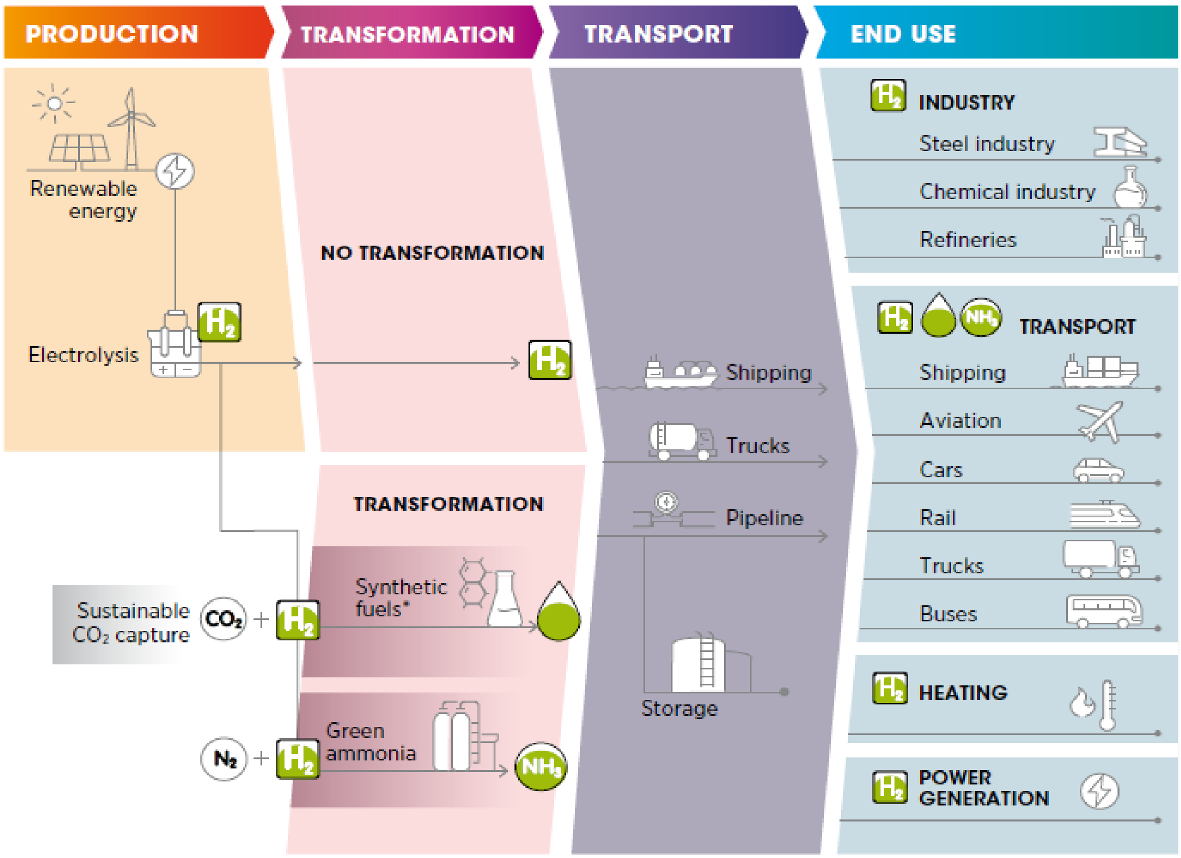
75 Roger Bezdek. The hydrogen economy and jobs of the future.

76 FCH & EU. '*Hydrogen roadmap- Europe*.' Hydrogen Roadmap Europe_Report.pdf (europa.eu); M.J. Smith, K. Turner, J.T.S. Irvine (Eds.) '*The Economic Impact of Hydrogen and Fuel Cells in the UK – A Preliminary Assessment based on Analysis of the replacement of Refined Transport Fuels and Vehicles*'. H2FC SUPERGEN, London, UK

77 UNDP. Sustainable Development Goals. Sustainable Development Goals | UNDP

competencies can only be built if basic TVET skills and capabilities are in place. Whether unemployed or in work, the skills people will need to build include running new kinds of equipment and new ways of managing production and distribution processes arising from the 4IR. From a South African perspective, ensuring that the relevant TVET colleges are able to provide quality foundational skills for industries will be a priority, and only thereafter specialised programmes to build green skills and skills for the GHE.

Figure 9 provides a schematic of the GE and offers insight into where specialised skills will be needed in the sector.[78]



Source: IRENA, 2020

3.3 Skills by category of activity

Skills required for the grey, blue, and green hydrogen production, and supply pathways and the RE pathway can be broadly defined into three categories. These are described below:

3.3.1 Skills required to design and set up operational plants

[78] IRENA. "*Green hydrogen: a guide to policy making.*"2020. International Renewable Energy Agency, Abu Dhabi.

These skills are largely STEM related skills, including but not limited to the full array of construction skills at the professional and artisanal (vocational) levels. These include:

- Design: All aspects of plant design including civil and structural engineering, piping, stress, electrical engineering and design, instrument design, vessels engineering and design, and mechanical systems engineering, as well as expertise in support of construction, start-up and troubleshooting activities; and
- Construction and estimating: The site-based and office-based construction team is responsible for all aspects of delivering a construction project to contractual technical, budget, schedule, and quality requirements.

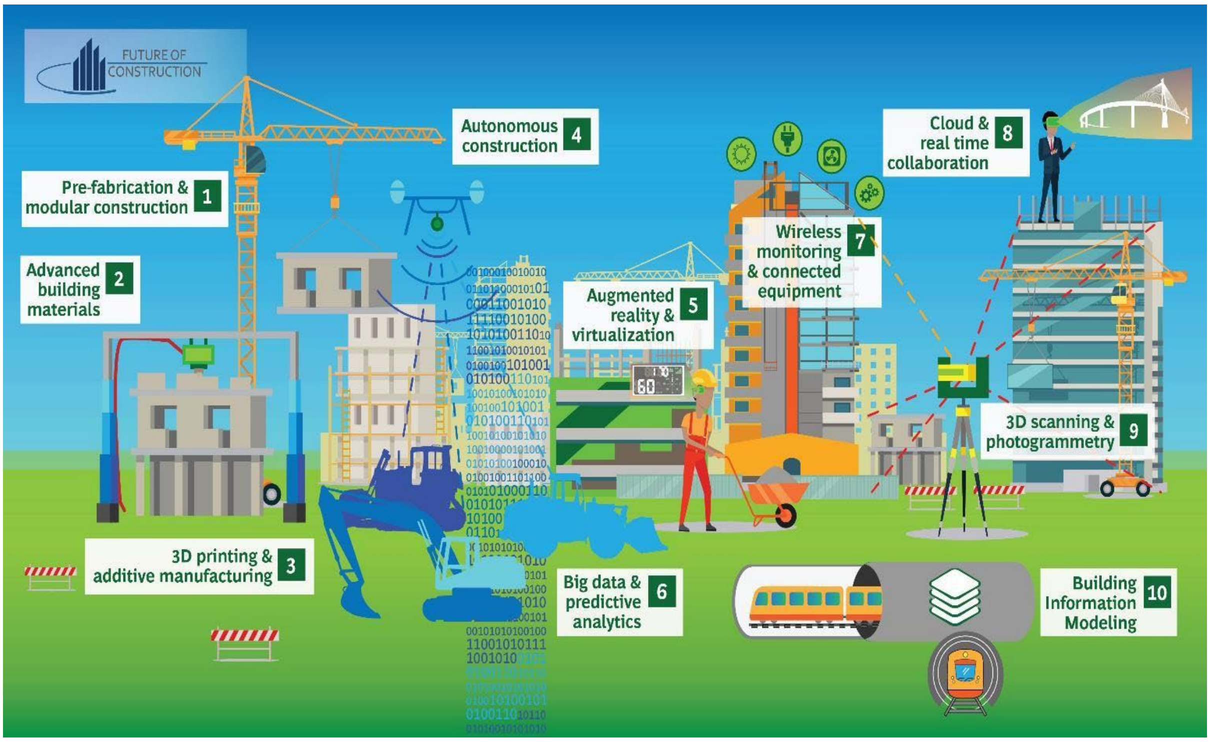
TVET skills at this stage include drafting, metal work (such as welding and metal plating), estimating, materials handling (driving and loading), occupational health and safety oversight, and many more as shown in the table included in annex 4. They include extensive design, construction, engineering and operation and maintenance skills, as well as logistics and distribution competencies. Softer skills are also essential, such as teamwork and conflict management, and these are listed in annex 5. The combination of so-called soft skills and technical skills is needed when designing and building a facility. They are critical because they directly affect safety and efficiency.[79]

Finally, in artisanal and engineering occupations, on-the-job experience is crucial, and employers require this to be an intrinsic element of skills development. The construction sector, however, is changing practices due to the 4IR and in response to the need to increase productivity. Digital skills are becoming essential and must be acquired side-by-side with the traditional skills shown above. These include building information modelling (BIM), prefabrication, 3D printing, wireless sensors and automatic and robotic equipment use and management. As digitisation moves forward in construction, data collection, collation and protection will become more important in the industry as shown in Figure 10.[80]

[79] Air Products International. https://www.airproducts.com/gases/hydrogen

[80] World Economic Forum. The Fourth Industrial Revolution is about to hit the construction industry. Here's how it can thrive. 2018. The Fourth Industrial Revolution is about to hit the construction industry. Here's how it can thrive | World Economic Forum (weforum.org)

Figure 9- Digital skills in future construction



Sources: World Economic Forum, Boston Consulting Group. 2018.

3.3.2 Skills required to design, build, and install process specific equipment and machinery

These skills are more STEM related (currently) than construction and require specialised knowledge, typically an engineering degree and specialised content knowledge specific to the equipment involved.

- Process technology: In *hydrogen production,* this is linked to separation core technologies, detailed process design of large process equipment, distillation columns, heat exchangers, storage tanks and machines amongst many others. In *RE production* this is linked to inverters and racking equipment, wind turbines, solar PV, solar thermal, geothermal, tidal, wave ocean thermal energy conversion (OTEC), hydro, power electronics and biofuels to name but a few. Each area will have its own content-specific training requirement.
- Machinery: All aspects of machinery engineering design, installation, commissioning, troubleshooting, maintenance, and optimisation of machinery, including all types of compressors, steam turbines, cryogenic expanders/companders, blowers, gearboxes, cooling towers, fin-fans and all types of pumps including cryogenic pumps as well as electronic control of equipment such as wind turbines, solar panels, biomass storage and other.

Skills required to handle, move, and store hydrogen. These skills are again relatively generic but require specialised training in safety standards and practices, in line with the transportation and storage of hazardous gases and chemicals. Industrial gas/chemical distribution, especially if the gas or chemical is hazardous, is a complex process. Efficient delivery of potentially hazardous gases to points of use, at the correct pressures and without leaks, requires a particular set of engineering skills and knowledge. At the vocational level, and depending on the mode of transport, specialised skills in pipeline operation and the ability to manage dangerous events are required. Most distribution and storage operators require specific accreditation and training before they are allowed to undertake this work, and many nations require workers to have specific licences. This applies to what is termed major accident hazardous pipelines (MAHP) and includes ammonia and hydrogen. Accident training and management skills are a critical part of skills development in this area, and this includes tanker and container transport, the transfer of the material to storage, and storage.[81]

While each area of RE production, CCS, and chemicals production requires generic skills, each also has its own specific set of content requirements and skills, which are often weighted differently.[82] An example of what is required in Solar PV is included in annex 6. For each renewable category there is a similar list of skills required, as well as for each major stage along the grey, blue and green hydrogen supply chains.

The STEM skills as outlined above apply to all hydrogen production at inputs and manufacturing level. For GH, inputs from RE are a critical part of the production process, and skills related to RE inputs and the production of RE are therefore essential precursors to the production of GH. For blue hydrogen, specific content skills related to CCS such as the operation of power plants and related capabilities are added to the standard supply chain. Because hydrogen is similar to natural gas in that it has to be liquified before it can be transported, the methods used for storage and logistics are also very similar. The skills required for design and construction are almost entirely the same, as are the skills required for process technology and machinery design and set up. Bioenergy and the implementation of Power-to-X (P2X), has an additional stage where the growing and harvesting of biomass skills are needed.[83]

An overview of hydrogen specific skills noted in Table 4 indicates the generic nature of skills along all hydrogen production and distribution paths, but with a need to contextualise these skills for hydrogen, and specific additional skills needed in hydrogen downstream applications such as Fuel Cells. A fuel cell design engineer for example, requires the generic skills of design engineering, but in the FC context.

Table 4-Hydrogen specific skills

o	Automotive Fuel Cell Electronics Engineer
o	Emissions Reduction Project Manager
o	Fuel Cell Design Engineer
o	Fuel Cell Plant Manager
o	Fuel Cell Power Systems Engineer

[81] Health and Safety Executive. Pipelines health and safety. 2021. Pipelines health and safety (hse.gov.uk)

[82] ILO. Skills and Occupational Needs in Renewable Energy. 2011. https://www.ilo.org › publication › wcms_166823

[83] Charalampos Malamatenious. Renewable energy sources: Jobs created, skills required (and identified gaps), education and training.

o	Fuel Cell Quality Control Manager
o	Hazardous Materials Management Specialist
o	Hydrogen Energy Engineer
o	Hydrogen Energy System Operations Engineer
o	Hydrogen Energy Systems Engineer
o	Hydrogen Fuel Cell R&D Director
o	Hydrogen Fuel Cell System Technician
o	Hydrogen Fuelling Station Designer
o	Hydrogen Pipeline Construction Manager
o	Hydrogen Plant Operations Manager
o	Hydrogen Power Plant Operations Manager
o	Hydrogen Systems and Retrofit Designer
o	Hydrogen Systems Program Manager
o	Hydrogen Systems Safety Investigator

Source: Brunel, 2020

In sum, the skills needed are similar along all production pathways, but with differences in on-the-job training, content, and equipment-specific know-how. Across the board digital skills related to manufacturing production, distribution, and storage, will be required. Other skills, largely commercial skills, such as energy consultancy, training, business development, marketing, customer facing services and the like, are cross-cutting. The ebb and flow of skills demand in quantitative terms is linked to the construction of production facilities and equipment, when there is a surge in demand for skilled people in design, construction, capital equipment commissioning and similar but thereafter the focus is on the running of operations, where factory operations, logistics, sales and after sales become more critical.

Thus, the core skills clusters for all RE, CCS and all forms of hydrogen, with variations as shown above, consist of i) engineering and technical, ii) logistics and materials handling, and iii) digital. The German approach to skills development acknowledges this, by focussing on the same fundamental skills development and training, but adapting content and on-the-job experiential training, to particular sub sector contexts. However, as digitisation of previously non digital activities progresses, this has become a core focus of skilling into the future where applicable in the supply chains.

3.4 The case of Germany

Most of Germany's skilled workforce has gone through the dual system of vocational education and training (VET). This is a combination of theory and training embedded in a real-life work environment. A key feature is cooperation between companies and vocational schools. This cooperation is regulated by law. The dual system comprises classroom study in specialised trade schools and supervised, on-the-job work experience, implemented simultaneously. Annually, approximately 500,000 students enter the system, and there are approximately 1,3 million apprentices in training. The host companies pay the apprentices on an increasing basis annually. Over 2/3rds of the students enter the firms where they undertook their on-the-job work experience exposure.[84]

- INTEGRATED APPROACH

A key finding from Germany is that rather than creating new, specific 'green' occupations, many occupations and training curricula have been adjusted and refined to take account of the skills needs of increasingly green aspects of mainstream industry and

Germany adopted its energy transition programme called *Energiewende*, in the early 2000s. It is a long-term energy and climate strategy, with a view to shifting German energy production and consumption from coal and nuclear energy to renewable energy. 46.6 percent of RE production was, in 2017, owned by citizens (a total of 933.5 GW).[85] Over time this has resulted in the creation of over one million new jobs in the RE and energy efficiency sectors. In the German VET system, not least because a number of these jobs required new qualifications and skills, there were no job profiles for the energy transition and existing occupations such as electricians, plumbers and technicians had to be retrained. Even today, in 2021, the process is dynamic as new occupations, descriptions and skills emerge regularly. This is likely to continue for some time.[86]

One lesson learned in the process of attempting to reskill, upskill and train for the energy transition has been the need for focussed and strategic planning. Until recently the *Energiewinde* programme had no master plan, which meant industries and educational institutions had to try to adapt in real time. One study analysed job vacancies (prediction was not possible at the time) and found that demand in Germany largely arose from the wind power sector, which accounted for over 50 percent of all new jobs in green energy in 2015, followed by building services, solar PV, solar thermal, transmission technology and bioenergy. At the same time, the energy system in Germany was undergoing very fast digitilisation and demand for people with skills in both Information and Communications Technology (ICT) and clean energy systems increased rapidly.[87]

A lack of preparation led to labour market shortfalls which persist. According to the Cologne Institute for Economic Research there are nearly half a million open posts for skilled people in mathematics, computer science, and energy related fields and there are many thousands of unfilled VET apprenticeships. At the VET level, this means mechanical, automotive, and electrical engineers and ICT professionals. The Federal Institute for Vocational Education and Training has predicted that the electrical engineering and supply professions could be short of 760,000 skilled workers by 2030, including metallurgy, plant engineering and construction, sheet metal construction, and installation. Even before there was a formal energy transition

[84] Paul Hockenos. How Germany's Vocational Education and Training system works. 2018. [How Germany's Vocational Education and Training system works | Clean Energy Wire]

[85] Agora Energiewende. The Energiewende in a nutshell. 2017. [Agora-Energiewende-Ten-frequently-asked-questions.pdf (lifeaftercoal.org.za)]

[86] Clean Energy Wire. Renewable Energy Agency. 2021. [Renewable Energies Agency | Clean Energy Wire]

[87] Clean Energy Wire. Bonn Science Shop. 2021. [Bonn Science Shop | Clean Energy Wire]

programme in Germany, some basic green skills training was being provided, such as repairing of wind turbines.[88]

The mix of education and on the job exposure, training and experience is considered vital. Over 60 percent of the companies in the renewable energy sector provided trainee posts to VET students, and Enercon, the wind power company, offered 320 apprenticeships at its German sites, spread over 20 fields of learning. The VET system is flexible and can adjust fairly rapidly. The private sector is an integral part of the system and communicates needs via the German Chamber of Industry and Commerce. This has resulted in regular updates to VET curricula over time.[89] As at 2017, none of the jobs associated with the energy transition had been classified separately and continued to be recorded under the VET systems existing classification of approximately 330 professions instead. Importantly, no new job descriptions were developed. The existing classification system was considered adequate by the private sector.[90]

4. South African hydrogen economy and TVET skills

4.1 South African energy status at a glance

In order to establish what skills should be supplied to the South African hydrogen industry by the TVET system, it is essential to understand the energy mix and proposed energy mix for the nation going forward. South Africa is a signatory to the Paris Agreement and as such, must meet its declared Intended Nationally Determined Contribution (INDC) as outlined below. Priority skills for South Africa are likely to be needed in RE (wind and solar and potentially biomass more than geothermal and hydropower) so that GH feedstock is available for production, thus rendering investment in electrolysers a viable option. These skills and occupations are outlined in annex 1.

Coal is currently the basis of the South African energy system and is responsible for approximately 70 percent of installed power generation capacity. The second largest is oil at 15 percent followed by gas, nuclear, renewables and another biomass. Thus, 88 percent of energy is derived from fossil fuels.[91]

Figure 10- South African primary energy consumption by fuel (2000-2050)

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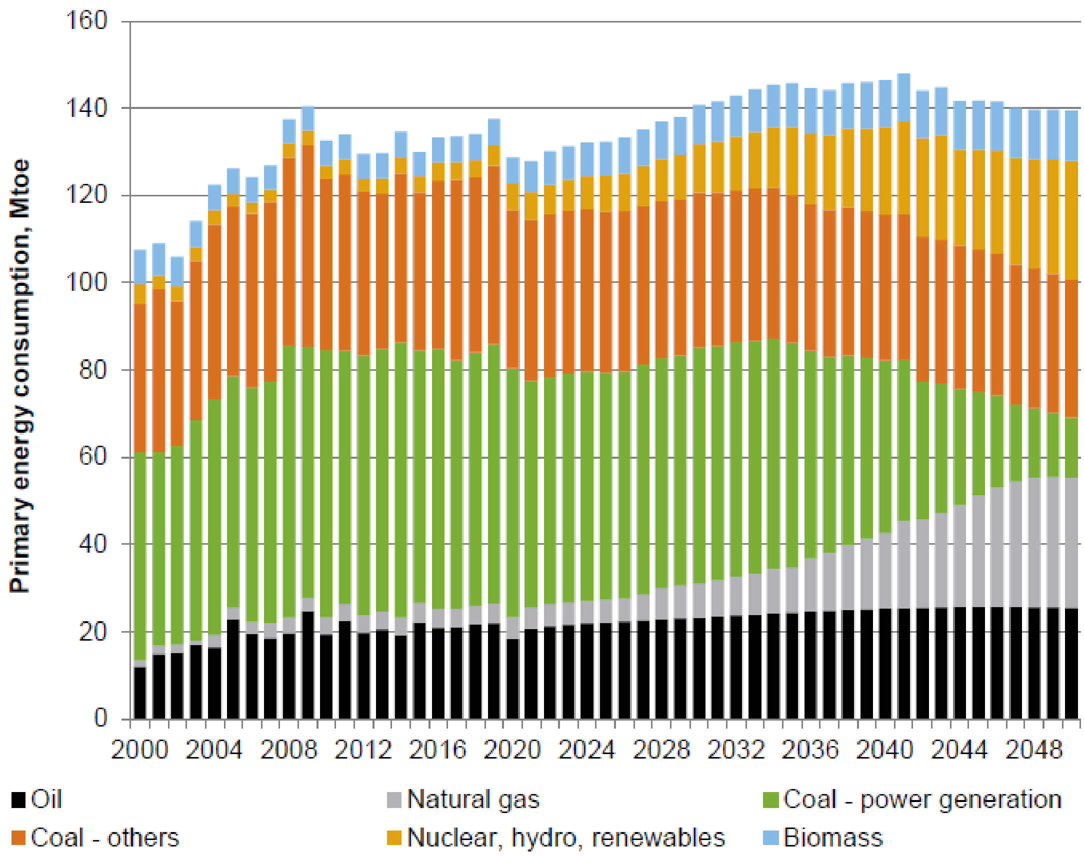
[88] Paul Hockenos, Germany's vaunted vocational training programme strains to meet Energiewende's demand for skilled workers. 2017. [Germany's vaunted vocational training programme strains to meet Energiewende's demand for skilled workers | Clean Energy Wire]

[89] Clean Energy Wire, 2021. Bonn Science Shop.

[90] Clean Energy Wire. Germany's vaunted vocational training programme strains to meet Energiewende's demand for skilled workers.

[91] HIS Market IEA. Agora EnergieWinde-super H2igh road scenario for South Africa'. 2021. Unpublished.

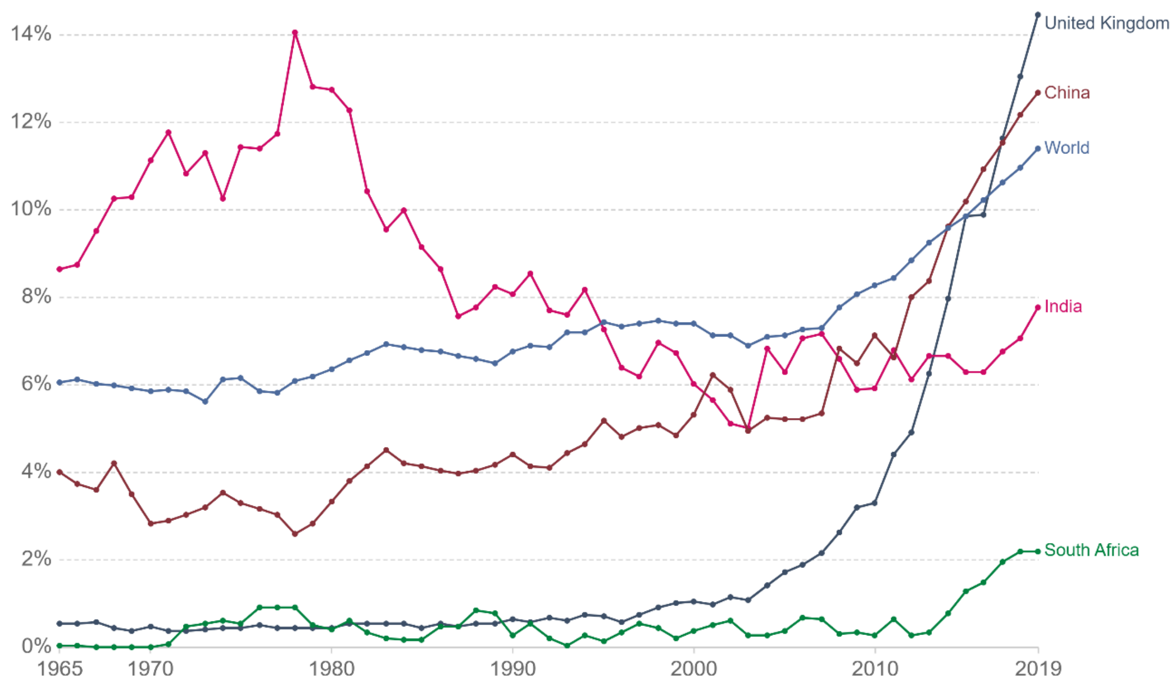


Source: IHS Markit, 2021

Over time, the demand for energy in South Africa has increased very significantly. In 2000, 77 percent of the population had access to electricity. This increased to 95 percent in 2018. Over the same timeframe, even with national electricity blackouts representing a binding constraint to industrial and commercial activity, CO_2 emissions (Mt CO_2) increased from 280 Mt to 480 Mt. Projections continue to show coal as the dominant source of energy in South Africa through to 2040, although the government is focussing on diversifying the power mix by introducing natural gas, hydrogen and RE, including concentrating solar power (CSP).[92]

Figure 11-% Share of primary energy from renewable sources (exc. biofuels)

[92]IEA. South Africa Energy Outlook. South Africa Energy Outlook – Analysis - IEA; IEA. South Africa electricity generation by technology in the Stated Policies Scenario, 2010-2040, IEA, Paris https://www.iea.org/data-and-statistics/charts/south-africa-electricity-generation-by-technology-in-the-stated-policies-scenario-2010-2040



Source: Our World in Data, derived from BP statistical review of World energy, 2020

South Africa emitted just under 500 million metric tons of CO_2 emissions from fossil fuel combustion and industrial purposes in 2019 and is one of the largest emitters of carbon dioxide worldwide, as a result of its high dependence on coal energy.[93] GHG emissions increased by 39 percent between 1990 and 2019. In 2019, South African GHG emissions were standing at 9.0 tcO^2e/capita, higher than the G20 average of 7.5.[94]

4.1.1 South African commitments to climate change

In 2016, South Africa committed to reducing emissions in terms of the Paris Agreement, through submission of its INDC. Adaptation and mitigation targets included policy instruments such as Carbon Taxes, regulatory controls and standards and desired emission reduction outcomes (DERO) for sectors. Targets for reduction were set at an upper limit of 614 MT CO_2e by 2025 and a similar amount by 2030.[95] A revised INDC will be submitted by the end of November 2021, with new targets which are likely to be set in a range of 398 million tonnes of carbon equivalent to 510 $MTCO^2e$ in 2025, and between 398-440 MT CO_2e by 2030, a 28 percent improvement in the target. The revised INDC has been released for comment by the Presidency and proposes

[93] STATISTA. Carbon dioxide emissions from fossil fuel and industrial purposes in South Africa from 1970 to 2019' • South Africa fossil fuel CO2 emissions 1970-2019 | Statista

[94] Climate Transparency. The G20 transition towards a net zero emissions economy. 19-9126_B2G_2019_South_Africa.indd (climate-transparency.org)

[95] UNFCCC Secretariat. All NDCs' South Africa.pdf (unfccc.int)

to ensure that carbon emissions will decline progressively from 2025, ten years earlier than originally planned.[96]

The INDC was developed in the context of South African policy which emphasises low carbon development, including but not limited to Constitutional environmental rights, the National Development Plan (NDP), and the 2011 National Climate Change Response Policy (NCCRP). Climate aligned sectoral plans include the National Sustainable Development Strategy, (NSDS), the Reinvigorated Industrial Strategy (RIS), the national integrated energy and electricity plans (IEP and IRP) and the National Climate Change Adaptation Strategy (NCCAP). This last policy framework, the NCCAP, serves also as a shared basis for climate change adaptation activities in South Africa across all levels of government and introduces the beginning of policy coherence.

The 2019 Integrated Resource Plan (IRP) sets out a long-term diversification of the power mix by 2030 and moves towards lightening the carbon footprint of the energy sector while meeting growing energy demand and ensuring a socio-economically JT.[97] The development of South Africa's Renewable Energy Independent Power Producer Programme (REIPPP) has led to approximately 20 percent of all South African energy now being produced from renewables and waste.[98]

More recently, the government announced a shift in the threshold of energy that companies can generate privately up to 100 MW via changes to the Electricity Regulation Act. This frees up large energy users to generate their own electricity and feed back into the grid. The mining industry in particular has signalled its intention to focus heavily on the use of RE to generate green power, although it is anticipated that the commissioning of private electricity generation plants is likely to take up to two years in many cases.[99]

There is thus a clear policy trajectory and mandate for South Africa to focus heavily on the reduction of GHG emissions through increased production of electricity via RE. One energy pathway to such production is via a shift to the production of GH and sectors targeted are transport, building and construction, mining, industrial processes, and export. Furthermore, as fossil fuel activities decline over time in line with GHG reduction targets, the GH option can provide alternative job and work opportunities for people to be redeployed or reskilled.

4.1.2 A just energy transition in South Africa

[96] Climate Transparency. The G20 transition towards a net zero emissions economy.

[97] IEA. Country report. South Africa - Countries & Regions - IEA

[98] Department of Science and Innovation (DSI). High-Level Hydrogen Society Roadmap for South Africa. Draft version 4.10. unpublished. 2021

[99] Business Day. Finally Ramaphosa sees the light and flicks a game-changing switch. June 11, 2021. https://www.businesslive.co.za/bd/opinion/editorials/2021-06-10-editorial-finally-ramaphosa-sees-the-light-and-flicks-a-game-changing-switch/

South Africa has high levels of poverty and inequality and ensuring a just energy transition is a core priority in national policy. The provision of alternative decent work is fundamental in the South African context. High levels of poverty and unemployment in South Africa require that climate policy must encompass a development pathway which caters for these issues.[100] The narrow unemployment rate (active job seekers only) was 30.8 percent at the end of Q3 2020, and the broad rate (includes people who are unemployed but discouraged and no longer seeking work) had increased to 43.1 percent and both rates are trending upwards. Youth unemployment is currently 55 percent and over 55 percent of South Africans live in poverty and 25 percent in extreme poverty, i.e. they cannot meet their needs for food.[101] The South African education system is not fully functional and is not delivering the skills and capabilities required to grow the economy. In 2016, 78 percent of South African Grade 4 children could not read for meaning in any language.[102]

Thus, policies promoting a JT and a JET must go beyond a focus only on people in work. The JT will need to take cognisance of unemployed or informally employed people as well as those employed, as the Paris Agreement notes. The agreement states that a JT towards sustainability can "only be achieved if the action taken to address climate change respects and promotes gender equality, the empowerment of women, and intergenerational equity".[103] Policies will additionally need to be environmentally sensitive and include climate-smart strategies to prevent, mitigate, and adapt to poor conditions – especially in agriculture where a large proportion of South Africa's working poor (especially women) are occupied. Many crops are threatened by increasing drought and extreme heat and this environmental degradation increases gender inequality and threatens food security.[104]

For those in work and in vulnerable sectors such as mining, a JLT is critical and should already have begun for early implementation. For example, the South African coal mining sector employs approximately 80,000 workers and is concentrated in regions where there is already high unemployment. Eskom, with 30 power stations (the majority coal fired) employs roughly 46,000 people.[105] These communities and workers require specific programmes to be developed to ensure a JLT in the immediate term, which will include upskilling and reskilling where possible and in the most appropriate site-specific ways. One possible set of intervention

[100] Jessie Burton, Andrew Marquard, and Bryce McCall. Socio economic considerations for a Paris Agreement compatible coal transition in South Africa. Energy Research Centre, UCT. 2019

[101] StatsSA. P0211 - Quarterly Labour Force Survey (QLFS), 4th Quarter 2020. Publication | Statistics South Africa (statssa.gov.za)

[102] [PIRLS] Ina Mullis, Michael Martin, Pierre Foy, and Martin Hooper. PIRLS 2016: International Results in Reading. International Association for the Evaluation of Educational Achievement (2017).

[103] UNFCCC. Paris Agreement.

[104] ILO. A just transition towards a resilient and sustainable rural economy. Policy guidance notes. 2020; United Nations Economic and Social Council. Challenges and opportunities in achieving gender equality and the empowerment of rural women and girls; ECOSOC, Commission on the Status of Women, 2018, agreed conclusions. E/CN.6/2018/L.

[105] Eskom. Company information overview. 2021 Company information overview (eskom.co.za)

options has been developed by the Energy Centre at University of Cape Town (UCT) and is outlined in Table 5.

Table 5-Typology of Just Transition interventions (including Just Labour Transition)

	No support	**Compensation or grandfathering** *(backward looking)*	**Structural adjustment assistance** *(forward looking, narrow)*	**Holistic adaptive support** *(broad)*
Workers	No support	Compensation for losses, such as redundancy payments, early retirement benefits	Cash or in-kind assistance to retain or relocate; wage subsidies, targeted unemployment payments.	Strong support to find new jobs and to maintain or develop new valued attachments such as work in the same community or work of a similar social standing
Regions/communities		Compensation for losses such as resource transfers to lower levels of government to compensate for reduced tax revenue.	Affected communities/regions are supported economically to diversify, e.g., via direct investment in public goods such as infrastructure or innovation; subsidies and/or tax incentives to businesses in growth sectors; technical assistance	Affected communities/regions are given broad socio-cultural assistance e.g., investment in social service provision, and/or community social and recreational facilities.
Coal mining companies		Compensation for lost asset value or existing assets are 'grandfathered' into the new regulatory regime; State subsidisation of company liabilities e.g., financial liabilities to employees and site remediation liabilities.	Businesses are provided cash or in-kind assistance to adapt to the new policy/context e.g., tied grants for technology upgrading.	

Source: Green, in Spencer et al., 2018

Planning and implementation of the JT and the JLT will require strong social dialogue between workers and their unions, employers, government, and communities as well as educational service providers such as TVETs to assist with reskilling and/or upskilling, depending on plans for the relevant site. Ideally, such plans will provide new decent jobs, social protection, economic opportunity, and more training opportunities for those affected.[106] The just energy transition (JET) "should be a transition to a low carbon economy in a way that allows equitable participation and inclusive growth for all in the future energy sector, protects the vulnerable and provides the opportunity for current and future citizens to capacitate and adapt themselves to find dignified employment and embrace the 21st century green economy".[107]

The South African TVET system therefore has a significant role to play in skilling people for energy change, improved methods of food production, different work skills, and ideally, will be part of the discussions determining JT and JLT processes.

4.2 South African hydrogen

Hydrogen, already produced in South Africa for local consumption and export, has the potential to become, in its green form, an important element of the future national energy mix and as such, will require major attention to future skills needs as the grey hydrogen economy declines over time and the green (or blue) hydrogen economy increases.

The use of hydrogen requires an entirely different approach to generating energy for the economy and for society at large – one that is economically inclusive and environmentally sustainable. The new national energy production mix must be capable of maintaining industrial competitiveness, reducing carbon emissions, and meeting social and developmental goals such as reducing energy poverty by ensuring access to energy for people living in disadvantaged circumstances.[108]

GH is a viable energy option for a number of industrial and consumer-based applications and can make a significant difference to emissions reduction. Hydrogen energy is commercially viable in its current form of grey hydrogen and technically viable in both blue and green forms. GH is sustainable once it has reached commercial scale (including RE inputs) in applications such as energy production, transport, and housing/heat.[109]

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[106] South African Renewable Energy Council (SAREC). 'South African Renewable Energy Masterplan'. 2019.

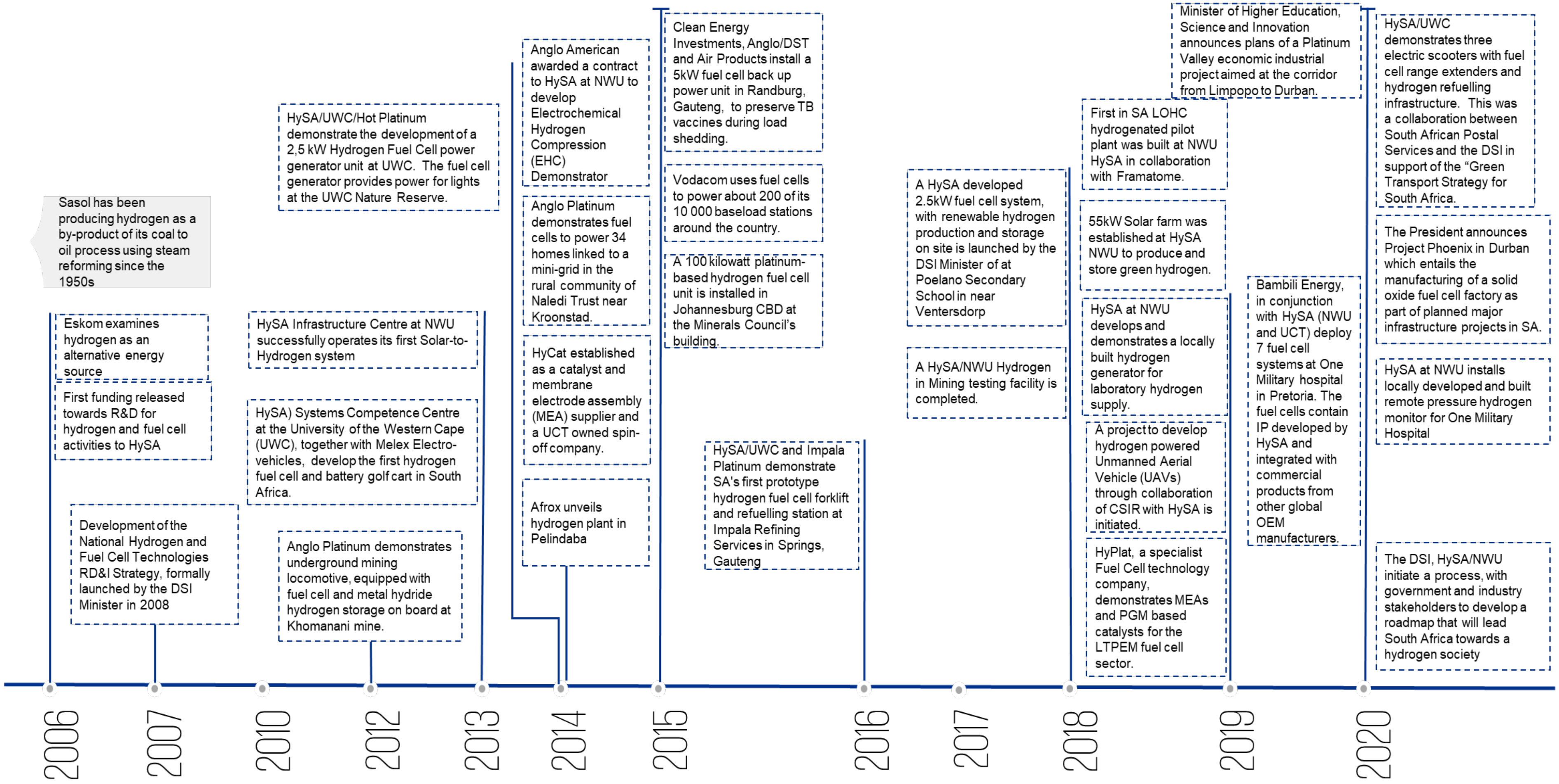
[107] South African Renewable Energy Council (SAREC). 'South African Renewable Energy Masterplan'; Mike Levington, Kabisolar. Interview by Josie Rowe-Setz. Online. Cape Town, May 2021

[108] Department of Mineral Resources and Energy. *Strategic plan: 2020 – 2025.* http://www.energy.gov.za/files/aboutus/DMRE-Strategic-Plan-2020-2025.pdf

[109] Hydrogen Council. Path to hydrogen competitiveness- a cost perspective. 2020. Path to Hydrogen Competitiveness: A Cost Perspective - Hydrogen Council

The draft South African Hydrogen Road Map (SAHRM) provides some insight into future policy for South Africa as it pertains to hydrogen as part of the national energy mix in the transition to a net zero carbon economy as outlined in Figure 13.

Figure 12- Draft high level hydrogen road map- South Africa



Source: DSI, 2020

4.2.1 Progressing the South African hydrogen economy.

In order to progress the hydrogen economy in South Africa, Hydrogen South Africa (HySA) was formed in 2007 and undertakes critical work in the following areas:

Table 6- HySA focus areas.

HySA Centre of Competence	Research Focus	Host Institutions
HySA Catalysis	Catalysts and catalytic devices for fuel cells and hydrogen production	• University of Cape Town (UCT) • South African Minerals Research Council (MINTEK)
HySA Infrastructure	Technologies for hydrogen generation/production, storage, and distribution.	• North-West University (NWU) • Council for Scientific and Industrial Research (CSIR)
HySA Systems	Systems integration and technology validation.	• University of the Western Cape (UWC)

Source: DSI, 2020

As yet, there is no clear South African hydrogen policy, and this will be required if the GHE is to be implemented effectively. The DSI provides a list of policies that are current, but are not sufficient in the hydrogen context, and notes the need for focussed policy to be developed and approved.[110]

- National Development Plan 2030;
- White Paper on Renewable Energy Policy (Department of Minerals, Resources and Energy, 2003;
- National Climate Change Response White Paper, 2011;
- Integrated Resource Plan, 2019;
- Beneficiation strategy for minerals industry of South Africa, 2011;
- National Energy Efficiency Strategy, 2008;
- National Integrated Energy Plan, 2016;
- Department of Public Works and Infrastructure Green Building Policy, 2018;
- Green Transport Strategy for South Africa, 2018; and
- National hydrogen and fuel cell technologies research, development, and innovation strategy, 2008.

Inserting hydrogen into mainstream South African policies and strategies, for example National Skills policies and strategies, should begin now. The High-Level Hydrogen Society Road Map for South Africa (HLHRM) has met essential milestones and developed significantly since South Africa's hydrogen programme was launched in 2008. Additionally, in the second week of April

[110] Department of Science and Innovation (DSI). High-Level Hydrogen Society Roadmap for South Africa.

2021, a number of announcements were made about the launch of scale projects linked to GHE and commercial applications. These include, but are not limited to:

- Sasol announced the formation of a partnership with Toyota South Africa Motors (TSAM) to explore the development of a green hydrogen mobility ecosystem beginning with the development of a *mobility corridor* on a main South African freight route which will pilot heavy duty hydrogen powered long-haul trucks. Ultimately, the programme seeks to produce renewable carbon feedstock at a commercially viable scale.[111]
- Anglo American has committed to collaborating with the South Africa DSI for the completion of a feasibility study to develop a *hydrogen valley*. The collaboration includes ENGIE, the South African National Energy Development Institute (SANEDI) and clean energy solutions provider Bambili Energy. The current concept is of a hydrogen valley which will be approximately 835 kms long between Mokopane in Limpopo and the south coast in Durban.[112]
- Anglo American is currently investing in renewable hydrogen production technology at its Mogalakwena PGMs mine and in the development of hydrogen-powered fuel cell mine haul trucks and low-carbon emission ships.

However, interviews with key actors in these programmes and collaborations indicate that none of the parties are yet at the point of considering future skills needs as their major concerns currently are technology viability and commercial potential at scale.[113] In addition, local respondents indicated that the skills gap is currently occurring at the TVET level. Universities are seen as delivering for the most part on the higher-level skills. Comments include:

- "The gap is within the technical support/technician/mechanician level."
- "We need the same skills as we have now but with further FC (hydrogen) training."
- "TVETs are not so set on quality."
- "The quality of (TVET) trainers would have to improve".

Current skills needs for grey hydrogen are for skilled artisans and tradespeople in areas such as welding, truckers, operations engineers, electrical technicians, truck drivers, safety supervisors, mechanics, boiler makers, chemical mechanics, diesel mechanics, millwrights, fitters, electrical fabrication, and others. In general, "The full ambit of running a typical manufacturing chemical production process".[114] In addition, the interviews conducted with industry partners made it clear that the industry needs to work directly with the local TVET or TVETs in the area from which skilled workers will be drawn and not necessarily with the overall system. Overall system weaknesses in the TVET system, however, need to be addressed to ensure that the foundation skills are in place before specialised skills are developed, including digital literacy skills.

[111] Business Maverick. Hydrogen mobility corridor: Sasol and Toyota boldly go in search of the Holy Grail of green fuel in SA. April 2021

[112] Anglo American. Anglo American collaboration on feasibility study for South Africa's Hydrogen Valley.'2021. [Anglo American collaboration on feasibility study for South Africa's hydrogen valley – Anglo American South Africa]

[113] Anglo American, SASOL, Eskom, DHE, MISTRA. Interviews by Andiswa Sibukhwana, Josie Rowe-Setz, online. South Africa May 2021

[114] Anglo American, SASOL, Eskom, DHET, DSI. Interviews

Some work is being undertaken to prepare specific TVET graduates for downstream hydrogen applications in FCs. Pilots were undertaken in specific TVETs and in collaboration with key firms in the South Africa hydrogen economy. In the process of piloting, however, a significant deficiency was uncovered in basic digital and computing skills which will need to be addressed at TVET colleges as South Africa moves into the 4IR.

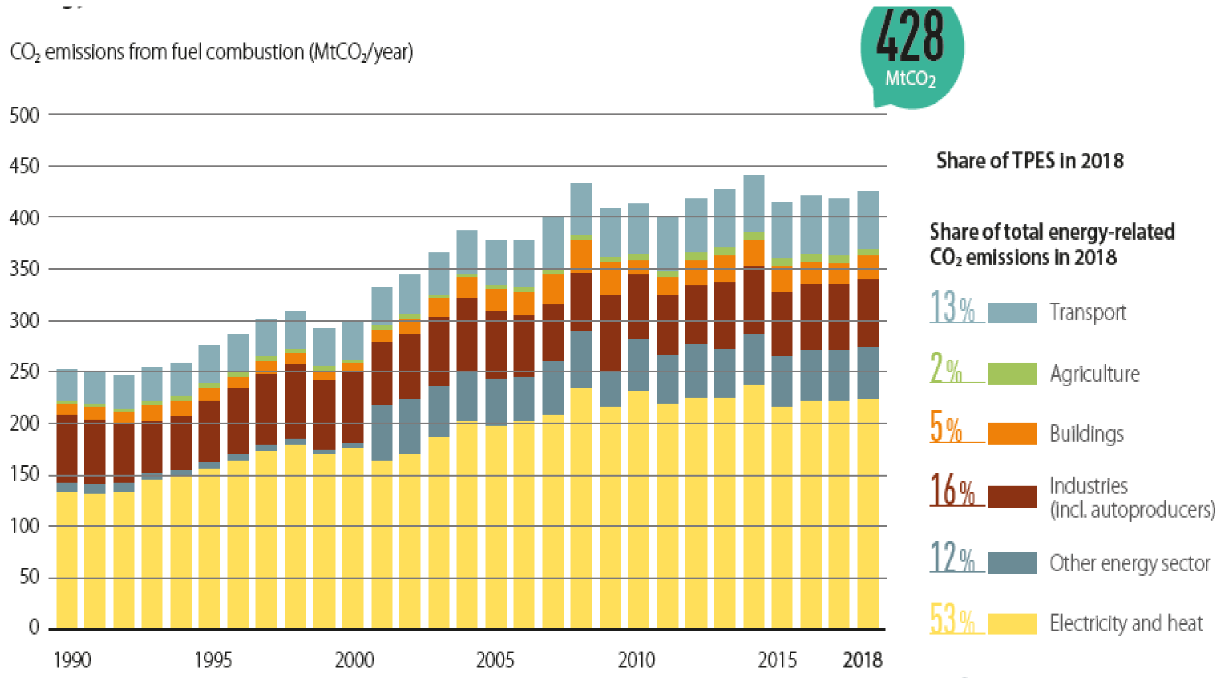
In sum, the commitment to decarbonisation in South Africa, and globally, has resulted in the pursuit of less carbon intensive energy sources. Investors, including global multinationals as well as governments, have significantly increased investment in reducing cost of decarbonisation and decarbonisation solutions. No concomitant investment in skills development (to the same extent) is observable at the time of this review and this has been confirmed by the interviews conducted with industry.

The timing of growth in the GHE is important for planning improved skills supply from the South African TVET system. It seems probable that there is time to repurpose the South African TVET system to ensure employability and a just transition in the GE, and that initial investment in new curricula and programme design for the JLT may need to be in RE production, without which there can be no transition to GH. In some downstream applications such as Fuel Cells and PEM for electrolysers, a speedier development of new curricula and a very collaborative mode of working with firms is immediately desirable as PEM FCs and membranes for FCs are already being manufactured in South Africa and new content is urgently needed if these sub value chains are to grow.

4.3 Hydrogen Sector profiles

South African GHG emissions are for the most part CO_2 emissions from fuel combustion and this has been the case consistently over the last ten years. The electricity and heat sectors are responsible for over 50 percent of all CO_2 emissions as shown in Figure 14.

Figure 13- Energy related CO_2 emissions



Source: Climate Transparency, 2019

Specific sectors are an important focus for hydrogen. Measures available to reach South African targets include the phasing out of coal power (and increasing renewables) for the power sector; the reduction of fossil fuel utilisation (currently 98.4 percent oil) in road transport and a concomitant increase in low carbon fuels in the fuel mix. Furthermore, it includes non-fossil fuel transport options such as FCEVs and the like; a reduction in buildings emissions through the implementation of near-zero carbon buildings going forward as well as retrofitting existing buildings for improved energy efficiency; and reduction in GHG emissions in steel and cement production in South Africa via energy management systems and innovations.[115]

[115] Climate Transparency. The G20 transition towards a net zero emissions economy.

Figure 14- Sector potential for application of Hydrogen energy in South Africa

Industries	Utilisation
Transportation	• Hydrogen can be used as fuel for hydrogen fuel cell vehicles for passenger vehicles/light weight road vehicles, commercial vehicles, heavy duty vehicles, ships, forklifts, trains and jets, heavy mining locomotives and equipment.
Power generation	• Hydrogen fuel cells offer the potential for efficient, clean, and quiet distribution of power generation. • Hydrogen can be used to power gas turbines and ammonia could also be used to reduce emissions in coal power plants. • In telecommunications, hydrogen fuel cells are used in data centres and cellphone towers as back up power.
Industrial and manufacturing process	• Hydrogen is used in industrial and manufacturing process including: • oil refining to produce fuels such as petrol, jet fuel and diesel • hydrogenation of vegetable and animal oils and fats • manufacture of chemicals and plastics • production of adhesives polymer precursors, • microchip manufacturing, • production of pharmaceutical products such as vitamins • production of carbon steels, special metals, semiconductors • ammonia-based fertiliser for food production.
Mining	• Hydrogen is used as a reductant in certain mining processes such as reduction of nickel. • Hydrogen can be used as a fuel for heavy mining locomotives and equipment.
Buildings	• Hydrogen can be used for domestic power supply, as a backup power for emergency and secondary uninterrupted power supply during power outage. • Hydrogen fuel cells can be used as a power source in remote areas.

Source: DSI, 2021

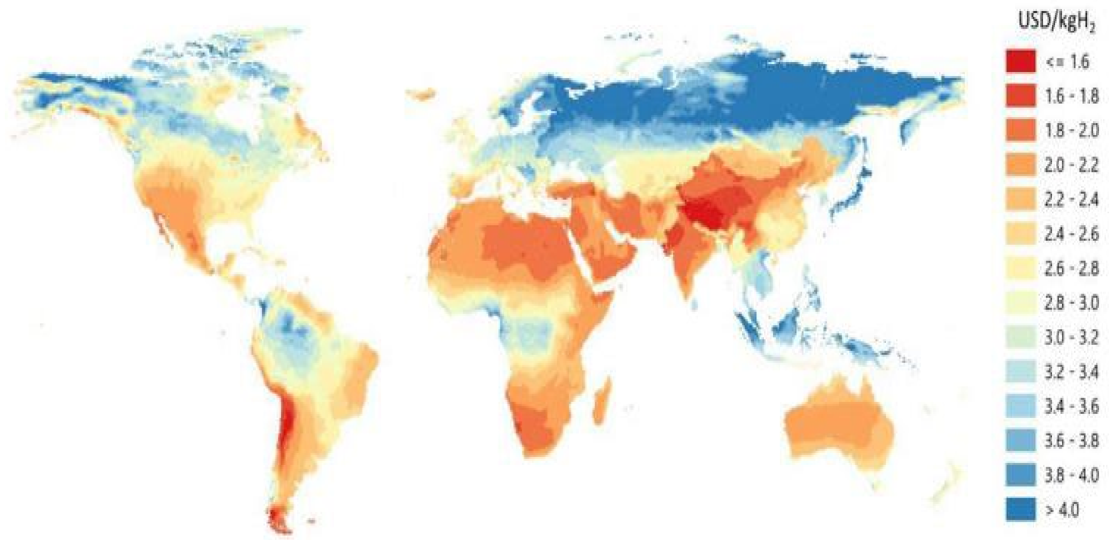
The South African Council for Scientific and Industrial Research (CSIR) considers hydrogen as part of a group of ''powerfuels'' with application in the green economy in particular in long range transport, including rail, maritime and aviation (where electrification options are not viable); industrial manufacturing such as cement, steel, ammonia, and ethylene *inter alia*; heating in buildings; and, commute transport. The CSIR considers all of the former as candidates for hydrogen.[116] In mining, there is an opportunity to replace diesel engines with hydrogen fuel cells because diesel fumes are carcinogenic. Their mitigation drive 20 percent of all mining electricity costs for ventilation. Hydrogen fuel and fuel cell systems are currently more expensive than diesel fuel and engines, but the system overall is cheaper when the ventilation burden is considered, and it is safer for workers.

[116] Thomas Roos and Jarrod Wright. Powerfuels and Green Hydrogen (Summary Report). CSIR 2021. EU-SA partners for growth.

There is also good potential for export. This is because the EU and Japan have targets to import 300 000 tonnes per year from 2030 at a target price of US$3/kg, rising to between 5 and 10 million tonnes per year in 2050 at a target price of US$2/kg. Both have committed to the importation of green hydrogen rather than manufacturing all requirements locally.[117] As long as South Africa can produce GH cost competitively these export markets will be available. Currently, South Africa can produce within the required price range, i.e., in a cost range of US$1.8 - 2.0 /kgH² in bulk production. South Africa has both land (an important consideration for RE and thus GH production) and excellent availability of solar and wind energy with a potential for biomass.

According to some calculations, South Africa is and will be well positioned from a cost perspective for exports of GH, especially when it is exported as green ammonia where freight penalties are less. At current cost levels however, South Africa cannot be competitive in blue hydrogen exports.[118]

Figure 15-Hydrogen costs from hybrid solar PV and onshore wind systems in the long term



Source: Roos & Wright, 2021

South African bulk hydrogen is currently cheaper than all other sources apart from Patagonia and Chile. South African bulk infrastructure at the ports of exit – potentially Saldanha Bay,

[117] Roos and Wright. Powerfuels and Green Hydrogen (Summary Report)

[118] IHS Markit. How competitive can South African exports of hydrogen be? Potential hydrogen supply cost to Europe in 2040. 2021

Richards Bay and possibly, Coega (Nqura) - can be built on and/or adapted for hydrogen export.[119]

4.4 Green skills supply in South Africa

The ILO report on Green Skills in South Africa notes that there is little mention of skills development in the NCCRWP, and no clear skills development strategy for the green economy overall. The report recommends that new skills required need to be integrated into the sector skills plans for Sector Education and Training Authorities (SETAs) and the National Skills Fund Development Plan (NSFDP) *inter alia*. From a JT perspective, the report notes the potential for green skills development to align with the National Employment Vulnerability Assessment (NEVA) and the Sector Jobs Resilience Plans (SJRPs). The NEVA aims to understand the impacts of climate mitigation and adaptation measures on the labour market, and checks job losses and well as job opportunities by sector and location, while the SJRPs try to identify job opportunities in the climate sector itself.[120]

The National Environmental Skills Development Planning Forum (NESDPF) was launched in 2010 by the then Department of Environmental Affairs (DEA) in order to "respond to the lack of a dedicated SETA for green skills".[121] From 2010, the Department of Higher Education and Training (DHET) became the main coordinating body for the SETAs, many of which were and some of which are still not optimally functional. The SETAs are responsible for the Sector Skills Plans (SSPs) as well as quality assurance through accreditation of South African skills and training programmes. They are required to coordinate and develop skills initiatives and programmes in their sectors, as well as to provide funding via grants and other mechanisms to the private sector for skills development initiatives. However, there is limited evidence to show the development of green skills, and/or the integration of green skills in the 21 SETAs currently in place.[122]

The Organising Framework for Occupations (OFO) is the means through which the DHET supports the SSP development process, including the development of green skills. This requires the development of new green occupations and the development of new green skills sets. This process began in 2015 and has continued since then. In the 2019 OFO, where 1,510 occupations are listed, the categorisation indicates those occupations and skills (separately) which can be considered "green", or which have a 'green' application. There are 51 (of 1,510) categorised as being green skills, and 91 as being green occupations.[123] This makes

[119] Roos and Wright. Powerfuels and Green Hydrogen (Summary Report)

[120] International Labour Organisation (ILO). Skills for green jobs in South Africa.

[121] International Labour Organisation (ILO). Skills for green jobs in South Africa.

[122]International Labour Organisation (ILO). Skills for green jobs in South Africa.

[123] EDTP SETA. OFO codes 2019. OFO Codes | ETDP SETA

categorisation and quantification of green, hydrogen, and/or occupations /skills/jobs prediction statistically impossible at this point.[124]

Further, the current system of green skills identification, using the SETA frequency model (the accepted skills identification model) is not conducive to effective identification for the future as such skills are picked up only if identified by a specific number of employers (frequency) via their Workplace Skills Plans (WSPs). There is also, as is the case for the global system, a lack of a common definition and a common understanding of green skills making it impossible i) to extract green skills and occupations from the current taxonomy and ii) to further extract hydrogen and/or green hydrogen skills and occupations. There is as yet no suggested methodology internationally or in South Africa for the development of a green economy skills/jobs/occupations formal system of categorisation. The initiatives attempting to introduce green skills, even conceptually, that do exist, are typically not linked to the TVET system or even individual colleges.[125]

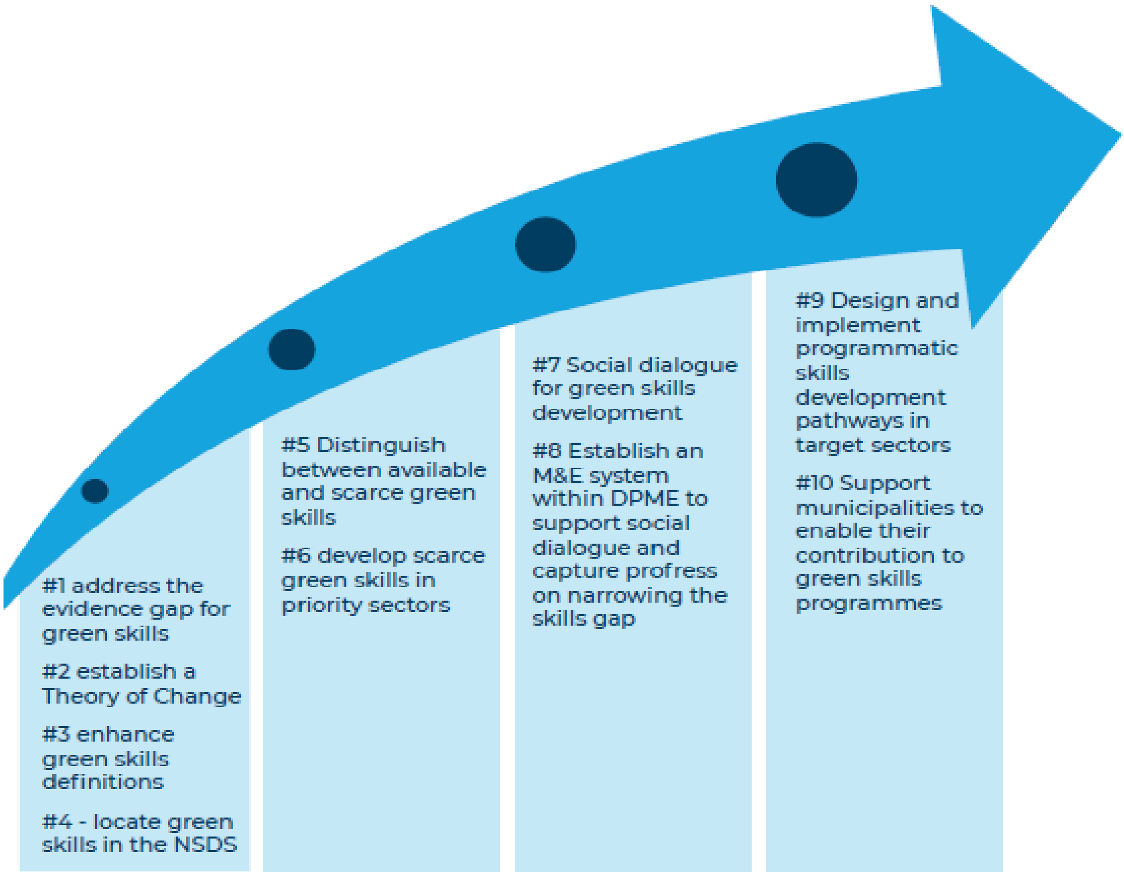
One possible process for the integration of green skills and occupations (including green energy) into the national system is shown below. It emphasises the need to establish a platform from which work can begin. Stage one requires the design and development of an evidence base, followed by a Theory of Change (ToC), location of green skills (and occupations) in the South African National Skills Development Strategy (NSDS) and the development of a rational, usable, and comparable taxonomy to begin the shift towards the green economy, thereby ensuring a just transition. Thereafter, the remaining stages focus on implementation of skills re-engineering and development.[126]

[124] EDTP SETA. OFO codes 2019.

[125] International Labour Organisation (ILO). Skills for green jobs in South Africa.

[126] International Labour Organisation (ILO). Skills for green jobs in South Africa.

Figure 16- Pathway to implementation of green skills development



Source: ILO, 2018

4.5 South African TVET system

In 2017, there were 50 TVET colleges in South Africa, nine Community Education and Training (CET) colleges, and 279 private technical colleges. Other informal vocational training is often supplied by non-government organisations (NGOs), as well as smaller companies and some church organisations.[127]

4.5.1 History of the South African TVET system

After democracy was implemented in South Africa in 1994 the education system was firmly grounded in the South African Constitution (1996), Section 29, which states "Everyone has a

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[127] HSRC Research. Vocational Education and Training in Southern Africa- a Comparative Study. Vocational Education and Training in Southern Africa a Comparative Study; Department of Higher Education and Training (DHET). Statistics on Post-School Education and Training in South Africa: 2016. 2018. Statistics on Post-School Education and Training in South Africa

right to a basic education, including adult basic education, and to further education, which the state, through reasonable measures, must make progressively available and accessible." Arising from this Constitutional mandate, a number of national imperatives and supporting legislation of critical importance to the TVET system came into play including:

- South African Qualifications Authority (SAQA) Act No. 58 (1995): provides for the development and implementation of the National Qualifications Framework (NQF) and establishment of SAQA.
- National Education Policy Act (1996): articulates the policy, legislative and monitoring responsibilities of the Minister and formalises the relations between national and provincial education authorities.
- Higher Education Act No. 101 (1997): provides a unified system of higher education; established the Council of Higher Education.
- Further Education and Training (FET) Act No. 98 (1998): provides for the governance and funding of FET colleges.
- Skills Development Act No. 97 (1998) - amended in 2008: creates the National Skills Agency, established Quality Council for Trades and Occupations, regulates skills development apprenticeships and learnerships.
- General and Further Education and Training Quality Assurance Act No. 58 (2001): establishes UMALUSI as the quality council for FET colleges.
- Further Education and Training (FET) Colleges Act No. 16 (2006): provides regulation of FET, establishment, governance, funding, and employment of staff for public FET and registration of private FET colleges.
- National Qualifications Framework (NQF) Act No. 67: manages the NQF, its qualifications and quality assurance.

Additionally, the government integrated skills development into industrial policy frameworks and consolidated the Departments of Education and Labour under the Department of Higher Education and Training (DHET). This system attempts to integrate education and training and enhance learner progress towards providing the skills the economy needs. The TVET system was initially designed to also promote personal, social and economic development. The stated mission of the South African TVET system is to "provide people with intermediate to high-level skills that will lay a foundation for higher education, facilitate the transition from school to work and develop autonomous life-long learners".[128]

Thus, a successful and aligned TVET system is central to South Africa's economic growth and the creation of decent work for South Africans. If TVET skills supply is not aligned to industry needs in terms of type, quality, and content, then employability is reduced, and industry lacks the resources needed to grow.[129] Furthermore, there are significant negative consequences for people who need decent work, as without a well-functioning TVET system they are unable to access jobs. As noted earlier, in 2018, those people in South Africa who received only up to secondary education level experienced an unemployment rate between 25.4 and 27 percent, but those who completed tertiary education showed an unemployment rate of 6.2

[128] UNESCO. World TVET database- South Africa. 2014

[129] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Employment for sustainable development in Africa (E4D). 2018. https://www.bmz.de/en/development-policy

percent.[130] This is clear evidence of a mismatch between industry needs for skills and the skills supply system.

This evidence of a mismatch is supported by some research studies. The TVET system as it stands is not considered ideal for general industry needs and a number of challenges need to be addressed. One current challenge for industry overall and thus in future for the GHE in South Africa is a lack of skilled persons available in some regions for some industries.[131] Furthermore, curricula, especially with regard to technology, are outdated;[132] the National Certificate (Vocational) NC(V) system does not require work training; many lecturers lack industry knowledge, experience, and training; and NC(V) graduates lack practical knowhow.[133] Field (2014) for the Department of Higher Education (DHE) further recorded South African TVET challenges to be as follows:

- Current architecture of the South African TVET system poses a confusing mix of overlapping and competing programmes and qualifications and inadequately developed programmes;
- Current TVET programmes are insufficiently responsive to the current labour market;
- Lecturers have inadequate skills and qualifications and there is a need to improve professional preparation of college leaders; and
- TVET colleges currently offer limited support for students in academic difficulties, and this reflects insufficient incentives at colleges to encourage completion.

If this is the current reality for industry at large in South Africa, then interventions will be required to ensure GHE readiness in the TVET system.[134]

4.5.2 Skills along the GHE value chains

There is no available research to indicate the skills required along the GHE value chains in South Africa. Respondents to interviews indicated however that the grey, blue and green hydrogen chains require essentially the same or similar skills, as are required for the production of any industrial chemical or gas with the added safety requirements which apply to a hazardous chemical or gas. These have been outlined above and detailed lists are available in annexes 3-9.[135]

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[130] OECD. Youth unemployment rate (indicator). 2019. https://www.oecd-ilibrary.org/employment/youth-unemployment-rate/indicator/english_c3634df7-enen

[131] Kühn, Martin. The South African Technical and Vocational Education and Training System from a German Perspective.

[132] Organisation for Economic Co-operation and Development (OECD). 2017. OECD skills outlook 2017: skills and global value chains. http://hdl.voced.edu.au/10707/429058

[133] Kühn, Martin. The South African Technical and Vocational Education and Training System from a German Perspective.

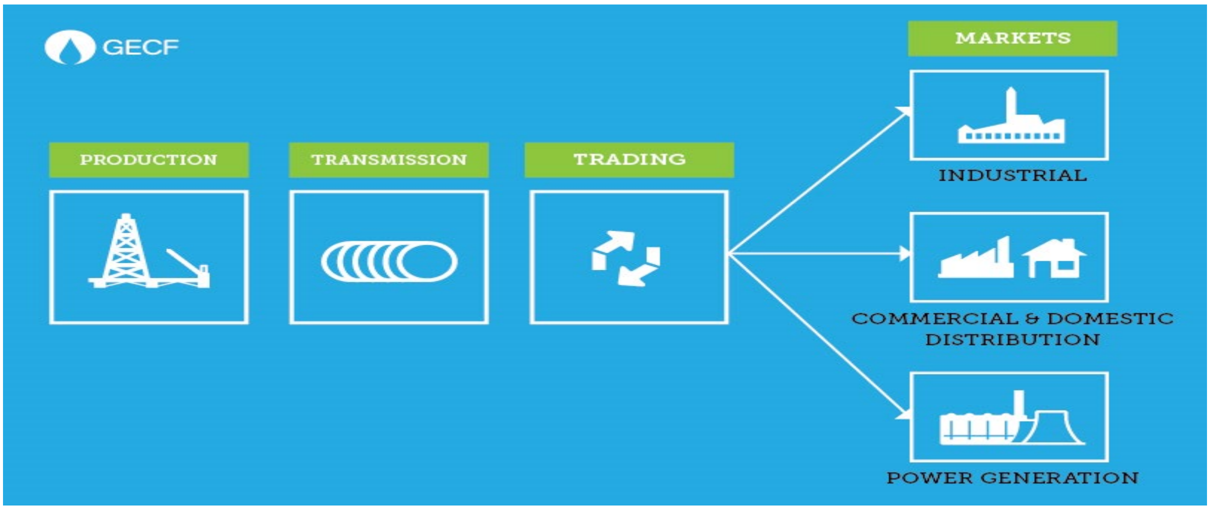
[134] Simon Field. Solutions for SA TVET system. 2014. https://www.dhet.gov.za/Latest%20News/THE%20TRUTH%20ABOUT%20SA.pdf

[135] Anglo American, SASOL, Eskom, DHET. Interviews

The industrial chemicals industry converts raw materials into organic and inorganic industrial chemicals, ceramics, agro-chemicals, petro-chemicals, polymers, and fragrances, most of which are used by intermediate firms to produce industrial or consumer goods. Typically, the industry is defined by the end user segment, as it provides inputs to almost all manufacturing sectors in an economy and this in turn can be aggregated into three key categories, commodity, speciality, and pharmaceutical chemicals. Raw materials prices have a major impact on whether a chemicals producer can maintain competitiveness and in South Africa, for green hydrogen, there is a competitive advantage in the availability of cheaper wind and solar power.[136]

The required skills for the current South African grey HE includes those skills needed in manufacturing, logistics and energy storage and utilisation of gas (refer annex 4 for detailed lists) with digital skills as an essential adjunct.[137] Additional content training and specific experiential training on equipment is needed for the grey HE and the future green HE, but the major differences in skills for the future economy will be more about digitisation than about physical skills. A summary overview of the value chain for industrial gas to power demonstrates the same components as for RE and all industrial gases with variations in technology applied which need to be added to TVET curricula.

Figure 17- High level industrial gas to end user value chain.



Source: GECF, 2021

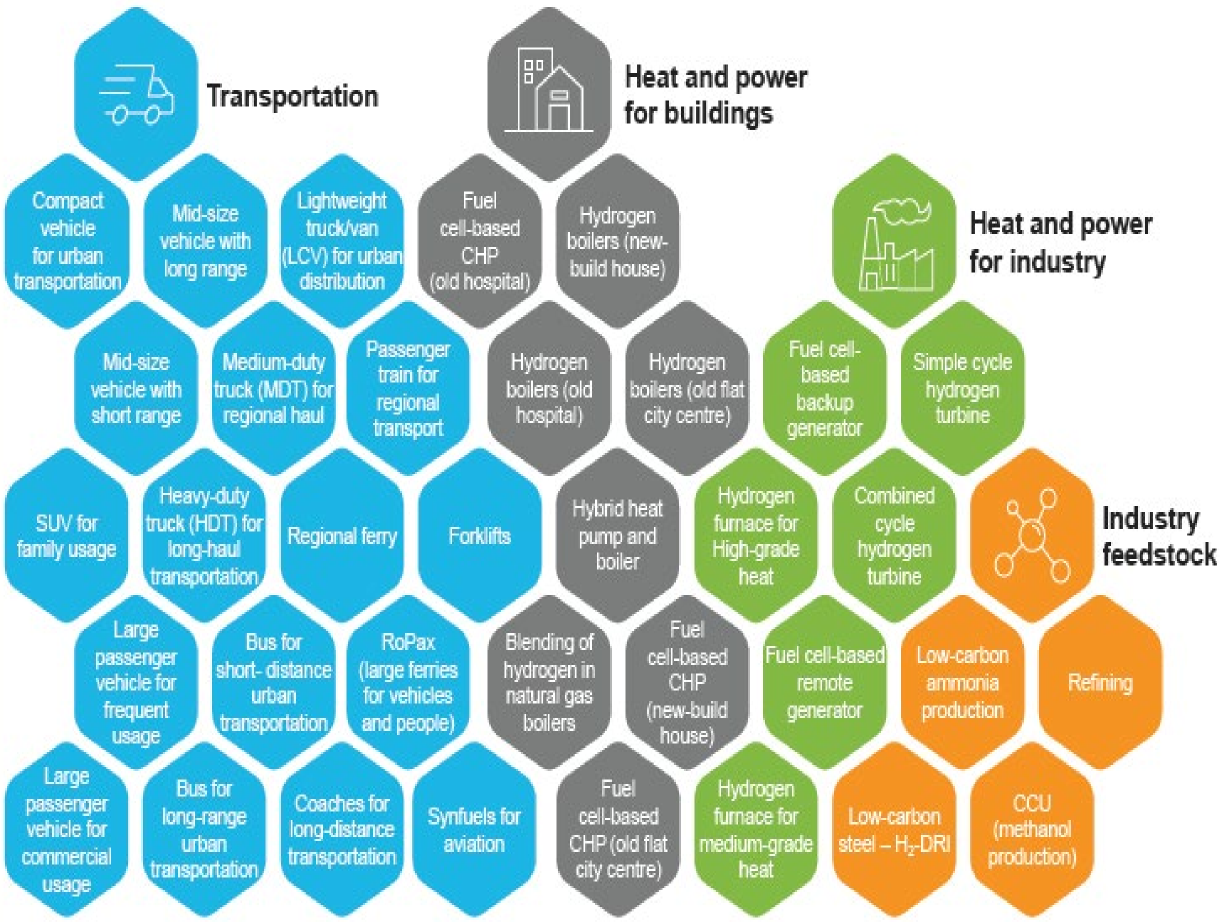
Where the grey and green hydrogen economies differ in important ways for skills is in i) the RE production industry ii) downstream battery applications (FCs) iii) membrane production for electrolysers, and possibly, iv) green ammonia utilisation as a carrier.

136 Roos and Wright. Powerfuels and Green Hydrogen (Summary Report)

137 IRENA. Measuring the socioeconomics of transition: Focus on jobs. 2020, Abu Dhabi

In South and southern Africa, the GH industry is essentially pre-commercial. It has not yet begun the growth associated with a viable industry. In the downstream areas, such as the design and manufacture of fuel cells, specialised marine transport, and other similar value-added applications, an entirely new set of knowledge, competence and thus, new curricula and training will be needed which would be largely content-based on new technology (including new materials). The following offers a summary view of GH production and the main (current) applications where specialised skills/knowledge/competency sets will be required.

Figure 18- Main applications for green hydrogen (2020)

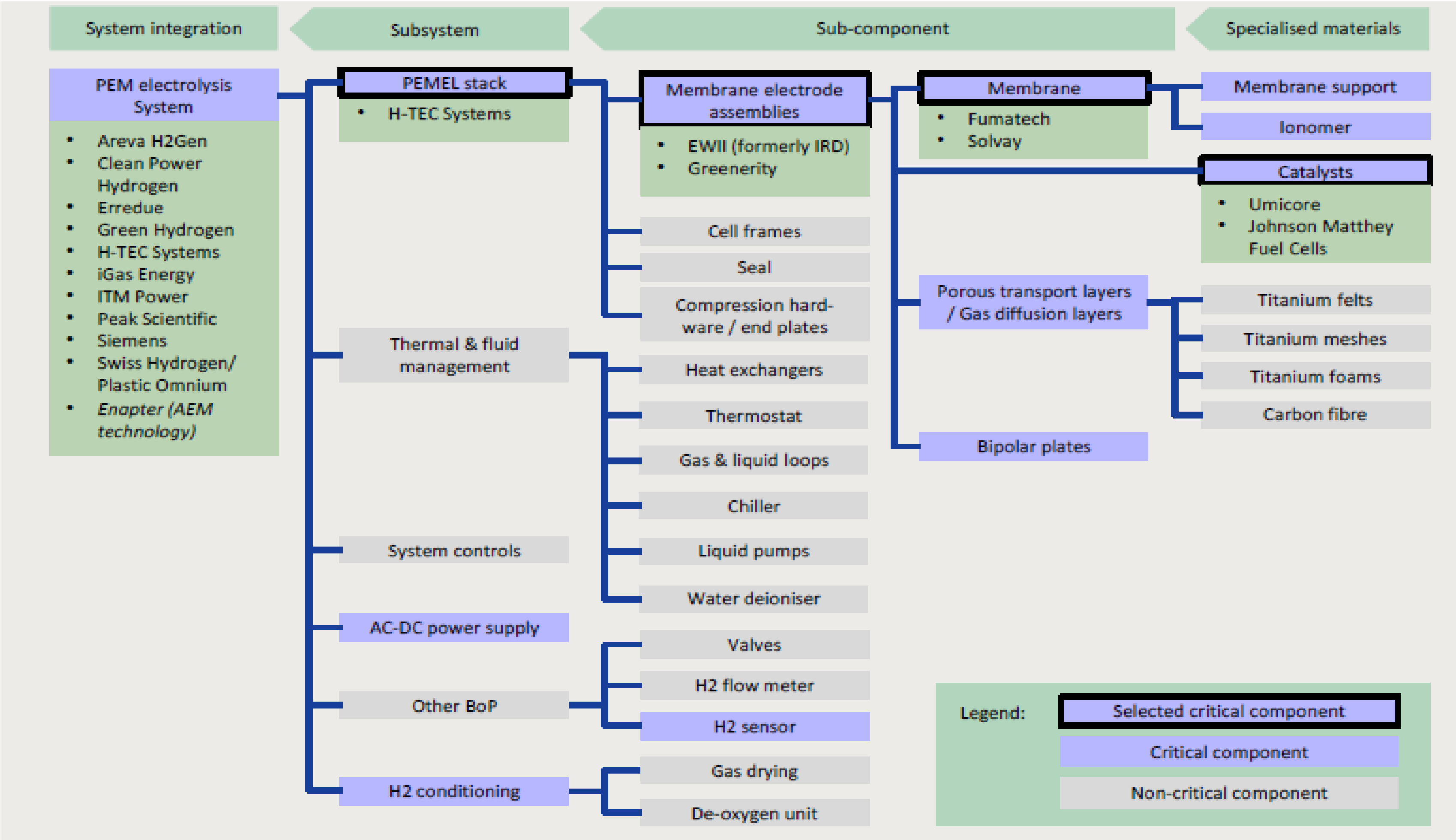


Source: Hydrogen Council, 2020

For each of these applications, in the main sectors of transport, heat and power, and power for industry, the value chain remains the same. That is, the supply of grey or green hydrogen follows the same pathway. One major element where the chain becomes high value add and advanced manufacturing, is in the design and manufacture of FCs or hydrogen driven and Platinum Group Metals (PGMs) catalysed batteries. In addition, all transportation (mobile) applications applicable to green hydrogen use FCs and some building heat and power applications. Skills for this specific hydrogen power storage unit, at the TVET level, are specific to FCs.

This suggests that there is an immediate need for specialised additions to the relevant site specific TVET curricula (sites where FCs are manufactured and/or assembled). This should happen in consultation with industry, in particular at this time with local firms which are investigating hydrogen driven heavy trucks, forklifts and other materials handling equipment, and FCEVs. The hydrogen PEM FC chain is shown below (with key private sector firms at each stage) but most elements are not present in South Africa today although Membrane Electrode Assemblies (MEAs) and catalysts are produced in small quantities. Therefore, skills inputs at the TVET level can be limited accordingly until investment in production is confirmed, at which point new skills should be provided. The EU FC value chain in Figure 20 offers a perspective of the full value chain and where skills will be needed over time.

Figure 19- PEM FC electrolysis value chain in Europe



Source: FCH, 2019

For transport applications, knowledge pertaining to the design and manufacture of key components of FC stacks is needed, that is, catalysts, membrane electrode assemblies, bipolar plates, and gas diffusion layers. This knowledge can also be applied to combined heat and power (CHP) and auxiliary power units (APUs). In the stationary FC applications, micro-CHP is a critical knowledge and skills set. Furthermore, knowledge in electrolysis, from component supply to final integration capability is applicable once RE production facilities are available to scale in South Africa. Consequently, there is a need to ensure that the national education and skills supply system, and for the purposes of this review, the TVET system, can provide an adequate supply of appropriate, sufficient, and quality skills, first for the implementation of RE and the support of the nascent FC and MEA industry and second, for the transition of the grey hydrogen economy to the GHE.

However, even at the basic skills level of digital literacy and basic technician training for the hydrogen status quo, (with the exception of performing TVETs), the current TVET system is not considered to be adequately preparing learners for industry needs. For example, there is a clear lack of skilled persons available in some regions for some industries. The supply of skills is site specific and thus there is a need to understand the spatial industrial landscape so that the supply of skills is available at the geographical point of demand.[138]

4.5.3 Supply of vocational and technical skills (excl Universities)

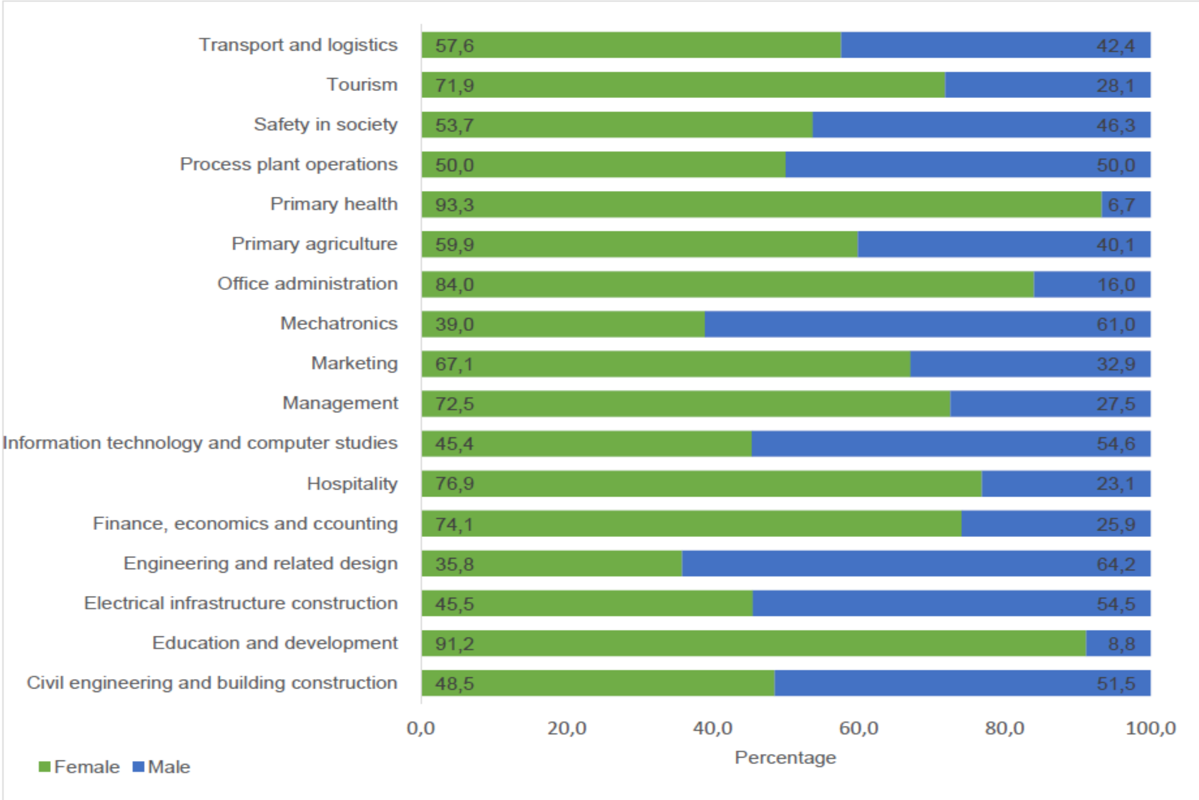
Between 2001 and 2016, enrolments at TVET colleges increased from 400,000 enrolled to just over 705,000 nationally. An almost equal gender split was noted in 2010 (but by 2016, women enrolments outnumbered men at 56.8 percent). 37 percent of all enrolments were for the National Certificate (Vocational) NC(V) category (19 vocational fields), while a further 49 percent were enrolled for the NATED programmes (24 fields of study), N1 to N6 and consisted of occupational and skills programmes previously offered by technical colleges. The NC(V) fields are those applicable to the HE and the GHE skills requirements.

The completion rate for NC(V) level 4 in the comparable year (2016) was 41.5 percent. Completion rates are calculated as the number of students who successfully completed the qualification expressed as a percentage of the number of students who were eligible to complete the qualification and who wrote the examination. There were more female graduates of the NC(V) level 4 for almost all fields of study with the exception of mechatronics (39 percent female); information technology and computer studies (45.9 percent female); civil engineering and construction (48.5 percent female).[139] In terms of how the TVET course are reported, there is no current possibility to link overall TVET skill supply with existing grey hydrogen demand, and/or potential demand for green hydrogen as the reporting categories are too general.

[138] Martin Kühn. The South African Technical and Vocational Education and Training System from a German Perspective.

[139] StatsSA. Education Series Volume V-Higher education and skills in south Africa. 2017. Report: 92-01-05

Figure 20- NC(V) TVET qualifications 2016



Source: StatsSA, 2017

Apart from an overall failure of the economy to employ people, especially younger people, for clear economic and education level reasons, there is also a failure to employ the graduates of TVET colleges *inter alia*. This is in part a function of lack of opportunities in the chosen fields of study, but also a poor fit between the TVET system and the technical skills needed by industry, and manufacturing. The transition from school to work in terms of building an inclusive society and the JT, requires intervention to achieve a significant improvement of particularly black South Africans in the mainstream economy. Field (2014) made the following recommendations to address a number of the challenges the TVET system faces.

- Merge upper secondary vocational programmes to two main tracks – school and work-based track; offer second chance programmes; develop diplomas and certificates at post-matric level;
- Make workplace learning mandatory for vocational programmes; co-ordinate vocational provision through a national strategic body; establish flexibility in some of the curriculum; invest in better data on labour market outcomes;
- Strengthen professional preparation of under-capacitated lecturers including in workplace experience and promote effective college leadership;
- Provide support to ensure adequate levels of literacy and numeracy including computer and digital literacy; ensure adequate incentives for completion for institutions and students; high-quality career guidance.

4.6 The case of Bambili South Africa

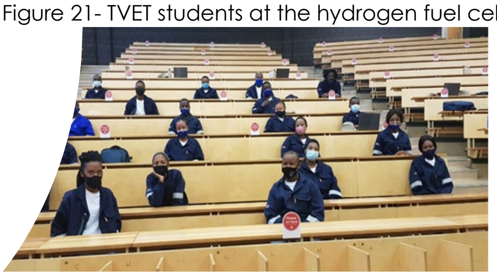
SUMMARY OF PROJECT FOCUS

Bambili Energy, in partnership with the Department of Science and Innovation (DSI), Department of Defence (DOD) and the Department of Public Works and Infrastructure implemented a hydrogen fuel cell system training programme which facilitated/assessed the current nature and quantum of curriculum and training offered by the TVET College System that would be useful to the Green Hydrogen (including grey hydrogen applications where relevant) economy ecosystem in South Africa to tackle youth unemployment.

Bambili Energy was selected by the DSI to deploy fifteen fuel cell systems to various sites for relevant market applications. In addition to this the fuel cell systems were to temporarily provide primary power to the COVID-19 field hospital at 1 Military Hospital, Pretoria from July 2020. In partnership with Bambili, Energy Horizon and Element One agreed to incorporate HySA Intellectual Property (IP) into their products, including five of the seven fuel cell systems deployed at 1 Military Hospital.

Through establishing the fuel cell systems, Bambili Energy conducted a hydrogen FC training programme. The training programme aimed to create a blend of theory and practice for the operation of fuel cell systems and was intended to nurture talent to support the emerging GHE. The training partners for the programme were the Energy and Water Sector Education and Training Authority (EWSETA) and the University of Pretoria (UP). The mandate was to train twenty-five TVET college graduates and ten professionals for six weeks. The purpose of the FC training programme was to develop work ready technicians for hydrogen FC systems in South Africa.

Figure 21- TVET students at the hydrogen fuel cell system training



The main goal was to ensure that graduates were not only upskilled from a training and learning perspective, but to make sure that graduates were confident in the execution of their duties having graduated from the programme. The programme identified the industry demand for skills. The training package included the following learning outcomes; system overview, major components and systems operations, FC system monitoring, trouble shooting and data analysis, fuel quality testing and refuelling, maintenance, basic computer literacy, and finally, health and safety at level one first aid. These learning outcomes were guided by who would eventually absorb the talent that was being developed.

4.6.1 The impact of the Bambili Energy hydrogen FC system training

The implementation of the training of the programme had its own challenges as it became apparent that some of the students required computer literacy training. This was considered an important requirement to ensure that the other components of the curriculum unfolded smoothly. This resulted in Bambili Energy having to extend the programme for an additional two to three weeks to teach learners how to use a computer and what this meant in the application of FC systems. At times, there were language difficulties as learners were more confident to express themselves or articulate their thoughts in their mother tongue languages whilst trainers had not been exposed to, nor did they have knowledge of all 11 official South African languages. Furthermore, due to COVID-19 regulations certain aspects of the curriculum could not be implemented as intended.

The maintenance and refuelling aspects of the curriculum required the physical presence of students at the site. At times this was very difficult as the number of students had to be maintained at a minimum to meet COVID health and safety requirements. Bambili Energy therefore provided videos, however, it was still very difficult to provide the practical on-site experience that graduates needed to ensure a full grasp of requirements. The involvement of industry made the programme successful. This industry input included namely: Anglo American Platinum, Hyplat (through the HySA Centres) and ArioGenix. These organisations provided guest lectures based on industry examples in the application of FCs and how to install FC systems successfully.

At the TVET level, artisans are unable to carry out FC R&D. It would require a deeper knowledge of FCs and electro catalysis. This could be provided by HySA in the future to contribute to ongoing development. A feasibility study is planned focused on creating a zero-emission valley between Limpopo-Gauteng-KZN which will be implemented through a private-public partnership between Anglo American Platinum, the DSI, Sanedi, Engie and Bambili Energy. This study leverages the work already underway to determine the viability of a hydrogen freight corridor.

Figure 22- Bambili graduates 2021

A total of 25 TVET graduates, three trainers and nine professionals were trained in the fourth quarter of 2020. Bambili Energy also selected three candidates for a 12-month internship programme and undertakes three-to-six-month follow-ups with graduates to see if they have been offered any opportunities. Furthermore, an additional seven professionals and 10 unemployed TVET graduates have been trained. Accreditation is under review with Quality Council for Trades and Occupations (QCTO). Currently, the QCTO does not have expertise in FC systems and is consulting externally. Once this is complete, graduate certificates will be revised under Recognition of Prior Learning (RPL) and awarded accreditation accordingly.

5. International TVET systems

5.1 International TVET systems for the green economy

A review of the international TVET philosophy, practice and structure provides an overview of how TVET is implemented successfully internationally and allows for comparison with the South African TVET system. While no one country is considered "ready" to ensure green skills in TVET, this research indicates that some nations, such as Germany and the Republic of Korea are at the leading edge of green skills development.[140]

This brief overview offers some options for South Africa to consider in dealing with challenges in the South African system. International plans for TVETs to cater for the skills needed in the green economy can offer an initial framework to consider when meeting South African current and future needs with quality TVET graduates. It also provides input to an understanding of i) what type of skills will be in demand in the future HE and GHE in South Africa and ii) what the gaps are between future GHE industry needs and current TVET ability to supply domestically.

5.2 International TVET system

The international TVET system is a key mechanism for meeting Agenda 2030 and the Sustainable Development Goals (SDGs).[141] This integrated approach to development confirms the intention of the international community to eradicate poverty, reduce and remove inequality, create inclusive and sustainable economic growth, achieve productive employment and decent work for women and men, and ensure full gender equality. In particular, SDG 4, "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" as expressed in the Incheon Declaration: Education 2030, is a critical platform for achieving all the SDGs. This requires a quality, agile and high performing education and skills supply system with TVET as an integral part.[142]

The TVET system is not only linked to the SDGs but is inextricably intertwined with the need to address climate change, and the shift to a zero-carbon global economy, as well as the need to address skills required by the new work world with the advent of 4IR. Global demographics suggest that unemployment is increasing in many developed and developing countries alike in South Africa the TVET system offers learning opportunities to disadvantaged and vulnerable communities, as well as school leavers and reskilling/upskilling adults.

[140] UNEVOC, GIZ & cpsc. "International Consultation Meeting on Transforming TVET for Meeting the Challenges of the Green Economy". 2011. Bonn, Germany.

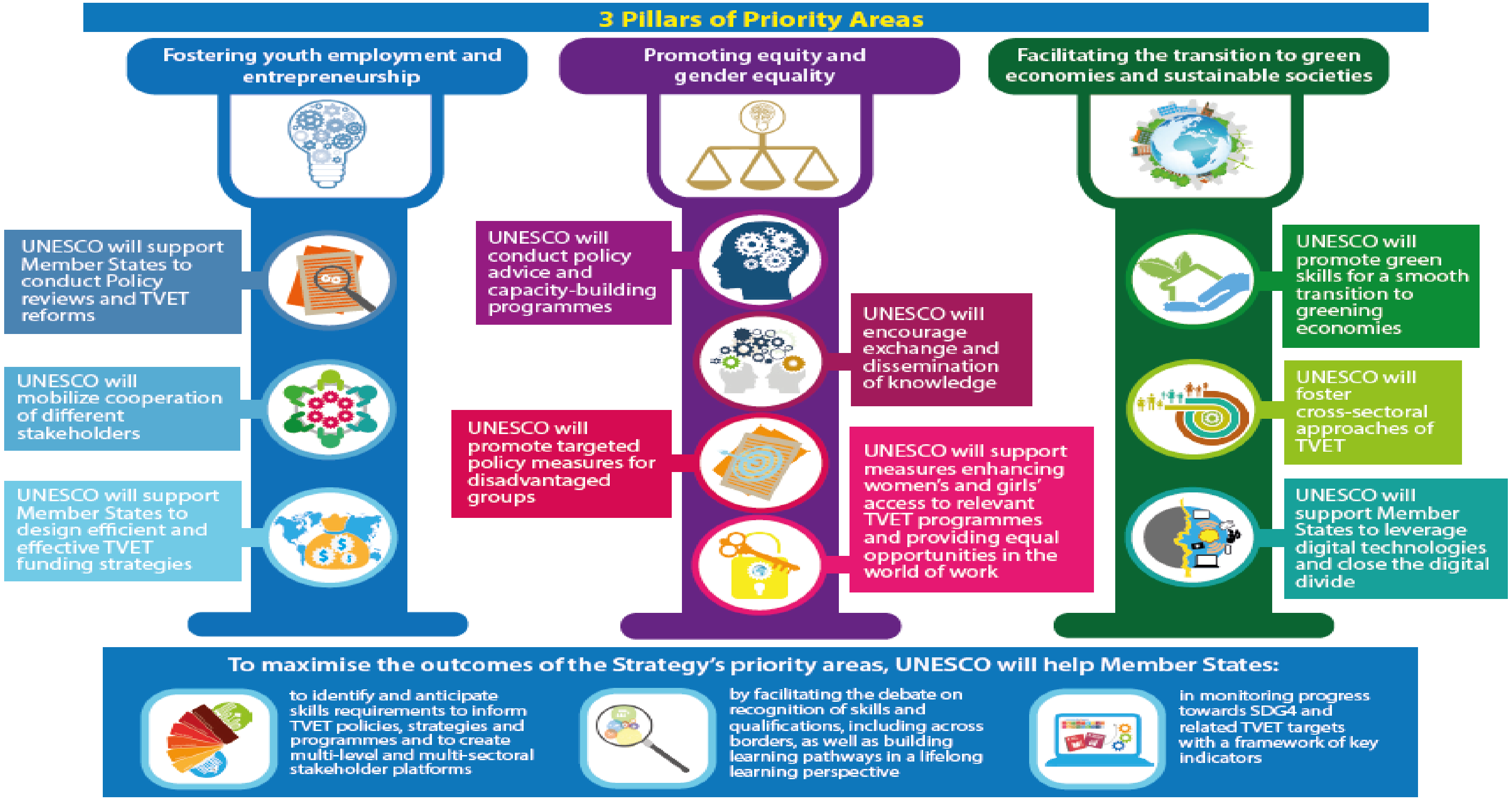
[141] UNESCO. 'Technical and Vocational Education and Training (TVET) (2016-2021)'. 2016, France.

[142] UNESCO. 'Technical and Vocational Education and Training (TVET) (2016-2021)'.

There are 1.44 billion workers worldwide in vulnerable employment and there are high levels of youth unemployment. 475 million new jobs need to be created annually in order to cater for the current 73 million young people unemployed and the 40 million new young people who enter the job market annually. There is persistent inequality and poverty, and climate change represents both a challenge and opportunity. UNESCO estimates suggest that 16 to 60 million new jobs (requiring new TVET skills) will be needed as the shift to a green economy takes place.[143] UNESCO provides significant TVET support to meet these challenges as shown in Figure 24.

143 UNESCO. 'Technical and Vocational Education and Training (TVET) (2016-2021)'

Figure 23- Pillars of UNESCO TVET support strategy



Source: UNESCO, 2016

Affordable access to TVET skills development leading to acquiring technical and vocational skills needed for employment and entrepreneurship, is a central pillar of the strategy. TVET will also help youth and adults to develop the skills they need for a just labour transition and support the development of new skills needed in the GE and for the 4IR.[144] In terms of support for GE skills, including those required by clean energy production such as GH (and blue to a lesser extent), the UNESCO strategy involves i) facilitating collaborations between industry, communities, educational institutions and development partners; ii) supporting a whole-institutional transformation which involves capacity-building of leaders, education managers and teachers to implement systemic reforms for embedding sustainability concepts in TVET; and iii) ensuring knowledge development and sharing in the field of green skills through the UNESCO-UNEVOC Network.[145]

5.2.1 TVET and digitalisation

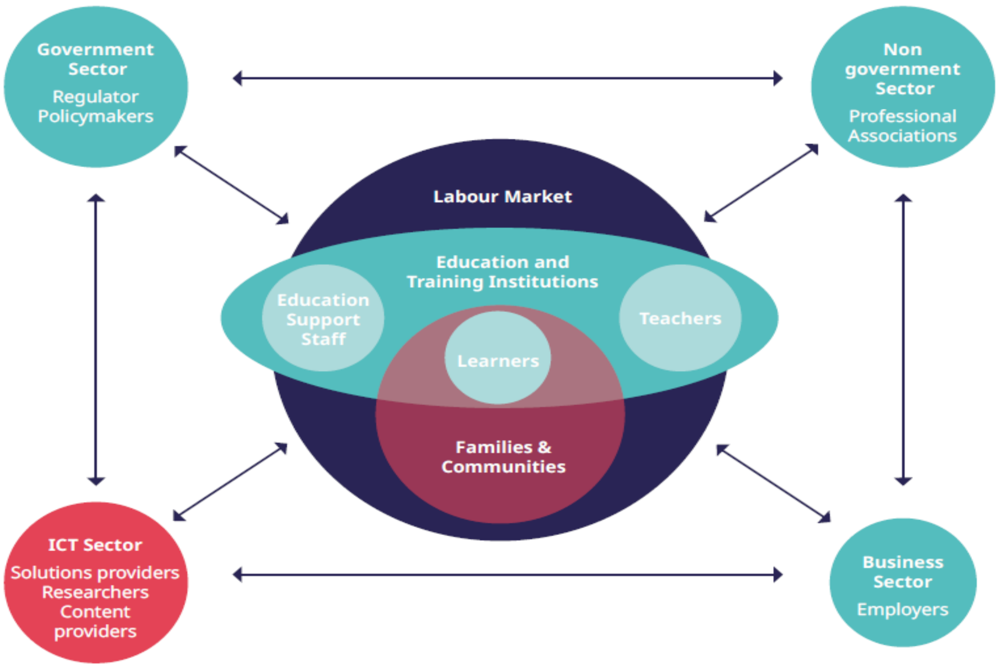
TVET will increasingly be required to focus on preparing knowledge workers and workers with strong digital skills to meet the needs of the 4IR. The ILO envisages a skills development ecosystem for the 4IR, as shown in Figure 25 which aims to ensure that the collaborative partnerships needed for the transition to be successful (and just) are formally established. New digital technologies also create new capabilities for education, which leads to new skills that capacitate people to adapt to and benefit from these transformations. Together they transform the nature of education, work, and society.[146]

[144] UNESCO. 'Technical and Vocational Education and Training (TVET) (2016-2021)'

[145] UNESCO. 'Technical and Vocational Education and Training (TVET) (2016-2021)'

[146] ILO & UNESCO. 'The Digitization of TVET and Skills Systems'. 2021. https://www.ilo.org › publication › wcms_752213/

Figure 24- TVET and skills systems



Source: Adapted from Keevey et al, 2019

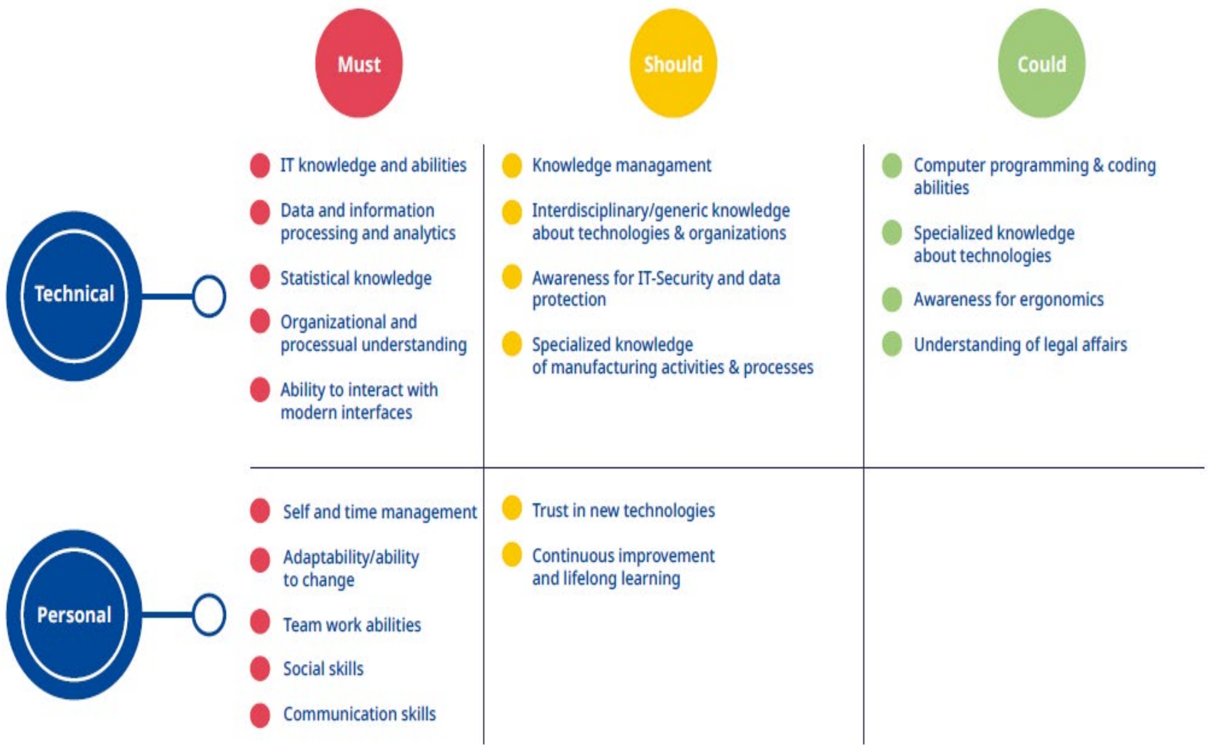
A strong focus on digital skills at every level of TVET is needed to, *inter alia*:

- Adapt to workplaces where manual tasks are being replaced by digital tasks; and
- Service digital workplaces by providing programming and engineering related skills.

Not only this, but as the digital workplace develops, and technologies continue to change rapidly, there will be a need for life-long digital updating and re-skilling to be provided by TVET including at least:

- ICT knowledge (email, standard software, using computers and so on);
- Digital literacy, including basic coding, data collation, processing, and analytics;
- Understanding of statistics (and measurement) and their use in the workplace;
- Knowledge management;
- The context, use and make-up of the relevant technologies for the workplace;
- Cyber security, awareness of and use of;
- Teamwork, communication skills and conflict management.

Figure 25- Selected future digital qualifications and skills needed.



Source: Gehrke et al, 2015

Added to the need for TVET learning to incorporate industry digital skills as an important intervention to ensure that the digital divide is addressed, is the need for, particularly among adults already in employment, re-skilling. Providing opportunities for such persons to re-enter TVET and acquire new, relevant digital skills is a major focus of policy development in many countries and is central to a JLT regardless of the sector involved. Challenges experienced in implementing digital skills in TVET are linked to i) training TVET teachers in the digital skills needed by learners for industrial jobs; ii) delivering learning opportunities using digital technology, such as simulation for example, or gamification; iii) lack of an enabling policy and regulatory environment; and iv) cost. As the technology becomes more sophisticated, cost of training equipment increases.[147]

5.2.2 TVET and hydrogen economy skills

According to some researchers, the international TVET system is not future ready. It is not yet able to cope with digitisation or with the need for so-called green skills.[148] Those countries

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[147] Erik Skov Madsen Arne. Bilberg, and David Grube. Hansen." Industry 4.0 and digitalization call for vocational skills, applied industrial engineering, and less for pure academics." (Paper, 5th World Conference, Production and Operations Management 2016.). https://portal.findresearcher.sdu.dk/en/publications/industry-40-and-digitalization-call-for-vocational-skills-applied"

[148] ILO & UNESCO. 'The Digitization of TVET and Skills Systems'; Margarita Pavlova. 'Emerging environmental industries: impact on required skills and TVET systems.' *International Journal of Training Research*. 2019:144-158.

which are making progress such as New Zealand and Hong Kong have a supportive policy and regulatory environment which deals with challenges such as lack of funding and inadequate levels of human capacity to effect the change in terms of knowledge, experience, and skills.[149]

The ILO estimated that the transition to the GE is likely to lead to a net increase of 24 million jobs, including in renewable energy and energy efficiency, and says that urgent action is needed to retrain workers in the new skills that will be required. However, in many countries the skills needed to transit to the GE are not yet integrated into the TVET curriculum, and/or are not yet defined – which is an essential task for industry and TVETs to undertake as soon as possible.[150]

The Shanghai consensus of 2012 acknowledged that TVET globally will require transformation and revitalisation to transition effectively to the green economy. Thus, the inclusion of green and digital education at secondary school level as well as in TVET qualifications and programmes are essential components of the future TVET system.[151] In sum, the international TVET system, and individual nations, are in the process of preparing for the delivery of essential green skills. Activities include policy coordination, updating the regulatory environment, capacity development, building of social collaborations, new knowledge generation mechanisms and resource development.[152]

6. South African TVET system

6.1 Post school education framework

The formal South African system includes 26 public universities, 125 private higher education institutions (HEIs), 50 public TVET colleges (multiple campuses in some cases), various specialist public colleges such as agricultural colleges, approximately 6000 accredited private providers and 93 South African Qualifications Authority (SAQA) recognised professional bodies. There are also six Universities of Technology[153] in South Africa, where the key difference between

[149] Ivana Capozza and Rachel Samson. Towards green growth in emerging market economies: Evidence from environmental performance reviews (OECD Green Growth Papers, 2019/01). Paris: OECD Publishing.

[150] ILO. 'World employment social outlook 2019: Greening with jobs—Key findings in Asia and the Pacific" 2018. https://www.ilo.org/weso-greening/documents/WESO_Greening_EN_web2.pdf

[151] Eureta Rosenburg. Solutions to anticipate and identify green skills demand. TVET for Green Skills. (Paper, UNESCO conference, Tangshan, China. 2017). Latest News - Prof Eureta Rosenberg attended a conference on Technical and Vocational Education and Training (TVET) in Tangshan in the People's Republic of China from 4-6 July 2017 (ru.ac.za)

[152] UNESCO-UNEVOC. Greening TVET and skills -Mapping the response to green transition.' (Paper at the ILO Global Forum on boosting skills for a just transition and the future of work parallel session (6 June 2019).

[153] Cape Peninsula University of Technology; Central University of Technology (Free State: Bloemfontein, Welkom, Northern Cape: Kimberley); Durban University of Technology; Mangosuthu University of Technology (KZN); Tshwane University of Technology (Gauteng, Limpopo, North West); Vaal University of Technology (Gauteng, Northern Cape).

these and standard universities is that they focus on technology innovation and transfer and offer technological career-directed educational programmes. They also work closely with the private sector to produce innovative problem-solving research. Many of the programmes offered include work-integrated learning that requires students to complete a structured programme while working in an organisation. This exposure to industry develops additional competencies that are not gained through purely academic programmes and assists graduates to find employment after graduation. Admission requirements differ between Universities of Technology, which require at least matriculation, and TVET which require a pass at Grade 9.[154]

All formal learning institutions are accredited and are approved by the National Qualifications Framework (NQF) Act 67 of 2008. The SA NQF has ten levels. A grade 12 school leaving certificate, the National Senior Qualification (NSC) or Matriculation certificate, is at NQF 4. A three-year bachelor's degree sits at NQF 7, and the highest qualification in the system is a doctorate [PhD or DLitt] at NQF10.[155]

The South African TVET system is a critical element of the South African Post School Education and Training (PSET) system and is overseen by the DHET TVET Branch. Most TVET colleges have a highest qualification of NQF Level 5, but some offer NQF Level 6. There are four main types of qualifications offered, i) the National Certificate Vocational, NC(V) qualifications; ii) the Report 191 Programmes iii) the National Introductory Certificate (N4) and; iv) National Certificates (N4).[156] There are 50 public TVET colleges on over 270 campuses nationally. They range from one TVET in the Northern Cape to nine in KwaZulu Natal. In 2011, there were also over 497 private TVET colleges registered with the DHET, operating 765 sites with the majority in Gauteng and the fewest in the Northern Cape.[157] This spatial reality may need to change when the sites of production of RE, electrolysers and GH are finalised. If the public sector TVETs do not enter to fill the gap the private sector TVETs may enter as long as there is commercial logic.

6.1.1 Current performance in the hydrogen economy

The findings from the most recent data and the interviews with industry suggest that the South African TVET college system is not capable of meeting current or future needs as it is currently set up. Even when there are functional industry/TVET college working relationships at specific sites, the graduates are not always employable. Industry respondents typically noted that often the basic requirements for technical skills are not met, and all respondents have

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[154] DHET. Technical and Vocational Education and Training Colleges. Department of Higher Education and Training - TVETColleges (dhet.gov.za)

[155] DHET (2018). Getting to grips with the SA post-school education and training system.

[156] DHET (2018). Technical and Vocational Education and Training Colleges.

[157] Human Resources Development Council (HRDC).' Profile of the TVET sector'.

additional internal training and skills development programmes to ensure workers can perform.[158]

The inability of the public TVET college system to provide adequate skills into industry is linked to a number of factors, including underfunding, poor lecturer quality, and poor industry/TVET working relationships.[159] This latter means that TVET colleges are often training learners for jobs that do not exist and that they are not in touch with current or future industry needs in their areas of operation. This is a truly significant weakness, as without a good working relationship at the local TVET level between the college and local industry, the local TVET will continue to miss the goal of training for employment, current and future.

6.2 TVET realities and challenges

South Africa's 50 public TVET colleges were created in 2002 in terms of the TVET Act 98 of 1998. The Act combined technical colleges and all colleges of education and training centres into the TVET colleges. This Act was repealed and replaced by the Continuing Education and Training Act 16 of 2006 and amended further in amendments in 2010, 2012 and 2013.[160]

Although the TVET college system is considered pivotal to the development of essential skills for industry in South Africa, over the years industry has criticised individual colleges and the overall system for an inability to deliver the skills to the quality and of the type that industry and the economy require.[161]

In the pursuit of the development of quality skills in the quantity and of the type required, the government set a target of three million enrolments by 2030. The National Development Plan (NDP) states that about 3 percent of 20-to-24-year-olds participate in further education and training and has set a goal of increasing participation rates in TVET colleges to 25 percent. Overall, national economic and education policy requires the TVET college system to play the central role in Post School Education and Training (PSET) and to do so in an effective manner.

6.2.1 Budget support

Funding to public TVET colleges represented 18 percent of the total higher education budget in 2011/12 with the balance allocated to the Higher Education Institutions (HEIs). In the 2019

[158] SASOL, Anglo-American, Eskom. Interviewed by Andiswa Sibhukwana, Johannesburg, May 2021.

[159] Human Resource Development Council (2019). Research on the nature and extent of post school educational institutions and industry partnerships; SASOL, Anglo-American, Eskom interviews, 2021.

[160] Also known as the Further Education and Training Colleges Act.

[161] Human Resources Development Council (HRDC).' Profile of the TVET sector'.2014; SASOL, Anglo American, interviews. May 2021

Medium Term Strategic Framework (MTSF), the budget for TVETs relative to HEIs was as follows:[162]

Table 7- TVET vs HEI budget MTSF (R millions)

ITEM	2019/2020	2020/2021	2021/2022	2022/2023
University education	73,410	80,083	84,332	88,168
TVETs	12,722 (17% of HEI)	13,813 (17% of HEI)	14,644 (17% of HEI)	15,279 (17% of HEI)

Source: National Treasury, 2019, 2020

This budget keeps pace with an estimated inflation rate of approximately 6 percent per annum but does not serve to increase the capacity of the TVET system to meet national goals. The TVET budget is also lower than the Sector Education and Training Authority (SETA) budget annually.[163] Given that the mandate of the DHET is to expand access to skills programmes that address the labour market's need for intermediate skills that include practical learning to produce job-linked programmes and graduates that are immediately employable, the budget allocation to TVETs is low.

Currently, the funding made available to TVETs by the department covers 62 percent of all students in all colleges. 38 percent of students are not funded at all and although already struggling with a budget too low to achieve national goals, TVETS are nonetheless expected to carry this deficit indefinitely. For example, in 2016/17, there were approximately 660 000 students, but funding only covered approximately 414 000. More than 200 000 students were not funded.[164]

Government's stated objective is that by 2030, over 2,5 million people will be learning at TVETs while 1,6 million will be learning at universities, thus shifting the balance to TVETs as the main PSET pathway to work. This is not reflected in the budget allocation. Significant programmes in the current TVET budget are i) Technical and Vocational Education and Training, which includes the development of new TVETs (R1.2 billion) and the improvement of TVET infrastructure, (R2.9 billion) ii) employee compensation (R23,1 billion) and iii) an artisanal skills development programme (R348 million).

[162] National Treasury. '2020 budget. Higher Education and Training. Vote 17. 2020

[163] Human Resources Development Council (HRDC).' Profile of the TVET sector'.

[164] Technical and Vocational Education Training Colleges Governors Council (2016). Commission of enquiry into higher education and training (fees commission) hearing. Position statement on autonomy of the TVET sector. Office of the National Treasurer General. Pretoria.

Table 8- Enrolments at Public and Private Universities and TVET Colleges, 2010-2014

Year	Public Universities	Private Universities	Universities Total	Public TVET	Private FET	TVET Total
2010	892 936	90 767	983 703	358 393	46 882	405 275
2011	938 201	103 036	1 041 237	400 273	134 446	534 719
2012	953 373	97 478	1 050 851	657 690	115 586	773 276
2013	983 698	119 941	1 103 639	639 618	154 632	794 250
2014	969 155	142 557	1 111 712	702 383	78 995	781 378

Source: DHET, 2016[165]

6.2.2 Admissions, courses, and throughput in public TVETS

Of the 578,468 candidates who wrote the 2020 National Senior Certificate (NSC) examination, 36.4 percent (198,993) obtained a bachelor's pass. A further 26 percent (150,402) achieved a diploma pass, while 13.7 percent (79,250) achieved a higher certificate pass. This requires 373,690 matriculants to find non-university pathways to further learning and the world of work.[166]

For those who do not have an NSC, Technical and Vocational Education and Training (TVET) colleges throughout South Africa offer the opportunity to matriculate as long as the learner has completed Grade 9. The learner achieves a National Vocational Certificate (NVC) on levels 2, 3 and 4, that are equivalent to grades 10, 11 and 12. Vocational and diploma certifications obtainable at TVET colleges typically range from National Qualifications Framework (NQF) levels 2 to 5 with some offering up to NQF level 6. There are over 50 TVET colleges in South Africa, with at least 264 campuses.[167] TVET programme types are outlined below.

Table 9- TVET programmes by type

National certificate (vocational)

[165] Reddy, V., Bhorat, H., Powell, M., Visser, M. and Arends, A., (2016) Skills Supply and Demand in South Africa, LMIP Publication, Human Sciences Research Council, Pretoria.

[166] Department of Basic Education (DBE). 2021.

[167] SA bursaries. 2021. TVET Colleges In South Africa | You Want To Apply For TVET College? Read This First (bursaries-southafrica.co.za)

Description / Definition	NC(V) programmes are delivered under the auspices of the Department of Higher Education and Training and quality assured by UMALUSI. The programmes integrate theory and practice and provide students with a broad range of knowledge and practical skills within specific industry fields.
Duration	3 Years (1 year per level)
Qualification	Full Certificates on NQF Level 2, 3 and 4 NC(V) Level 4 Certificate is equivalent to National Senior Certificate (matric)
Admission Requirements	Grade 9 + college requirements set per programme
Resources	Bursaries available for financially and academically qualifying students
Description / Definition	NC(V) programmes are delivered under the auspices of the Department of Higher Education and Training and quality assured by Umalusi. The programmes integrate theory and practice and provide students with a broad range of knowledge and practical skills within specific industry fields.
NATED / Report 191	
Description / Definition	NATED / Report 191 programmes are delivered under the auspices of the Department of Higher Education and Training and quality assured by Umalusi. The programmes consist of 18 months theoretical studies at colleges and 18 months relevant practical application in workplaces. Engineering studies range from N1 – N6 while Business and Utility Studies range from N4 – N6
Duration	1 Year for N1 – N3 Engineering Studies 1 Year for N4 – N6 Engineering Studies 3 Years (18 months theoretical studies + 18 months' workplace application) for N4 – N6 Business and Utility Studies
Qualification	N6 Diploma
Admission Requirements	Grade 9 for N1 admission Grade 12 for N4 admission

Resources	Bursaries available for financially and academically qualifying students
National Higher Certificate	
Description / Definition	These are Higher Education programmes offered at colleges in partnership with Higher Education Institutions.
Duration	Specific to programme *
Qualification and Part Qualification	Specific to programme *
Admission Requirements	Grade 12 + requirements set by HE institution and college
Learnerships	
Description / Definition	This is a route to a NQF registered full qualification and is offered under the auspices of SETAs and quality assured by SETA ETQAs.
Duration	Specific to programme *
Qualification	Full qualification
Admission Requirements	Specific to programme *
Skills Programme	
Description / Definition	These programmes are based on a cluster of NQF registered unit standards and are offered under the auspices of SETAs and quality assured by SETA ETQAs. Skills programmes can build up to a full qualification.
Duration	Specific to programme *
Qualification	Part qualification with credit recognition towards full qualification
Admission Requirements	Specific to programme *
NQF Full Time	
Description / Definition	National Qualifications Framework (NQF) registered qualifications offered to full time private students under the auspices of SETAs and quality assured by SETA ETQAs.
Duration	Specific to programme *

Qualification	Full qualification on various NQF Levels
Admission Requirements	Specific to programme *
Non-Formal	
Description / Definition	Enrichment programmes that result in an attendance certificate or programmes that are company-based training against a specific demand.
Duration	Specific to programme *
Admission Requirements	Specific to programme *
ABET Or AET	
Description / Definition	Adult (basic) education and training programmes.
Duration	Specific to programme *[168]
Qualification and Part Qualification	Specific to programme *

Source: Department of Education and Training, 2021

In 2016, public TVET enrolment was just over 705,000 learners. The number of students writing exit exams for the TVET Report 191 level N3 programmes increased from 41 201 in 2013 to 59 409 in 2016 and the certification rate improved from 44.6 percent in 2013 to 65.8 percent in 2016.

For the Report 191 level N6 programme, the number of candidates writing certification exams increased from 42 841 in 2013 to 91 772 in 2016 and the certification rate increased from 36 percent to 66 percent. Certification rates for NC(V) 4 programmes increased from 37 percent in 2013 to 42 percent in 2016. Throughput rates are poor, as confirmed by a pseudo–cohort analysis, and many students do not complete their studies for various reasons, thus completion and final certification rates are low. For example, approximately 36 percent of those who wrote NC(V) Level 2 examinations in 2013 wrote the Level 4 examinations in 2015.[169]

Approximately 37 percent of lecturers were unqualified to teach at the TVET level in 2015, where a relevant diploma/degree and a teaching qualification were the basic requirements

[168] * Each TVET sets its own programmes.

[169] Department of Higher Education and Training (DHET). Post school education and training monitor- macro indicator trends. 2019. https://www.dhet.gov.za/Planning%20Monitoring%20and%20Evaluation%20Coordination/Post-School%20Education%20and%20Training%20Monitor%20-%20Macro-Indicator%20Trends%20-%20March%202021.pdf

– 19 percent of lecturers at that time did not have a diploma.[170] At the same time, the lecturer-student ratio increased from 40:1 in 2010, to 60:1 in 2016, potentially contributing to a weaker quality of education.[171]

In 2011 in the Eastern Cape TVET college system, 52 percent of lecturers did not have teaching qualifications, 30 percent did not have technical qualifications, and 70 percent did not have work experience.[172] A 2009-10 survey of lecturers in Gauteng and KwaZulu-Natal, found that only 43 percent of TVET lecturers had both a technical qualification and industry experience, 26 percent had neither and 29 percent had no teaching qualification or experience. The limited experience that lecturers had of practising their trades in the workplace "negatively affected the quality of instruction and their ability to prepare their students adequately for the world of work".[173] Additionally, there appears to be limited motivation amongst a number of lecturers to improve their skills. Many note poor pay and limited to no career progression as the reasons.[174]

Table 10- Lecturer student ratio TVETs

Year	Total staff	Total students	Ratio
2010	8,126	326,889	40.2
2011	8,686	369,339	42.5
2012	9,199	490,105	53.3
2013	10,106	612,621	60.6
2014	10,842	661,437	61
2015	10,592	706,452	66.7

Source: DHET, 2019

Concern over the reduction in quality of output at TVETs was expressed by a Ministerial Committee that investigated funding of TVET colleges "…in recent years TVET college quality

[170] ETDP SETA. Sector Skills Plan update 2013/14. 2014; Michael Cosser, Andre Kraak and Lolita Winnaar, Further Education and Training (FET) colleges at a glance in 2010: FET colleges audit: May-July 2010. HSRC 2011. http://www.hsrc.ac.za/en/research-data/view/5775

[171] Department of Higher Education and Training DHET). Post school education and training monitor- macro indicator trends.

[172] Bongwani Bantwini and Timothy McBride. Baseline study on the FET College lecturer skills. The case of the Eastern Cape: 2010/11. 2011.

[173] Adrienne Watson and Volker Wedekind, Pedagogy in a TVET college. Being the visible difference – An analysis of a TVET lecturer at work *SAQA Bulletin*, 15(1), 2016:161–190.

[174]Bernd Zinn, B., Kevin Raisch and Jennifer Raimann. Analysing training needs of TVET teachers in South Africa: An empriical study. 2019. *International Journal for Research in Vocational Education and Training (IJRVET)* 6, 2, (2019:174-197). https://eric.ed.gov/?id=EJ1226571

has been compromised because of the pressure to increase enrolments without compensatory increases in staff and other resources. Provision must therefore be made to ensure qualitative improvements to meet labour market needs, even if it has to be at the expense of further increasing quantitative growth in enrolment. *Indeed, as the reviewed literature indicates, current certification rates are abysmal.* Currently learners in the TVET system graduate at an exorbitant per capita cost which is unsustainable. Moreover, the absorption rate of TVET graduates in the economy is also cause of serious concern".[175]

In 2010 the lack of reliable data linking TVET colleges to the supply of skills was identified as a key weakness in the planning framework of the DHET and resulted in a tracer study being commissioned.[176] This was conducted to determine the status of the transition of TVET graduates into the labour market. Over 71 percent of all respondents viewed the role of the TVET in supporting the transition to the labour market as very important, but the TVETs rated poorly in terms of preparing the graduates to find a job. In 2011, 24.7 percent were unemployed after graduation, but this had risen to 47.7 percent in 2015. Additionally, only 3.7 percent of respondents (µ=>3,000) were able to secure apprenticeships and 13.8 percent were able to secure internships.[177]

6.2.3 Private TVET colleges

A large number of private TVET colleges provide a range of accredited and non-accredited South African and international courses which lead to an official qualification. Some of these courses and qualifications are considered better quality than some national qualifications such as the City and Guilds qualifications. Some large firms have in-house training facilities that lead to nationally accredited certificates, in particular in the mining, construction, and manufacturing industries. Many offer specialised and focussed courses only and have close relationships with the industries they serve.[178] The DHET estimates that there are approximately 6,000 private TVET providers, with only 400 registered with Umalusi, and a further 600 registered with one of the SETAs.[179] Furthermore, the almost complete isolation of the private system from the public TVET system is contrary to international experience and represents a capacity that is underutilised at the national level.[180]

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[175] DHET. 'Macro Indicators Report: Monitoring the performance of the post–school education and training.

system. Unpublished report. Ministerial Committee. South Africa. 2019.

[176] SSACI, NBI, Jet Education Services. Tracer Study of the Transition of Students from TVET Colleges to the Labour Market. 2016. Research Reports (ssaci.org.za)

[177] SSACI, NBI, Jet Education Services. Tracer Study of the Transition of Students from TVET Colleges to the Labour Market.

[178] SSACI. The role of a high-quality skills development system in a dynamic economy: Considerations for South Africa. 2016. Research Reports (ssaci.org.za)

[179] SSACI. The role of a high-quality skills development system in a dynamic economy: Considerations for South Africa.

[180] Simon Mcgrath and Salim Akojee. 'Regulating private Vocational Education and Training (VET) in South Africa: The national development imperative'. *Africa Education Review*. 7(1) 2010:16-33

7. TVET Skills Gap Analysis: Hydrogen Economy

At the systemic level, it is clear from the research that the TVET college system overall requires intervention to improve performance especially in terms of the STEM skills required as the basis for most if not all technical learning. As noted, the lack of qualified and experienced lecturers, poor relationships with industry and business overall in local areas, limited or no focus on digital skills, poor throughput and low to non-existent work/experiential learning on-the-job, has meant that the TVETs have been producing graduates who remain unemployed. Industry views TVET education as lacking in delivering the quality of graduate who could be employable directly after certification. This means that even where there are some graduates who are acceptable for further training, the quality of those graduates is insufficient. Companies solve this largely by means of in-house training and orientation programmes. This section provides a high-level summary of skills gaps by value chain stage, derived from interviews and available data.

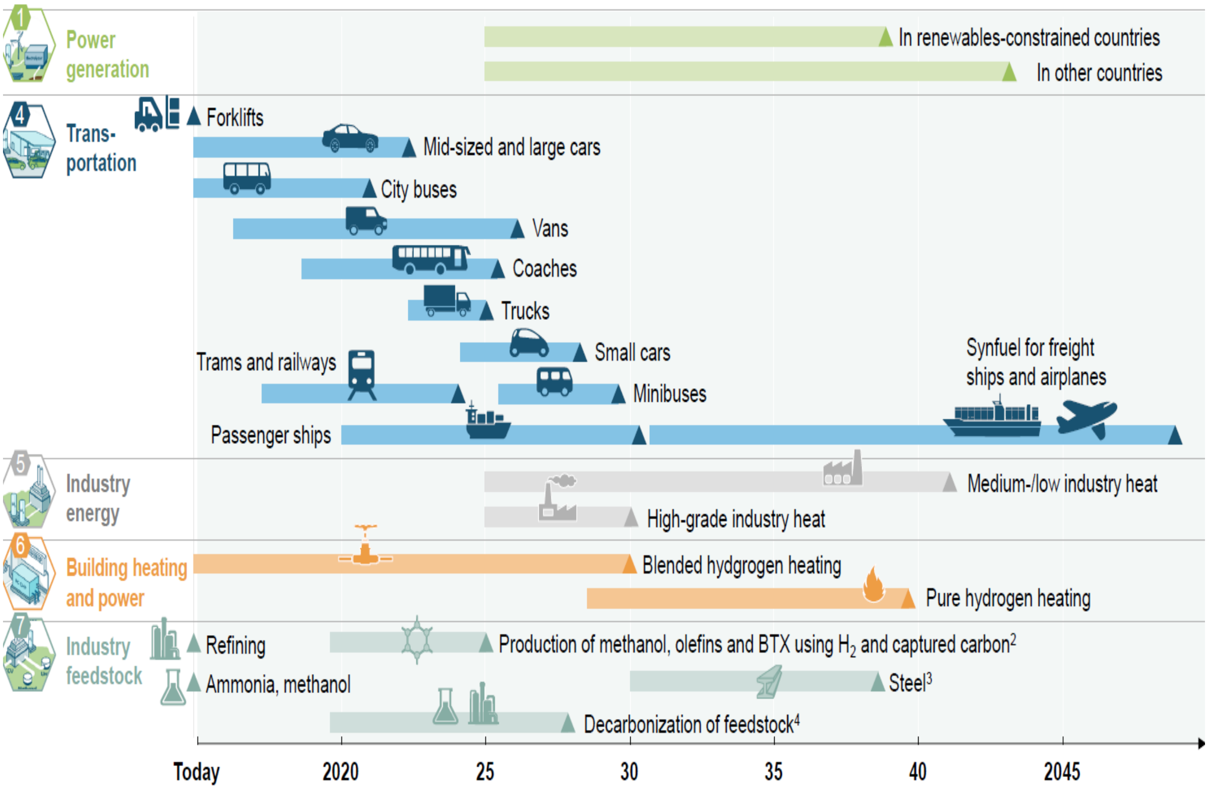
7.1 Time horizon

The timing of the move to a clean energy economy, with GH as the central source of clean energy in key domestic sectors and for export, is important when planning skills interventions.

Figure 27 offers a summary of the anticipated time frames (using an international average) for the implementation of the GHE. From a South African skills supply and demand perspective, the shift to the GHE must begin with provision of the skills needed to generate RE, largely from solar and wind, as this is the precursor activity to the national ability to produce GH.

At the same time, activity in FCs, mobile and stationary, has grown significantly over the last four years. Application of FCs is underway in all end user sectors, as it offers a short term and in many cases a cost-efficient option for replacing fossil fuels. In the South African context, FCs provide backup power to essential services such as hospitals. Thus, the need for skills supply into the FC manufacturing/assembly industry and in the RE industries is almost immediate and should be given priority by those public sector TVETs close to production sites or specialised private sector TVETs, should there not be resources to deliver the skills in the public sector colleges.

Figure 26- Hydrogen commercialisation timeline- global



Source: McKinsey, 2017

Transport applications and building (heat and power), both of which require the use of FCs, are the two areas on the brink of full commercialisation and thus immediate skills supply interventions are required. Similarly, in RE production, South Africa enjoys a useful competitive position and recent announcements of the freeing up of energy production in South Africa will undoubtedly see large energy users committing to RE generation on site to provide for their own needs.

7.2 Renewable energy gaps

Renewable energy production involves stages from R&D, project development, engineering, manufacture of components, commissioning, and then ongoing service and maintenance. The RE supply chain is shown below. There are variances, depending on the nature of the possible five RE sources being harvested. Each chain requires different skills at the primary input level of the chain due to major technology differences but thereafter the skills required are equipment and process specific and largely technical in nature. For example, the manufacture of components for wind and solar energy requires very different skills. Turbines for wind energy require very high-quality technical work as do solar panels. The plant and equipment used to derive energy from a renewable source are specialised, and often run digitally. Basic skills such as electrician, mechanical skills and the like as supplied by the TVET college system currently need to be built on with specialised content and equipment training, as well as digital skills, to meet growing demand in both RE sectors.

Figure 27- RE supply chain

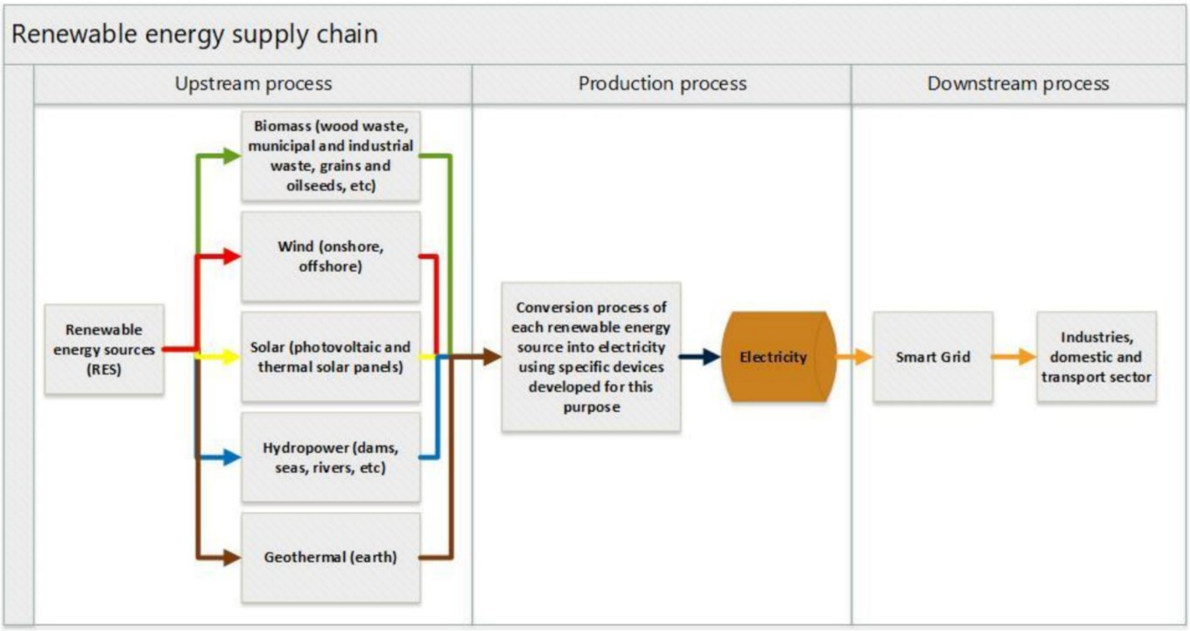


Table 11- Supply and Demand for TVET RE skills (wind)

Skill/competency	**WIND (offshore & onshore)**		
	Main category	Demand	Supply[181]
Design, installation, operations, management, and repair of wind turbines	Wind Turbines	Expanding	Very low
Components manufacture and assembly	Mast, propeller, nacelle, blade, and rotor	Expanding	Very low
Manufacturing, assembly, installation, operation, and repair of transformers **Automation & control technicians**	Maintain transmission to the electrical grid	Expanding	Very low
Digital energy distribution storage and management	Grid connection Electronically controlled network	Expanding	None

[181] Small number of individual TVETs working with the various industries.

Skill/competency	WIND (offshore & onshore)		
	Main category	Demand	Supply[181]
Cross cutting skills			
Teamwork, conflict management, problem solving, communication, diplomacy & persistence		Ongoing and high	None/low
Digital literacy	Equipment and systems control	Ongoing and increasing	Very low
Quality assurance **Certification and compliance**	ALL	Ongoing and increasing	None (specialist)
Occupational health & safety	ALL	Ongoing and increasing	None (specialist)
Baseline STEM skills especially engineering and/technology			

Source: Author compilation, 2021

The South African TVET college system, (with the exception of some TVET colleges aligned to independent power producers (IPPs) does not supply any skills related to the areas outlined in the RE chains above in terms of content and specific training. Basic technical skills such as electrician, metal working and so on (refer Annex 1 for detailed lists of skills) are provided, but sector specific skills and digital skills are not, nor is the quality of graduate what is required.

Table 12- Supply and Demand for TVET RE skills (solar)

Skill/competency	SOLAR (photovoltaic & thermal)		
	Main category	Demand	Supply
Design, installation, operations, management and repair of PV modules and solar concentrating collectors	PV modules Thermodynamic cycles	Expanding	Low
Components manufacture and assembly	Panels, masts,	Expanding	Low
Manufacturing, assembly, installation, operation, and repair of solar thermal power generation systems	Maintain transmission to the electrical grid	Expanding	Very low

Skill/competency	SOLAR (photovoltaic & thermal)		
	Main category	Demand	Supply
Automation & control technicians			
Digital energy distribution storage and management	Gird connection. Electronically controlled network	Expanding	None
Cross cutting skills			
Teamwork, conflict management, problem solving, communication, diplomacy & persistence		Ongoing and high	None/low
Digital literacy	Equipment and systems control	Ongoing and increasing	Very low
Quality assurance **Certification and compliance**	ALL	Ongoing and increasing	None (specialist)
Occupational health & safety	ALL	Ongoing and increasing	None (specialist)
Baseline STEM skills especially engineering and/technology			

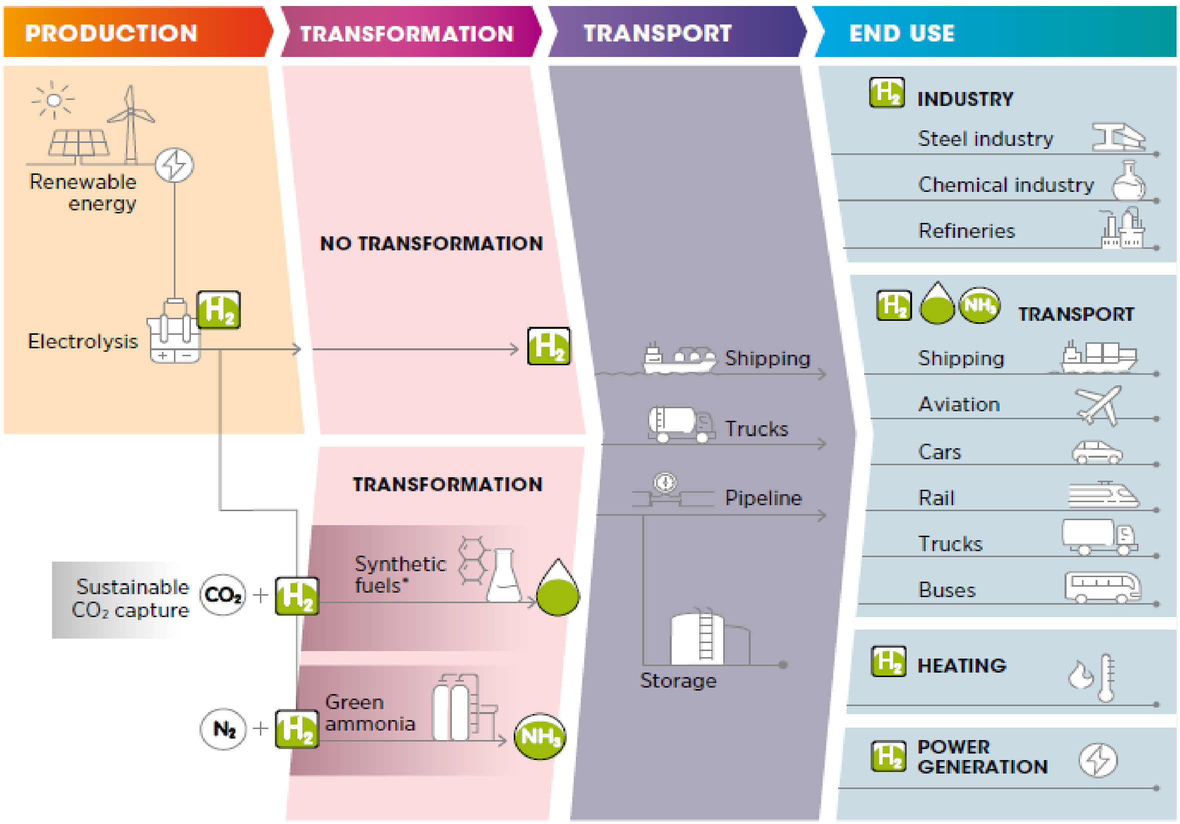
Source: Author compilation, 2021

7.3 Hydrogen skills (main chain) supply and demand

While there are a number of pathways for hydrogen production and distribution, the main technologies currently are *grey hydrogen* (where hydrogen is generated from fossil fuels and delivered as a gas or liquid chemical), *blue* hydrogen (where the carbon derived from the process is captured and stored) and green hydrogen, where RE is used as the primary raw input.

The current grey hydrogen produced in South Africa requires the same skills as are needed for any chemical or gas production and distribution system and includes welding, truckers, operations engineers, electrical technicians, truck drivers, safety supervisors, mechanics, boiler makers, chemical mechanics, diesel mechanics, millwrights, fitters, electrical fabrication, and other similar occupations. However, the TVET system does not have the ability to fully supply these needs so companies provide additional training in-house for quality upgrades and specific content required.

Figure 28- Hydrogen skills supply & demand



Source: IRENA, 2020

The blue and green hydrogen pathway skills gaps are outlined in **Error! Reference source not found.**.

Table 13- Supply and demand for TVET hydrogen production and distribution skills

Skill/competency	**HYDROGEN (blue & green)**		
	Main category	Demand	Supply
Hydrogen power plant installation, operations, engineering, and management CCS plant and equipment Electrolysis plant and equipment	Hydrogen system technicians, systems operators, energy systems installers Millwrights fitters, other	Low but growing	None specialised
Hydrogen distribution and logistics **Automation & control technicians**	Pipelines, storage, tankers, containers et al Drivers, fuel transporters	Low	None specialised

Skill/competency	HYDROGEN (blue & green)		
	Main category	Demand	Supply
Cross cutting skills			
Teamwork, conflict management, problem solving, communication, diplomacy & persistence		Ongoing and high	None/low
Digital literacy	Equipment and systems control	Ongoing and increasing	Very low
Quality assurance **Certification and compliance**	ALL	Ongoing and increasing	None (specialist)
Occupational health & safety	ALL	Ongoing and increasing	None (specialist)
Baseline STEM skills especially engineering and/technology			

Source: Author compilation, 2021

The additional skills needed to work in blue hydrogen involved specialist skills linked to CCS, while in green hydrogen, it is in the specialist content knowledge and work experience required in the primary conversion stage when RE is converted via electrolysis.

7.4 Supply and demand for TVET skills by sector

In order to meet Paris Agreement targets, South Africa needs to significantly reduce GHG emissions. Specific sectors are responsible for the majority of emissions in South Africa and will be the focus of green energy deployment in the early stages. The vast majority of South African GHG emissions are as a result of fossil fuel emissions in the production of electricity from coal using the Eskom plants. Other sectors are transport, buildings (heat and power), mining, and industry (especially hard to abate industries like cement and steel production). Refer Figure 30 for more detail. It is useful to note that FCs play a major role in back up energy supply which can evolve into main supply and in almost all mobile applications. Thus, the most critical area for short term TVET skills supply apart from RE will be FCs. RE and FCs are the two areas where large firms are undertaking investigation and are piloting specific applications.

Figure 29- Sector targets for clean energy

Industries	Utilisation
Transportation	• Hydrogen can be used as fuel for hydrogen fuel cell vehicles for passenger vehicles/light weight road vehicles, commercial vehicles, heavy duty vehicles, ships, forklifts, trains and jets, heavy mining locomotives and equipment.
Power generation	• Hydrogen fuel cells offer the potential for efficient, clean, and quiet distribution of power generation. • Hydrogen can be used to power gas turbines and ammonia could also be used to reduce emissions in coal power plants. • In telecommunications, hydrogen fuel cells are used in data centres and cellphone towers as back up power.

Industrial and manufacturing process	• Hydrogen is used in industrial and manufacturing process including:
	  • oil refining to produce fuels such as petrol, jet fuel and diesel
	  • hydrogenation of vegetable and animal oils and fats
	  • manufacture of chemicals and plastics
	  • production of adhesives polymer precursors,
	  • microchip manufacturing,
	  • production of pharmaceutical products such as vitamins
	  • production of carbon steels, special metals, semiconductors
	  • ammonia-based fertiliser for food production.

Mining	• Hydrogen is used as a reductant in certain mining processes such as reduction of nickel. • Hydrogen can be used as a fuel for heavy mining locomotives and equipment.
Buildings	• Hydrogen can be used for domestic power supply, as a backup power for emergency and secondary uninterrupted power supply during power outage. • Hydrogen fuel cells can be used as a power source in remote areas.

Source: DSI, 2021

7.4.1 Mining supply and demand

There is significant potential to decarbonise mining operations using hydrogen. It can be used to store electricity in FCs, it can power equipment, forklifts, trucks, and cars using FCs and can run costly fossil fuel applications (like air conditioning systems in deeper mines) using FCs via the use of micro-grids. The main use of clean hydrogen on mines will therefore be in stationary and mobile FCs for materials handling and running electrically driven operations such as A/C, cage handling and other. They can provide an alternative energy-storage mechanism for off-grid mine sites. Should the mines decide (as some already have) to use GH on their sites, then they will require the skills applicable to RE and could integrate recycling in their value chains.

Table 14- Supply and demand for TVET skills in mining

Skill/competency	**MINING (excl RE)**		
	Main category	Demand	Supply
Design, piloting, testing of mobile and stationary FCs in specific applications (trucks, forklifts, cages, air condition, backup power, mini grids and more	FC designers, technicians, electricians, metal workers, assemblers, other	Low but growing fast.	None specialised
Implementation of FC driven alternative energy in mining operations. Installation, operations, maintenance, repair and refuelling of FCs	FC installation and O&M technicians, mechatronics, electricians, metal workers, FC systems managers, refuelling technicians and more.	Low but growing Will grow exponentially if FEDVs begin production in SA.	None specialised
PEMFC membranes and other component manufacture, testing, assembly, and delivery, **Catalyst, FC stacks et al**	Membrane technicians, electrical technicians, component manufacturing, assembly, tool room skills, metal working skills.	Low but growing Will grow exponentially if FEDVs begin production in SA.	None specialised.
Cross cutting skills			
Teamwork, conflict management, problem solving, communication, diplomacy & persistence		Ongoing and high	None/low
Digital literacy	Equipment and systems control	Ongoing and increasing	Very low
Quality assurance **Certification and compliance**	ALL	Ongoing and increasing	None (specialist)
Occupational health & safety	ALL	Ongoing and increasing	None (specialist)
Baseline STEM skills especially engineering/technology			

Source: Author compilation, 2021

7.4.2 Transport supply and demand

Issues of range and haul strength, amongst others, determine the mode of transport and the technology required. Thereafter, it matters whether goods or people are being transported, and how ie air, road, marine, space, train, other, and how much. New prototypes are under investigation, as there could be application for FCs in scooters, wheelchairs, cargo-bikes, small trucks, and minibuses, as well as mass passenger and freight transport. In all cases, however, the use of hydrogen in transport is dependent on FCs and refuelling stations (which are needed to extend range). GHG emissions are concentrated heavily in cities and metropolitan bus fleets are one focus area for South Africa.

Table 15- Supply and demand for TVET skills in transport

Skill/competency	**Transport**		
	Main category	Demand	Supply
Design, piloting, testing of mobile FCs in FECVs, mass passenger transport, long and short haul goods vehicles, aircraft, trains, cargo ships, submarine vessels, UAVs (drones) and other	FC designers, technicians, electricians, metal workers, assemblers, battery specialists, other	Low but growing for metro mass transport, and FECVs, and commercial vehicles in some sub sectors	None specialised
Installation, operations, maintenance, repair and refuelling of FCs	FC installation and O&M technicians, mechatronics, electricians, metal workers, FC systems managers, refuelling technicians and more	Low but growing Will grow exponentially if FECVs begin production in SA.	None specialised
PEMFC membranes and other component manufacture, testing, assembly, and delivery, **Catalyst et al.**	Membrane technicians, electrical technicians, component manufacturing, assembly, tool room skills, metal working skills; System integration technicians	Low but growing Will grow exponentially if FECVs begin production in SA.	None specialised.

Skill/competency	Transport		
	Main category	Demand	Supply
Cross cutting skills			
Teamwork, conflict management, problem solving, communication, diplomacy & persistence		Ongoing and high	None/low
Digital literacy	Equipment and systems control	Ongoing and increasing	Very low
Quality assurance **Certification and compliance**	ALL	Ongoing and increasing	None (specialist)
Occupational health & safety	ALL	Ongoing and increasing	None (specialist)
Baseline STEM skills especially engineering and/technology			

Source: Author compilation, 2021

7.4.3 Industrial/manufacturing supply and demand

For many years hydrogen has been used largely by the chemicals, agriculture, and petrol refining industries where it has been used to produce ammonia (42 percent) (a major element of fertilisers) and in hydrocracking to develop petroleum products (51 percent) such as diesel and petrol, as well as to remove sulphur where it is a contaminant, and to create methanol. It is also used in much smaller quantities in the following industries:

Table 16- Other industrial uses of hydrogen

Industry sector	Use
Food	Turns unsaturated fats into to saturated oils and fats.
Metalworking	Used in many applications including metal alloying and iron flash making.
Metallic Ore Reduction	Tungsten & Copper
Welding	Atomic Hydrogen Welding.
Flat glass production	A mixture of hydrogen and oxygen is used to prevent oxidation related defects.

Industry sector	Use
Electronics manufacturing	Hydrogen is used to create semiconductors, LEDs, displays, photovoltaic segments, and other electronics.
Medical	Hydrogen peroxide
Space	Liquid hydrogen fuel

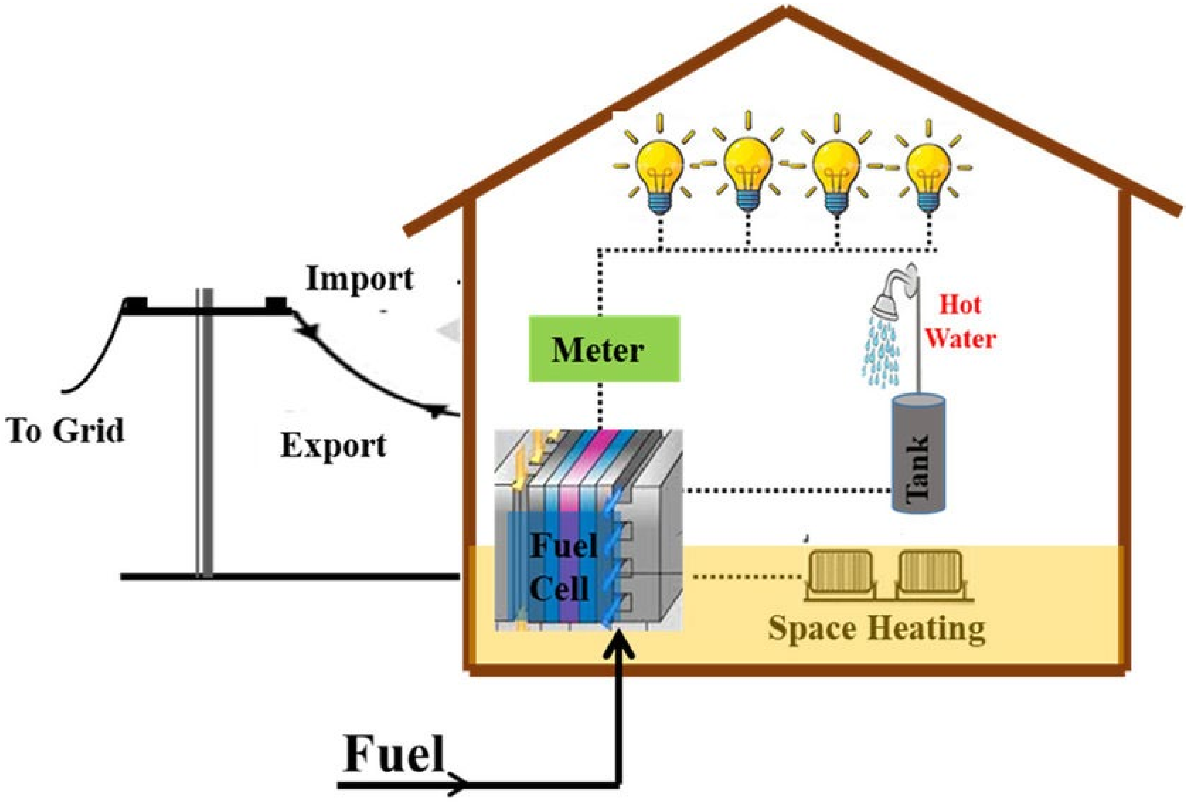
Source: Author compilation, 2021

For each sector, the basic skills remain the same, but the content and context of those skills and the specialised equipment and operating conditions, are different, requiring focussed on-the-job and theoretical training before the person becomes fully employable. There is potential to move to GH which will mean a shift in technology and skills required from SMR to electrolyser-based production resulting in the production of green ammonia instead of grey ammonia. CCS can also be used to produce ammonia, resulting in blue ammonia. The skills requirements are the same as those outlined above for hydrogen production, but with specific reference to either SMR or electrolysis production processes. The TVET college system does not cater for these skills at the moment, other than in local TVETs located close to SASOL facilities where one caters for chemical technical training and one for maintenance, fitting and other mechanical technical requirements.

7.4.4 Building supply and demand

Heat and power are the main applications for energy in buildings, residential, commercial, and industrial. GH can play a role in decarbonising energy in buildings through use in combined heat and power applications. The system requires the use of FC co-generation technology (also known as combined heat and power or CHP) where the FCs reduce primary energy consumption and emissions arising from buildings. Although there are other technologies such as gas turbines, FCs have the highest electrical conversion efficiency. The hydrogen skills gap analysis for this sector are discussed under the FC value chain and skills requirements as they are identical.

Figure 30- FC CHP overview

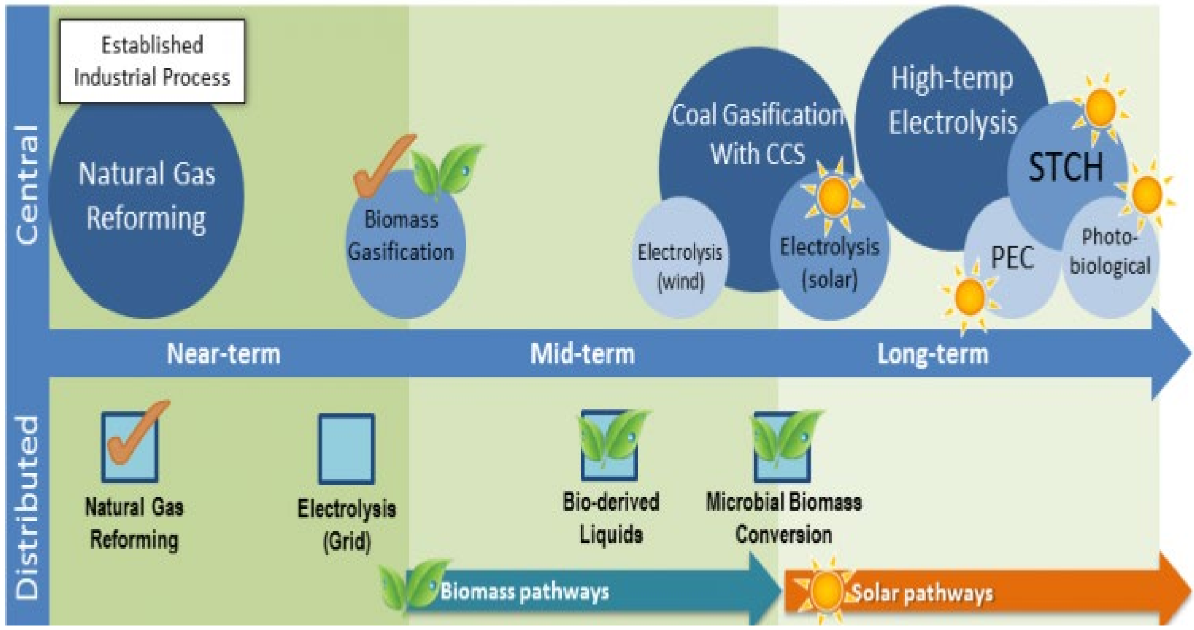


Source: Olabi et al, 2020

7.4.5 Power generation supply and demand

The production of electricity accounts for approximately 27 percent of global GHG emissions, but over 65 percent of South African emissions due to Eskom electricity being produced largely from coal. The replacement of coal as the primary feedstock is via RE technologies such as solar, wind and biomass in South Africa. FCs and hydrogen storage as green ammonia or gas are additional technologies which may grow over time. Consequently, the skills supply and demand gap is the same as for the RE sector outlined above.

Figure 31- Power generation pathways



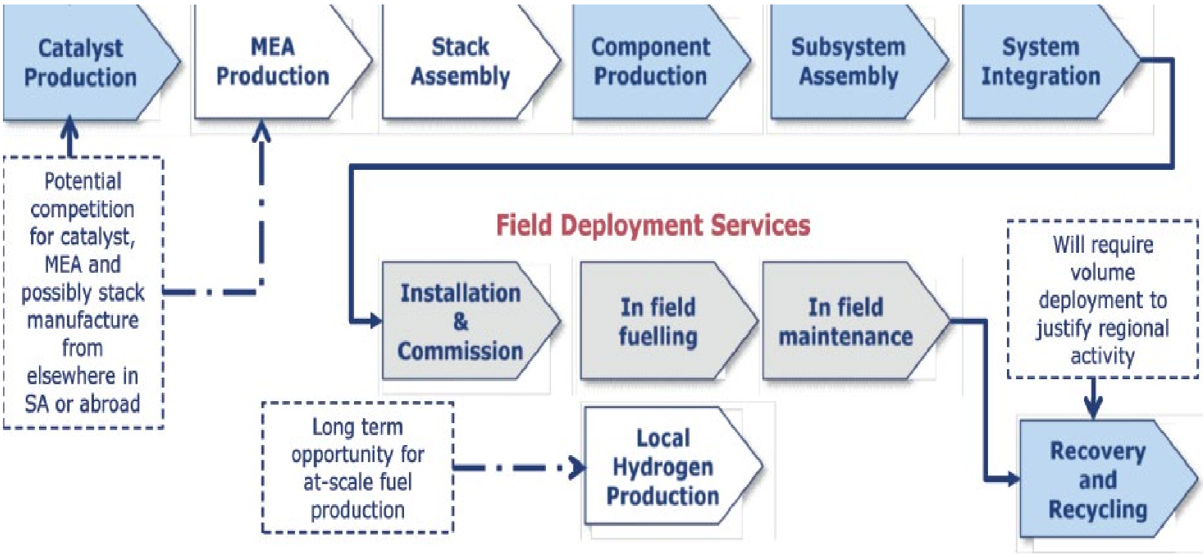
Source : https://www.energy.gov, 2021

Other than for biomass, the skills required are technical and related to the production of RE inputs to power generation and the manufacture of a liquid chemical or a gas. In biomass, general agricultural skills sets are needed and when coal is the primary input, general mining skills are needed, including relevant general artisanal skills such as fitting, turning, metal working, electrician, plumber, HVAC technician and the like. Currently the TVET system provides artisanal skills within the system, but the specific skills offered depend on the individual TVET college. Based on the research, these are not always of good quality or fit for employment purposes.

7.5 Fuel cells supply and demand.

Clean hydrogen energy supply can be delivered via a liquid carrier such as ammonia, a hydrogen gas or stored in an FC. For most stationary and mobile applications, FCs are either the sole or an important co-supplier of energy to the relevant applications. Furthermore FCs (usually PEMs) and some of their components, are being manufactured in the early stages of the product life cycle in South Africa. As for RE, discussed above, the timing of basic and specialised skills supply for FCs is therefore a priority.

Figure 32- Fuel cell production chain



Source: Carbons Trust & Orion Innovations, 2013

From the South African perspective, FC catalysts have been designed and prototypes developed and tested, and can be produced locally, as well as some MEA production. All of these components, however, can easily be imported and will be if South Africa cannot reach the standards, accreditations, certifications, and qualification levels required by clients. At the TVET level, skills needed are linked to manufacturing of components, assembly at various points, system integration, installation, maintenance and possibly recycling as Figure 33 demonstrates. None of these specialised skills are currently provided by the South African TVET college system.

7.6 Timing

To meet the existing demand for quality TVET graduates an immediate first step will be the engaging of the relevant individual TVET colleges, the DHET and the relevant industry stakeholders to ensure improved outcomes and graduates who are able to undertake the jobs that are available. The tentative timetable for the roll out of TVET skills supply moving into the GHE in South Africa is shown below.

Table 17- Tentative timetable

Stage of chain	Short term (1-3 years)	Medium term (4-7 years)	Long term (8-15 years)
Upstream	Renewable energy construction (digital skills), equipment installation, operation and management, service, and repair.	Electrolyser construction and technical	Green hydrogen production

Stage of chain	Short term (1-3 years)	Medium term (4-7 years)	Long term (8-15 years)
	Electrolyser construction (digital skills), equipment installation, operation and management, service, and repair.	CCS technicians (should industry determine to invest in blue hydrogen capabilities)	Expansion
		Green Ammonia production	Expansion
Midstream	Fuel cells, stationary and mobile. Production, installation, maintenance, service, repair. Current demand for export and some local.	Expansion Sales, marketing, logistics, digital	Investment dependent
	Membranes, Production, installation, maintenance, service, repair (current demand for export and some local)	Expansion Sales, marketing, logistics, digital	Investment dependent
	CCS technicians (should industry determine to invest in blue hydrogen capabilities).	Expansion Sales, marketing, logistics, digital	Investment dependent
	Solar PV and Wind component manufacture and assembly such as panels and blades.	Expansion Sales, marketing, logistics, digital	Investment dependent

Source: Author compilation, 2021

There are a number of options for early-stage implementation mechanisms including i) focus on upgrading lecturers and curricula in public and/or private TVET colleges where RE, GH and FC manufacturing is/will take place in the immediate term, and in partnership with the relevant private sector firms and/or ii) at the same time implement a Centre of Specialisation (CoS) where post TVET graduates can train effectively in further skills required.[182]

[182] The Centres of Specialisation (CoS) Programme is a project initiated by the South African Department of Higher Education and Training (DHET). The programme is aimed at addressing shortages in the trades and skills areas identified as priorities for national development such as clean energy and the green economy and; improving the public TVET college system so that it delivers high-quality trade qualifications that meet the needs of employers. CoS aims to model ways in which industry and employers can partner with public colleges and other relevant bodies to revitalise the delivery of trade and occupational qualifications to meet industry standards and the needs of the economy. Aligning supply and demand through Centres of Specialisation in South Africa | AUDA-NEPAD

8. Discussion, findings & recommendations

8.1 Discussion

The progression of climate change at an increasing rate around the world, with significantly negative impacts on all life, is driving a shift in the nature, type and means of energy produced and used in all human activities. Thus, the search for alternative energy solutions to fossil fuels and other causes of GHGs has resulted in decisions to shift the energy economies of nations, via the Paris Agreement of 2015. While a mainstream GHE based on net zero carbon energy solutions is some time away, certain applications which can begin to have an important impact on reducing emissions, are already scalable and commercially viable. Upstream, the use of solar PV and wind energy is growing, providing clean energy for manufacturing hydrogen. Downstream, the ability of FCs to store clean energy as a main power source or a source of back-up power, is already scaling up in some mobile and stationary applications. There is virtually no doubt that the global move to clean energy will take place and that GH has a significant role to play.

Key issues which remain to be addressed are linked to the cost of GH production and distribution and the scaling up of all operations. Because of the impact the move away from fossil fuels will have in South Africa on those dependent on these industries, issues of social and economic justice are important for people who work in and rely on fossil fuel industries. These include the companies and countries which rely on these revenues who need support to transit to new green industries in a just transition. This means that reskilling and upskilling will be essential for workers employed in these industries so that they can participate in the GE. Similarly, given current unemployment rates, especially youth unemployment, effective skilling of young people to enter the GE is fundamental to ensuring that South Africa has the right skills, at the right time and in the right quantity.

South African policy states that the TVET system should be the main supplier of quality TVET skills needed for the South African economy. Analysis of PSET budgets, however, indicates that the TVET budget allocation is inconsistent with the system's mandate and national policy goals. As things stand, entrants to the TVET system have been found to show very limited or no real STEM skills capacity which is problematic when learners pursue technical courses, and the throughput of learners is low. Those who do qualify do not have the expected quality of artisanal skills required by industry. Comments included:

- "The gap is within the technical support/technician/mechanician level."
- "We need the same skills as we have now but with further FC (hydrogen) training."
- "TVETs are not so set on quality."
- "The quality of (TVET) trainers would have to improve".

Individual TVET colleges often do not engage with industry or business in their catchment areas and there is a significant disconnect between TVET education and what industry and commerce in their local areas require. Lecturers are underqualified, often below the minimum requirements, and very often have no work experience in their teaching subjects. On-the-job or experiential training is at low levels and experienced as poor by industry. This has resulted in TVET qualified graduates often unable to find work either because the quality of their education is inadequate for the purpose of employment, or because the skills with which they graduate are not required in the labour market. Relevant digital education and often basic digital literacy are not provided for the most part and some learners do not know how to use a computer. The TVET system does not typically supply more advanced digital skills required across all industrial sectors, such as Computer Numerical Training (CNC) and similar. One respondent noted "This resulted in Bambili Energy having to extend the programme for an additional two to three weeks to teach learners how to use a computer and what this meant in the application of fuel cell systems".

The international TVET experience in certain developed countries indicates a degree of preparedness that is not the case in South Africa. In Germany, the existing dual focus TVET system and the close working relationship between the TVET colleges and industry has resulted in pre-emptive development of newly required courses and/or course content based on industry inputs to the system of the type and number and timing of skills that are needed. Even so, the supply of skills into the German economy as it pertains to quantities of skills required is insufficient, although the quality of TVET graduates is considered excellent. This is in part a result of the construction phase of new investment in industries. Where new plant and equipment is required, the construction industry and industry specialists in equipment and technology are in high demand as facilities are commissioned but when investments decline, many are left without local work. Nonetheless the German TVET system allows for new content and new technology skills to be built on top of an excellent existing dual focused education and training and this is currently what is taking place.

8.2 Findings

Skills needed to produce zero or low carbon energy fuels and hydrogen applications are in general terms very similar to those needed for the production, distribution, and storage of industrial and/or hazardous chemicals and gases. The production and distribution of grey hydrogen today is grounded in these largely STEM skills, and these same basic skills will apply to GH. However, the skills and know-how and experience needed will require additional content and specialised training as well as on the job experience especially in downstream hydrogen production applications such as fuel cells, storage and logistics solutions, and processes and technology (such as electrolysers) where RE is the source of energy for hydrogen processing. Related 4IR skills at the vocational level will soon be an essential requirement for employment, and thus TVET graduates will need a much better basis in these skills than South African colleges currently offer. In essence, skills, knowledge, and experience sets will need to be integrated and provided.

The South African TVET college system is not adequate to provide the quality, quantum, and capability supply of essential skills into the current HE and the future GHE in South Africa. A number of challenges need to be addressed linked to a lack of skilled persons available in some regions for some industries;[183] outdated curricula especially with regard to technology;[184] the National Certificate (Vocational) NC(V) system does not require work training; many lecturers lack industry knowledge, experience and training; and NC(V) graduates lack practical know-how.[185] Additionally, the current architecture of the South African TVET system is not optimally organised to respond to current or future industry needs. Current TVET programmes are insufficiently responsive to industry needs; TVET colleges offer limited support for students in academic difficulties and this reflects insufficient incentives at colleges to encourage completion. The current skills gap is partly bridged by the companies which undertake in house training, and in some cases by private TVET colleges. It is the norm that TVET graduates entering technical occupations require extensive further training and development.

Thematic analysis of responses in interviews found that the GHE and HE work opportunities are likely to grow in range as well as quantity but that the current TVET system in South Africa does not provide essential skills for future activities in the green hydrogen economy at any level or for any specific skills set. These opportunities require a particular subject choice and/or level of education. The state of readiness of the South African TVET college system was of significant concern to respondents in terms of curricula and hydrogen content availability. Of equal importance is the need for the South African TVET system to acknowledge the need for, and immediately implement throughout the entire system, digital skills in manufacturing and logistics.

There are gaps in TVET skills provision for the current grey hydrogen economy. Graduates require further skilling when they are hired and this is typically undertaken by the companies involved. This skills gap is largely a matter of application and system content but also of STEM competence and digital capacity. Currently the TVET system overall suffers from a lack of effectively trained educators; intake of learners with very limited to no STEM skills capabilities and very limited or sometimes non-existent relationships with industry relating to subject matter and on-the-job deployments. This has resulted in poor outcomes and limited employability for TVET system technician graduates.

Without extensive intervention in course content, relevant and extended work experience, technology innovation, lecturer expertise and digital skills, the TVET colleges will not be able to provide the future skills needed. The GHE requires quality technical and engineering skills at the vocational level, where theory and on-the-job experiential learning together produce employable graduates. Skills needed are almost entirely linked to manufacturing and distribution processes, typically technical and digital in nature, and although there is often an important physical component in the work today, this will reduce over time as the 4IR continues to grow and activities require equipment programming rather than physical engagement.

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[183] Martin Kühn. The South African Technical and Vocational Education and Training System from a German Perspective. 2019.

[184] Organisation for Economic Co-operation and Development (OECD). OECD skills outlook 2017: skills and global value chains. 2017. **http://hdl.voced.edu.au/10707/429058**.

[185] Kühn, The South African Technical and Vocational Education and Training System from a German Perspective.

Successful TVET systems such as in Germany ensure a close working relationship with the private sector which is lacking in the South African system. With a good ongoing working relationship, the job of the TVET system to predict and cater for upcoming needs is greatly improved. Business can give early warning of new investments and needs providing the TVET system with the time to prepare. Similarly, issues of course content and on-the-job training can be more easily addressed in such a working partnership. Thus, key findings are:

- As a supplier of technical vocational skills, the South African TVET system is not ready and does not currently have the capacity to provide GE or 4IR skills and training to the level that will be required for the HE or the GHE along the value chain. Current TVET programmes are insufficiently responsive to the needs of industry and the needs of the learners to find viable employment.[186]
- Skills required for the HE as it stands are similar to those needed for industrial chemicals and gases production, storage, and distribution and the TVET system currently does not meet industry needs. There is limited to no on-the-job experience made available to learners and work/life skills are not adequate. Some lecturers have inadequate skills and qualifications as well as limited or no experience with the industry and very limited support is provided to students.
- Skills needed for the GHE are similar to those needed in the HE, but their application in the workplace is not necessarily similar and different content (curricula) and on-the-job exposure is required. At the primary level, some skills will be transferable with additional content and on-the-job training. However, as the value chain progresses downstream, the level of different content and training needed increases significantly.
- Future skills needed will be directly linked to 4IR skills throughout the value chain from the process of primary production through to logistics and complex downstream design and manufacture.
- The gap between the ability of the TVET system as it stands to meet industry needs currently, is typically very large. The implication is that it may be necessary to repurpose TVET architecture as well as systematically review how the system operates. In many cases, industry is dissatisfied with the quality and quantum of graduates. If the supply system itself does not improve in relation to industry demand, even new training content and skills development processes will not be sufficiently helpful to bridge the gap.[187]

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[186] Interviews (2021); Field, S. 2014. '*Solutions for SA TVET system*'. DHET; Badenhorst, & Radile, 2018. '*Poor Performance at TVET Colleges: Conceptualising a Distributed Instructional Leadership Approach as a Solution*". Africa Education Review. Available from 222967656.pdf (core.ac.uk); Kraak, Paterson & Boka, (eds.) 2016. '*Change management in TVET colleges. Lessons learnt from the field of practice.*' African Minds. Available from JET-TVET-text-and-cover-web-final-1.pdf (africanminds.co.za); Kühn, M. '*The South African Technical and Vocational Education and Training System from a German Perspective*'. Balkan region conference on engineering and business education. 1. 226-234; Terblanche & Bitzer, 2018. *'Leading curriculum change in South African technical and vocational education and training colleges.'* Journal of vocational, adult, and continuing education and training. 1. 104.

[187] Interviews (2021); Field, S. 2014. '*Solutions for SA TVET system*'. DHET; Badenhorst, & Radile, 2018. '*Poor Performance at TVET Colleges: Conceptualising a Distributed Instructional Leadership Approach as a Solution*". Africa Education Review. Available from 222967656.pdf (core.ac.uk); Kraak, Paterson & Boka, (eds.) 2016. '*Change management in TVET colleges. Lessons learnt from the field of practice.*' African Minds. Available from JET-TVET-text-and-cover-web-final-1.pdf (africanminds.co.za); Kühn, M. '*The South African Technical and Vocational Education and Training System from a German Perspective*'. Balkan region conference on engineering and business education. 1. 226-234; Terblanche & Bitzer, 2018. *'Leading curriculum change in South African technical and vocational education and training colleges.'* Journal of vocational, adult, and continuing education and training. 1. 104.

There is in essence, a type of trust deficit between the private sector firms and the public TVET college system. This can be dealt with to the benefit of the graduates, private sector and the DHET, by insisting that solid working and planning relationships should be implemented at the local TVET level, as well as the national system level, where the HE is present or likely to occur in the future.

8.3 Recommendations

With these recommendations implemented as a foundation, South Africa can ensure that well-informed skills transition pathways and opportunities for new skills, improved skills, and the redeployment of existing skills would become very clear and progress towards a JT will be measurable.

Table 18- Recommendations

Recommendation	Rationale
Develop a green skills (including the GHE) Master plan for South Africa.	The development of a supportive policy environment through a Green Skills Master Plan for South Africa. This process is grounded in the co-creation of a future involving all key stakeholders. Those countries which are making progress such as New Zealand and Hong Kong, have a supportive policy and regulatory environment which deals with challenges such as lack of funding, and inadequate levels of human capacity to effect the change in terms of knowledge, experience, and skills.
Set up a system of co-planning between industry and TVET colleges at the local level, where hydrogen activities are and will be located. For example, close to SASOL, at outlet ports, and so on.	The creation of strong formal ties and links between industry and the TVET system as well as between individual firms and local TVET colleges. If individual TVETs and local industry have a solid working relationship this is the best predictor of skills demand in quantity and quality at a local level and can lead to co-investment of resources to reach skills goals.
Implement a Centre of Specialisation (CoS)	Using the existing CoS programme set up a CoS focusing on the Green hydrogen value chain from Renewable Energy inputs to Fuel Cell manufacture, maintenance and repair; spatially suitable for HE investments now and in the future. There may be potential for two, one in Gauteng, and one in the SEZ in Durban.
Consider accessing international Green Funds (grant) for the set-up and implementation of a just transition reskilling programme focussing on vulnerable workers and communities. Set up a green skills fund with clear and transparent governance focussed entirely on green skills development (and the GHE skills required) and implementation.	There is a need for investment in reskilling, upskilling and new skills development for the green economy, *including essential digital skills*. International funding for the green economy is available via the Paris Agreement mechanisms and could be used to fund the just transition, at least in part and for the most vulnerable. There is potential for the development of RE supply into the grid for example, at the community level, providing livelihoods for local people.
Set up a senior private sector led and driven working team (firms and DHET) to review the TVET system in terms of international best practice relevant to green skills development and determine how the system could be redesigned to meet needs, as well as attempting to quantify	There is currently a planning and implementation disconnect between the TVET college system and industry which, if not addressed, will lead to increasing gaps between supply of GH skills and demand for these skills. The largely successful German system of collaboration between industry and vocational education institutions

Recommendation	Rationale
and qualify skills needed and to ensure collaborative planning into the future.	should be adopted at the national and local levels where firms are or will be, located.
Begin a process of inserting GHE skills needs and priorities into national skills policies and strategies, as well as into the national education system and the sector skills plans for the Sector Education and Training Authorities (SETAs).	If GH skills are not prioritised in the national, provincial and sector planning and budgeting systems, implementation will be severely hampered. The same is true for all relevant SETAs.
Urgent TVET budget review is proposed.	An urgent review of the misalignment between the TVET budget allocation and national policy for TVET expansion is required: budgets should reflect national policy imperatives.
Step up current efforts to develop improved GHE training and development at the TVET level, and scale them up and focus them. Continue to implement emerging skills training and development in partnership with the TVET college system, *in partnership with announced programmes (Sasol, Anglo American and Toyota for example*). **Content additions to STEM education should be designed and included in curricula, and vocational institutions need to systematically evaluate the generic STEM skills on offer as well as content specific to the hydrogen economy. There should be an immediate focus on incorporating digital skills into all TVET college curricula.** **Develop a compulsory programme for on-the-job exposure in RE, hydrogen, and FC production for lecturers, potentially via exchange agreements with countries which are further along the production path.**	1. Initial pilot skills training with TVET students has had good outcomes and lessons learned. This should immediately scale up in collaboration with the leading firms and with TVETs which are optimally geographically located for the announced new and existing HE and GHE programmes and activities. 2. Content additions to STEM education across the board in the TVET college system need to be reviewed and adapted, for hydrogen but also downstream applications which are already moving into full commercialisation locally, such as membranes and fuel cells *inter alia*. 3. Quality of STEM skills requires review and upgrade. There may be a need for bridging training and an acceptance standard for technical training. 4. Such skills may be needed much earlier than anticipated. South Africa has one of the lowest delivered cost positions in the world in the production of hydrogen and export could scale up considerably prior to domestic consumption taking off.
Develop a compulsory programme for on-the-job exposure in RE, hydrogen, and FC production for lecturers, potentially via exchange agreements with countries which are further along the production path.	This requires the development of a TVET lecturer/educator skills and experience upgrade system including on-the-job experience as an essential component and a priority, and preferably prior to the development of new curricula, and as the industry expands.

Recommendation	Rationale
Consider a post TVET STEM qualification in the short term. **There is potential for partnerships with private TVET institutions and other PSET entities.**	There is potential for post TVET STEM qualification/s which will be technical content specific, where TVET graduates with appropriate qualifications can apply for specific courses linked to green hydrogen production chains. This will allow for the TVETs to focus on elevating the current quality of technical graduates and simultaneously will develop a skills base for deployment as the industry grows.
Consider the need for the design and implementation of pathways to clean energy production, jobs, and work at the community level. Potential for pilots in coal mining communities could be prioritised and reskilling implemented using material developed for TVET.	There is significant potential for the democratisation of energy at the community level over time. This would create jobs, occupations and provide low-cost energy to communities, as well as potentially providing a source of income by selling energy into the national grid. Such pathways can contribute to a just transition. Outreach methods to remote communities can be utilised *(refer German community energy practice outlined in this review)* to ensure an inclusive approach and outcomes.

With these foundational recommendations implemented, South Africa can begin to build well-informed skills transition pathways and opportunities for green economy and green hydrogen new skills, improved skills, and the redeployment of existing skills. This will support the growth of industry, improve work opportunities for the unemployed, improve the quality of TVET graduates and ensure a shared commitment and strategy for the implementation of a just transition.

9. Conclusions

Demand in the GHE in South Africa is pre-commercial therefore there is little known about related skills supply and demand. The type and content of skills which will be required as the green economy unfolds are not well researched at this time. This preliminary assessment is needed so that the South African TVET system can adequately prepare to deliver skills to industry involved in the GHE even if full scale demand may be some years away.

It was hypothesised that the South African current TVET college system is not adequate to meet the needs of a future GHE. The aim of the research was therefore to develop a profile of the nature of skills required for the South African grey hydrogen industry, and what the skills needs of industry would be for the South Africa GHE in the future. At the same time, the current ability and capacity of the TVET system to supply these was assessed and the gap between the ideal state of TVET skills supply for the GHE and the current state was undertaken. High level recommendations on intervention areas were provided.

Although the research is limited by a lack of quantitative data the findings from the literature and statistics review were qualitatively corroborated by means of interviews with large firms either already participating in the hydrogen economy, or which intend to produce grey and/or green hydrogen in the future.

The findings clearly indicate that the South African TVET college system is weak and unable to cater fully for the existing hydrogen economy. Many of the basic technical skills, including digital skills are not well delivered. There is a significant lack of pragmatic and helpful engagement between the TVET colleges and the local industries they are supposed to serve. This results in graduates struggling to find work because they are either trained for jobs that are not available, or they are not of sufficient quality to be acceptable in the job market. A review of the German model of TVET which has a dual focus and where learners are developed in a practical and positive relationship between the colleges and industry, indicates an almost ideal state to which South Africa can aspire. In the short term, immediate action is needed at those specific TVET colleges which should be supplying the existing hydrogen industry and discussions should begin regarding future skills needs. Focus at this time will be on RE as without adequate supplies of RE, green hydrogen cannot be produced, and on FCs as either the back-up energy or the primary clean energy solution in specific sectors.

Some early wins are possible, which can demonstrate strategic intent, support, and at the same time, begin the process of revitalising TVETs and restoring morale. For example, one programme which can begin immediately will be to begin to bridge the existing gap between individual TVETs catering for the current RE, grey hydrogen and FC sub-sectors, and the industries being served. A second quick win, and an essential component of any improvement strategy, is to begin a programme which provides on-the-job training for lecturers. With industry cooperation, and possibly in an exchange programme with Germany, such a programme could serve to train TVET leaders through observation of how the dual focus TVET system works and is governed (TVET principals and DHET officials) as well as providing theoretical and on-the-job training (lecturers). A final essential and quick win will be to begin to digitally skill workers and young people in communities where earlier closure of fossil fuel operations is planned. The workers and young people could be the early recipients of digital literacy and digital coding programmes. Not only are there no pre-dependencies for this programme to begin, but the skills will also be deployable in most industries, and this will significantly contribute to the process of ensuring the JT.

Annex 1- Detailed lists of skills required in renewable energy [188]

Table 19- Skills needed - wind value chain.

Equipment Manufacture and Distribution	Project Development	Construction and Installation	Operation and Maintenance	Cross-cutting/ Enabling Activities
• R&D (e.g. materials, componentry • Component design and manufacture (e.g. blade, tower, nacelle, generator) • Modelling and testing (e.g. prototype development) • Raw materials supply • Assembly • Quality assurance • Certification • Marketing Sales • Delivery	• Wind farm design • Wind resource assessment • Environmental and social assessment (birds, visibility, water, etc.) • Land agreements • Economics and financing • Permit application, monitoring and amendment • Power purchase agreement and grid connection contract • Selection of supplier	• Infrastructure development • Turbine erection and commissioning • Grid connection	• Operation and maintenance • Financial management • Repowering (or removal)	• Training • Policy-making • Management and administration • Insurance • IT • Health and safety • Financing • Communication

188 ILO. Skills and occupational needs in renewable energy.

Table 19- Skills needed - solar value chain.

Equipment Manufacture and Distribution (only for active solar)	Project Development	Construction and Installation	Operation and Maintenance	Cross-cutting/ Enabling Activities
• R&D • Design and manufacture of components, solar panels and other equipment • Modelling and testing • Quality assurance and quality control • Marketing • Sales • Delivery	• Solar system/farm design • Site assessment (shadows, radiation, etc.) • Environmental and social impact assessment • Land agreements • Economics and financing • Permitting • Power purchase agreement and grid connection contract • Selection of supplier (only for active solar)	• Construction of solar system/ farm • Solar panels installation • Quality assurance and quality control • Grid connection	• Operation and maintenance • Recycling*	• Training • Policy-making • Management and administration • Insurance • IT • Health and Safety • Financing • Communication

Table 20- Skills needed - hydro value chain

Equipment Manufacture and Distribution	Project Development	Construction and Installation	Operation and Maintenance	Cross-cutting/ Enabling Activities
• R&D • Design and manufacture: turbine; generator and excitation; other hydro-mechanical components (e.g. valves, penstocks); other electrical components (e.g. transformers, power, electronics etc.); governor and control systems • Quality assurance • Marketing and Sales • Delivery	• Design • Site investigations and feasibility studies • Insurance • Environmental and social assessments • Land agreements • Financing • Licensing/ Permitting • Selection of supplier	• Project construction • Project commission	• Routine operation and maintenance • Minor equipment overhauls • Major equipment overhauls	• Training • Policy-making • Management and administration • Insurance • IT • Health and Safety • Financing • Communication

Table 21- Skills needed - geothermal value chain

Equipment Manufacture and Distribution	Project Development	Construction and Installation	Operation and Maintenance	Cross-cutting/ Enabling Activities
• Design and manufacture: Drilling tools, heat pumps, pipes, collectors, other heating systems components (heat exchanger, floor heating, valves measuring and control instruments, etc.) • Auxiliary substances (grout, loop fluids, refrigerant • Quality assurance • Marketing and Sales • Delivery	• Design • Feasibility studies • Permit planning • Thermal response test • Land agreements • Selection of supplier	• Well drilling and installation bore hole heat exchanger • Services for deep geothermal drilling (mud service, casing service, directional drilling, hydraulic fracturing, logging, cementation, etc.) • Heat pump installation • Power plant installation • District heating/ cooling system installation	• Heat contracting • Power plant operation • Monitoring geothermal reservoir • Service and maintenance (pumps, pipes, etc.)	• Training • Policymaking • Management and administration • Insurance • IT • Health and Safety • Financing • Communication

Table 22- Skills needed - bioenergy value chain

Equipment Manufacture and Distribution	Project Development	Construction and Installation	Operation and Maintenance	Biomass Production	Cross-cutting/ Enabling Activities
• R&D • Design (digesters, refineries, components, etc.) • Quality assurance • Marketing • Sales • Delivery	• Design • Resource assessment • Environ-mental and social assessment • Financing • Land agreements • Permitting • Selection of supplier	• Plant con-struction • Pre-pro-cessing and upgrading • Processing • Quality assurance • Conver-sion (heat, power, or fuel)	• Operations and main-tenance	• Cultivation • Harvesting • Transport	• Training • Policy-making • Manage-ment and administration • Insurance • IT • Health and safety • Financing • Communica-tion • Biopower transmis-sion and distribution

Table 23- Occupations in renewable energy-equipment manufacture and distribution (Solar/Wind)[189]

	Wind	Solar (photovoltaic, ST, CSP, PS)
Equipment Manufacture and Distribution	• R&D engineers (computer, electrical, environmental, mechanical, wind power design) (H) • Software engineers (H,M) • Modellers (prototype testing) (H,M) • Industrial mechanics (M) • Manufacturing engineers (H) • Manufacturing technicians (M) • Manufacturing operators (L) • Manufacturing quality assurance experts (H,M) • Certifiers (H) • Logistics professionals (H,M) • Logistics operators (L) • Equipment transporters (L) • Procurement professionals (H,M) • Marketing specialists (H,M) • Sales personnel (H,M)	• Researchers (chemists, physicists, engineers with specialization in electrical, mechanical, chemical, materials, system design or process engineering) (H) • Chemical laboratory technicians and assistants (M) • Software engineers (H,M) • Modellers (H) • Manufacturing engineers (H) • Manufacturing technicians (H,M) • Manufacturing operators (M,L) • Building systems specialists (H) • Manufacturing quality assurance experts (H,M) • Logistics professionals (H,M) • Logistics operators (L) • Equipment transporters (L) • Procurement professionals (H,M) • Marketing specialists (M,H) • Sales personnel (M,H)

[189] H= high skilled (degree and postgraduate); M=medium skilled (technician, skilled crafts, supervisory); L= low skilled (semi-skilled and unskilled)

Table 24- Occupations in renewable energy-project development (Solar/Wind)

Project Development	• Project designers (engineers) (H) • Environmental impact assessment specialists (H,M) • Economic/financial/risk specialists (H) • Atmospheric scientists (H) • Social impact specialists (H) • Lawyers (feed-in contract, grid connection and financing contract, construction permit, power purchase agreement) (H) • Planners (permit monitoring, amendment and application) (H) • Land development advisor (H) • Land use negotiator (H) • Lobbyist (H)	• Project designers (engineers) (H) • Architects (H) (small projects) • Atmospheric scientists and meteorologists (H) • Resource assessment specialists and site evaluators (H) • Environmental consultant (H) • Lawyers • Debt financier representatives (H) • Developers/facilitators (H,M) • Land development advisor (H) • Land use negotiator (H) • Lobbyist (H) • Mediator (H)

Table 25- Occupations in renewable energy-construction (Solar/Wind)

Construction and Installation	• Project managers (H) • Electrical, civil and marine engineers (H) • Small wind turbine installers (M) • Construction electricians (M) • Power line technician (M) • Construction worker (M,L) • Quality control inspectors (M) • Instrumentation and control technicians (M) • Business developers (H) • Commissioning engineer (electrical) (H) • Transportation workers (L)	*Solar Thermal (ST)* • System designer (H,M) • Plumbers specializing in solar (M) *Small Photovoltaic* • System designer (electrical engineers or technologists) (H,M) • Electricians specializing in solar(M) *Small Photovoltaic, Solar Thermal* • Roofers specializing in solar (M) *Large Photovoltaic* • System designers (electrical/ mechanical/structural engineers) • Installers (M) *Concentrated Solar (CSP)* • Welders (M) • Pipe fitters (M) *Small Photovoltaic, Large Photo-voltaic, ST, CSP* • Electricians specializing in solar (M) *Small Photovoltaic, Large Photo-voltaic, ST, CSP* • Project designers and managers (H)

Table 26- Occupations in renewable energy- operation and maintenance (solar/wind)

Operation and Maintenance	• Windsmith/millwright/ mechanical technician or fitter/ wind service mechatronics technician (M, some H) • Operations and maintenance specialists (M) • Power line technician (M) • Field electricians (M)	• Photovoltaic maintenance specialists (electricians specialiszing in solar) (M) • ST maintenance specialists (Plumbers specializing in solar) (M) • CSP maintenance specialists (M) • Inspectors (M,L) • Recycling specialists (H)

Table 27- Occupations in renewable energy- cross cutting (solar/wind)

Cross-cutting/ Enabling Activities	• Policy-makers and government office workers (H,M) • Trade association and professional society staff (H,M,L) • Educators and trainers (H) • Management (H,M) • Administration (H,M,L) • Publishers and science writers (H,M) • Insurer representatives (H,M)	• Policy-makers and government office workers (H,M) • Trade association and professional society staff (H, M,L) • Educators and trainers (H) • Management (H,M,L) • Administration (H,M,L) • Publishers and science writers (H,M) • Insurer representatives (H,M) • IT professionals (H,M)

Table 28- Occupations in renewable energy-equipment manufacture and distribution (Hydro/Geothermal/bioenergy)

Hydropower	Geothermal	Bioenergy
• Design engineers (civil, mechanical, electrical, hydropower) (H) • Modellers (H/M) • Software developers (H) • Manufacturing engineers (H) • Manufacturing technicians (M) • Manufacturing operators (L) • Quality assurance specialists (H,M) • Marketing specialists (H,M) • Sales personnel (H,M)	• Designers (H) • Electrical engineers (H) • Mechanical engineers (H) • Software developers (H) • Machinists (M) • Welder (M) • Sales personnel (H,M)	• Biochemists and microbiologists (H) • Agricultural, biological, chemical and physical scientists (H) • Chemical, biological, mechanical and electrical engineers (H) • Material scientists in R&D (H) • Software engineers (H) • Manufacturing engineers (H • Manufacturing quality assurance specialists (H,M) • Manufacturing technicians (H,M) • Quality assurance specialists (H,M) • Logistics professionals (H,M • Logistics operators (L) • Equipment transporters (L) • Procurement professionals (H,M) • Marketing specialist (H,M) • Sales personnel (H,M)

Table 29- Occupations in renewable energy-equipment project development (Hydro/Geothermal/bioenergy)

- Engineers (civil, mechanical, electrical) (H)
- Project managers (H)
- Skilled construction workers (heavy machinery operators, welders, pipe-fitters etc.) (M)
- Construction labourers (L)
- Business developers (H)
- Commissioning engineer (electrical) (H)
- Transportation workers (L)

- Hydrologists, hydrogeologists (H)
- Geologists (H),
- Geophysicists (H)
- Geothermal engineers (H)
- Geochemists (H)
- Chemical laboratory technicians and assistants (M)
- Drilling engineers (H)
- Architects (H)
- Structural engineers (H)
- Surveyors (H)
- Designers (H)
- HVAC technicians (H)
- Drilling technicians and operatives (roughnecks) (M)
- Welders (M)
- Pipe fitters (M)
- Plumbers (M)
- Construction equipment operator (M)
- Drilling equipment operator (M)

- Biochemists and microbiologists (H)
- Environmental engineers (H)
- Laboratory technicians and assistants (M)
- Chemical, biological, mechanical and electrical engineers (H)
- Project designers and managers (H)
- Software engineers (H)
- Construction professionals (H)
- General electricians, plumbers, roofers (M)
- General construction workers (L)
- Business developers (H)
- Commissioning engineer (electrical) (H)
- Transportation workers (L)

Table 30- Occupations in renewable energy-construction (Hydro/Geothermal/bioenergy)

• Engineers (civil, mechanical, electrical) (H) • Project managers (H) • Skilled construction workers (heavy machinery operators, welders, pipe-fitters etc.) (M) • Construction labourers (L) • Business developers (H) • Commissioning engineer (electrical) (H) • Transportation workers (L)	• Hydrologists, hydrogeologists (H) • Geologists (H), • Geophysicists (H) • Geothermal engineers (H) • Geochemists (H) • Chemical laboratory technicians and assistants (M) • Drilling engineers (H) • Architects (H) • Structural engineers (H) • Surveyors (H) • Designers (H) • HVAC technicians (H) • Drilling technicians and operatives (roughnecks) (M) • Welders (M) • Pipe fitters (M) • Plumbers (M) • Construction equipment operator (M) • Drilling equipment operator (M)	• Biochemists and microbiologists (H) • Environmental engineers (H) • Laboratory technicians and assistants (M) • Chemical, biological, mechanical and electrical engineers (H) • Project designers and managers (H) • Software engineers (H) • Construction professionals (H) • General electricians, plumbers, roofers (M) • General construction workers (L) • Business developers (H) • Commissioning engineer (electrical) (H) • Transportation workers (L)

Table 31 - Occupations in renewable energy- operation and maintenance (Geothermal/hydropower/bioenergy)

Hydropower	Geothermal	Bioenergy
• Design engineers (civil, mechanical, electrical, hydropower) (H) • Modellers (H/M) • Software developers (H) • Manufacturing engineers (H) • Manufacturing technicians (M) • Manufacturing operators (L) • Quality assurance specialists (H,M) • Marketing specialists (H,M) • Sales personnel (H,M)	• Designers (H) • Electrical engineers (H) • Mechanical engineers (H) • Software developers (H) • Machinists (M) • Welder (M) • Sales personnel (H,M)	• Biochemists and microbiologists (H) • Agricultural, biological, chemical and physical scientists (H) • Chemical, biological, mechanical and electrical engineers (H) • Material scientists in R&D (H) • Software engineers (H) • Manufacturing engineers (H) • Manufacturing quality assurance specialists (H,M) • Manufacturing technicians (H,M) • Quality assurance specialists (H,M) • Logistics professionals (H,M) • Logistics operators (L) • Equipment transporters (L) • Procurement professionals (H,M) • Marketing specialist (H,M) • Sales personnel (H,M)

Table 32 - Occupations in renewable energy-cross cutting (Geothermal/hydropower/bioenergy)

Hydropower	Geothermal	Bioenergy
• Insurer representatives (H,M) • IT professionals (H,M) • Human resources professionals (H) • Other financial professionals (accountants, auditors and financers) (H) • Health and safety consultants (H,M)	• Insurer representatives (H,M) • IT professionals (H,M) • Human resources professionals (H) • Other financial professionals (accountants, auditors and financers) (H) • Health and safety consultants (H,M) • Clients (H,M,L)	• IT professionals (H,M) • Human resources professionals (H) • Other financial professionals (accountants, auditors and financers) (H) • Health and safety consultants (H,M) • Sales and marketing specialists (H,M) • Clients (H,M,L)

Annex 2 – Climate change

Global warming is an increase in the average global temperature which occurs when CO_2 and other greenhouse gases and air pollutants absorb sunlight and solar radiation that have bounced off the earth's surface- and collect in the atmosphere. In previous years, the radiation would have moved into space, but due to the very high level of current emissions the additional heat is trapped, and Earth gets hotter. Certain gases in the atmosphere block heat from escaping and remain semi-permanently in the atmosphere. These do not respond to changes in temperature and are categorised as shown in Table 33.

Table 33- Greenhouse gases

Gas	Characteristics
Water vapour	Most abundant. Important feedback mechanism in the form of clouds and rain
Carbon Dioxide (CO_2)	Released by breathing, deforestation, land use changes and burning fossil fuels. CO_2 has been driving recent global warming
Methane	Hydrocarbon gas, produced via waste decomposition, agriculture (especially rice production) ruminant digestion (cattle). More active but less abundant than CO^2.
Nitrous Oxide	Produced via soil cultivation practices (fertiliser use). fossil fuel burning, burning of biomass, and nitric acid production.
Chlorofluorocarbons (CFCs)	Synthetic compounds now regulated in production and release to the atmosphere by international agreement

Source: NASA (2021)[190]

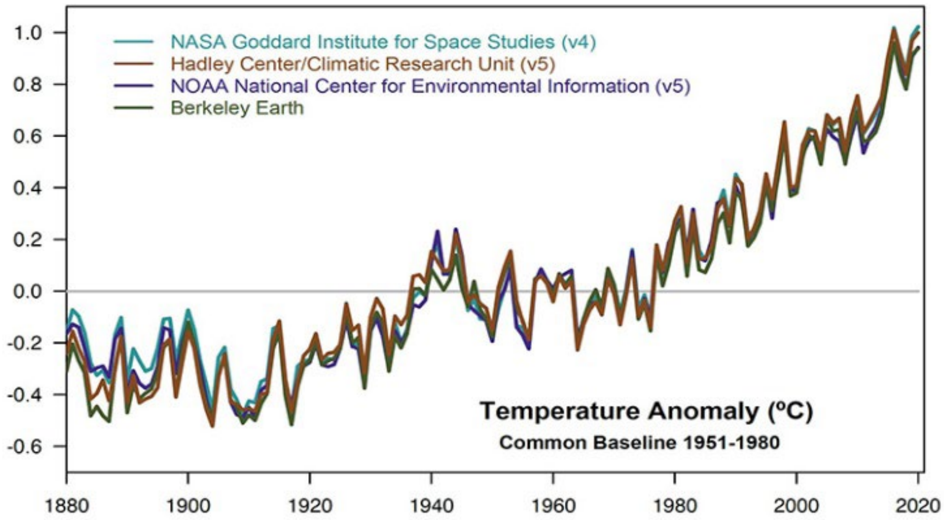
The resulting increase in earth temperature has significant effects on climate systems. Because the bulk of emissions trapped in the atmosphere are carbon based and are derived from fossil fuels and manufacturing production, there is an urgent need to develop and transition to fuels that do not use carbon, thus reducing the negative greenhouse effect and by extension, global warming.

Rising temperatures have worsened extreme weather events (including heat, drought, storms, and floods) and increased disease spread (including an increasing range of malarial mosquitos) *inter alia*. This has resulted in reducing water availability, lower yields in food

[190] NASA. 'The effects of climate change". Causes | Facts – Climate Change: Vital Signs of the Planet (nasa.gov)

production, health impacts and flooding and erosion in coastal areas to name but a few consequences.[191] The Intergovernmental Panel on Climate Change (IPCC) involves over 1,300 scientists from many countries. It forecasts a temperature rise of 1 - 3 degrees Celsius over the next century as shown in **Error! Reference source not found.**.[192] Adapting to and mitigating climate change is seeing the development of new technologies (such as Computer Numerical Control (CNC)), and this in turn requires the development of new curricula in terms of content and on-the-job learning at the TVET level. New knowledge, skills and skills development pathways will be needed for vocational education internationally - for example, in areas where there are very limited apprenticeships and internships available, simulation technology can be used to replicate experiential learning to some extent.[193]

Figure 33- Consensus on global warming



Source: NASA (2021)[194]

Addressing global warming and climate change

There are two key strategies to addressing global warming and climate change- both of which will have a significant influence on skills required in the future. The first is *mitigation*, which requires that there be a significant reduction in current global emissions of greenhouse gases, and that the current levels in the atmosphere, are stabilised. The second is *adaptation*, requiring that globally humanity adapts to the gases already present and the consequences. These are shown in Table 34.

[191] NASA. 'The effects of climate change". Effects | Facts – Climate Change: Vital Signs of the Planet (nasa.gov)

[192] IPCC. Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[193] SASOL. Interview by Andisa Sibukhwana. Online interview. Johannesburg May 2021.

[194] NASA. 'The effects of climate change". Causes | Facts – Climate Change: Vital Signs of the Planet (nasa.gov)

Table 34- Strategies & requirements

Strategy	Sub strategies	Required outcomes
Mitigation	• Reduce sources (fossil fuels) • Enhance sinks (oceans, forests, soil)	Avoid significant human interference with the climate system; Stabilise current greenhouse gas levels to allow for natural adaptation to climate change and maintain food security.[195]
Adaptation	• Reduce vulnerability through local, regional, national, and global development planning.	Manage unavoidable and harmful effects of climate change (rising of sea, extreme weather events, food insecurity *et al*)

Source: NASA (2021)[196]

The response to both strategies became formalised internationally in 1992, when a number of countries began to participate in the United Nations Framework Convention on Climate Change (UNFCCC). Its purpose was to limit average global warming and climate change and to find means of coping the impacts. In 1997, the Kyoto Protocol was adopted which set binding emission reduction requirements for 37 industrialised countries. In 2010, it was agreed that global temperature increases should be limited to below 2 degrees Celsius. [197]

The current mechanism for strategy implementation- largely for mitigation- is the Paris Agreement. It is a legally binding international treaty on climate change comprising 196 committed parties and requires specific goals to be met in emissions control. Its overarching goal is to limit global warming, preferably to not more than 1.5 degrees Celsius above pre-industrial levels. This means achieving a climate neutral world by 2050. In order for the Paris Agreement to be implemented, major social and economic transformation will be needed internationally. Nations provide formal commitments to specific goals and actions for climate change, and this translates into a Nationally Determined Contribution (NDC)- or each nation's plan for climate action. These plans include mechanisms and principles which attempts to ensure that the transition to clean energy production is just- those working in current industries

[195] United Nations Intergovernmental Panel on Climate Change (UNIPCC). *Summary for Policy Makers.* ipcc_wg3_ar5_summary-for-policymakers.pdf

[196] NASA. 'The effects of climate change".

[197] Amina Mohammed. 'More Financial Support Is Needed for Climate Adaptation". UNFCCC

which will be heavily affected by the transition need reskilling to ensure they are not left behind.

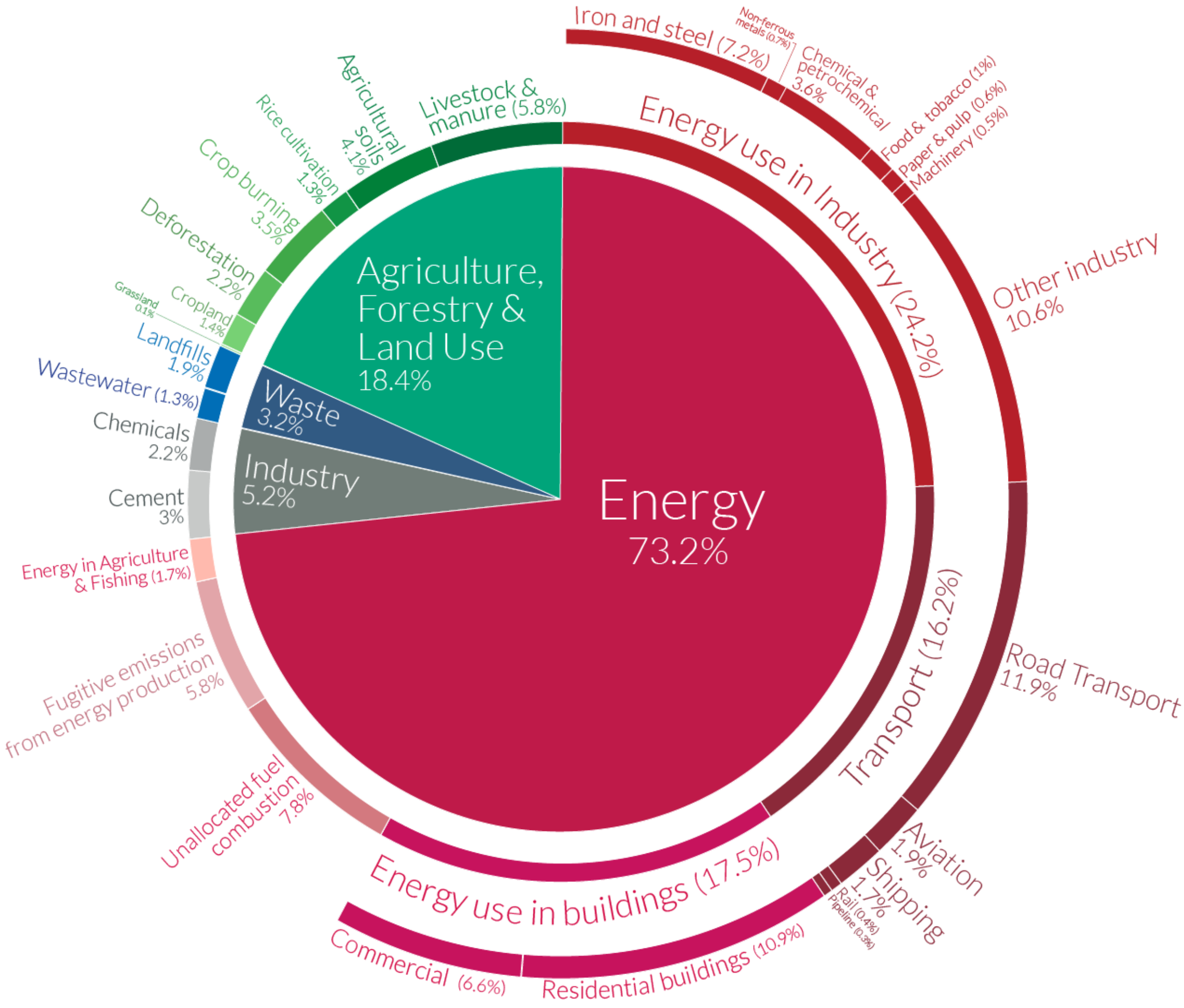
NDCs are organised around two broad themes- the actions which will be implemented to reduce their greenhouse gas emissions, and the actions they will take to sustainably adapt to rising temperatures. Further, the Paris Agreement commits to a framework in terms of finance, capacity building and technological support. Adjusting emissions downwards (mitigation) is a costly process, and climate finance is needed to support those nations which cannot afford to undertake it independently. Large scale investment is needed not only for mitigation, but also for adaptation. Technology support is provided through the technology mechanism, and capacity building activities in all nations, but especially those still developing, are funded through the agreement.[198] Currently, the establishment of carbon neutrality targets – to achieve net-zero emissions- is accelerating significantly amongst countries, cities and companies, and zero-carbon solutions are becoming competitive particularly in the power and transport sectors.

Mitigation and adaptation require a number of strategies to be implemented within nations. Improving energy efficiency, expanding the use of renewable energy, renewable natural gas, and hydrogen in energy networks, reducing emissions, and investing in storage technologies, are some of the main thrusts. Each of these strategies has its own new knowledge requirements which affect skills development. One of the most critical is in building sustainable and viable renewable energy resources, such as the production of green hydrogen and the increased use of renewables, thus the application of non-fossil fuel energy sources to the highest emitting sectors. Urgent sustainable solutions are required for the electricity, heat production (buildings) and transport (mostly cars) sectors (73.2 percent), thereafter agriculture (18.4 percent), followed by manufacturing and construction (5.2 percent). The balance is accounted for by waste decomposition. There are significant regional variances between sectors. While most emissions from agriculture emanate from methane the vast bulk of the remainder are carbon based.[199] Figure 35- World emissions by sector (2016) below provides an overview and average weighting (globally) of the various sources of emissions.

[198] UNFCC. 'The Paris Agreement'. The Paris Agreement | UNFCCC

[199] Hannah Richie and Max Roser. ' Emissions by Sector' Emissions by sector - Our World in Data

Figure 34- World emissions by sector (2016)



Source: Climate Watch, based on raw data from IEA. www.iea.org/statistics

Annex 3- US Hydrogen economy jobs

Table 35- Examples of US hydrogen economy and FC jobs, and minimum qualifications

Occupational title	Minimum educational requirements
Director of hydrogen energy development	Bachelor's (Business)
Hydrogen fuelling station manager	Bachelor's Computer Engineering (CE)
Hydrogen/fuel cell R & D director	Doctorate
Hydrogen fuel cell system technician	High School Diploma (HSD); General Education Diploma (GED); On the Job training (OJT) Technical Supervision (TS); or apprenticeship
Junior hydrogen energy technician	HSD/GED/OJT/TS/apprenticeship
Fuel cell engineering intern	HSD/GED/OJT/apprenticeship
Fuel cell manufacturing technician	Associate degree (between high school and bachelors)
Fuel cell fabrication and testing technician	Associate degree
Hydrogen power plant installation, operations, engineering, and management	Bachelor's Electrical Engineering (EE); Mechanical Engineering (ME) and Computer Engineering (CE)
Hydrogen energy systems designer	Apprenticeship/TS
Fuel cell plant manager	Bachelor's (EE, ME)
Hydrogen energy system operations engineer	HSD/GED
Hydrogen fuelling station designer & project engineer	Bachelor's (Engineer)
Hydrogen fuel transporter - trucker	OJT
Hydrogen fuelling station operator	OJT
Hydrogen fuels policy analyst & business sales	Bachelor's (Business)
Hydrogen systems program manager	Bachelor's (Engineer)
Emissions accounting & reporting consultant	Bachelor's (Various)
Fuel cell quality control manager	Master's (Science/Engineering)
Hydrogen pipeline construction worker	HSD/GED/OJT/TS/apprenticeship

Occupational title	Minimum educational requirements
Fuel cell designer	Master's (Science)
Hydrogen energy engineer	Bachelor's (Engineer)
Fuel cell power systems engineer	Master's (EE)
Fuel cell fabrication technician	HSD/GED/OJT/TS/apprenticeship
Hydrogen systems & retrofit designer	Bachelor's
Fuel cell retrofit installer	HSD/GED/OJT/TS apprenticeship
Fuel cell retrofit manufacturer plant labour	HSD/GED
Hydrogen vehicle electrician	HSD/GED/OJT/TS apprenticeship
Fuel cell vehicle development engineer	Bachelor's (Engineer)
Hydrogen systems safety investigator - cause analyst	Bachelor's (various)
Hydrogen lab technician	Associate's
Hydrogen energy system installer helper	HSD/GED
Hazardous materials management specialist	Bachelor's (Science)
Hydrogen energy system installer	HSD/GED/OJT/TS apprenticeship
Fuel cell power systems operator and instructor	HSD/GED/OJT/TS apprenticeship
Fuel cell backup power system technician	HSD/GED/OJT/TS apprenticeship
Senior automotive fuel cell power electronics engineer	Bachelor's (EE)
Emissions reduction credit portfolio manager	Bachelor's (Business)
Emissions reduction project developer specialist	Bachelor's (Various)
Emissions reduction project manager	Bachelor's (Various)
Hydrogen systems sales consultant	Bachelor's (Business)
Hydrogen plant operations manager	Bachelor's (EE, ME)

Source: Cavendish LLC in Bezdek, 2019

Annex 4- TVET skills in design and construction

Table 36- Vocational skills in design and construction

DESIGN
Interpreting blueprints
Giving and following directions
Project management
Flexibility
Construction management
Construction reports
Estimating
Identifying the building process
Identifying material costs
Understanding the design
CAD software
Basic mechanical and electrical knowledge,
CONSTRUCTION
Masonry
Carpentry
Painting
Drywall
Electrical
Plumbing
Framing
Building site supervision
Construction management
Construction reports

Concrete
Roofing
Sheet metal work
Demolition
Renovations
Repairs
Building codes
Electrical codes
Environmental codes
OSHA safety requirements
Interpreting specifications
Reading and interpreting drawings
High voltage grid connections
Inspecting
Measuring
Organize building materials
Reading and interpreting drawings
Engineering support *including Computer Science, Programming Languages* *Statistics, System Design and Analysis, Process Management and Communication*
Erecting
Hazardous materials
Heating, ventilation, and air conditioning (HVAC)
Installation
Ironwork
Metal lathing
Pipe fitting
Refrigeration

Rigging
Steam fitting
Surveying
Trim
Construction equipment
Maintenance
Power tools

Source: Air Products International (2021)

Annex 5- Selected soft skills.

Table 37- Soft skills required.

• Interpreting blueprints
• Giving and following directions
• Project management
• Flexibility
• Construction management
• Construction reports
• Estimating
• Identifying the building process
• Identifying material costs
• Understanding the design
• Teamwork
• Commitment to ongoing learning
• Verbal and non-verbal communication
• Critical thinking and problem solving
• Conflict management
• Persistence and
• Diplomacy

Annex 6- Solar PV specific skills

Table 38- Solar PV skills

Solar PV Fundamentals
o Solar power concepts
o Solar PV module characteristics and technologies
o Inverter characteristics and technologies
o Other system components
o Solar PV generation
Solar PV System Design: Off-grid & On-grid
Electrical Fundamentals of Solar PV system
o In-depth understanding of module and inverter characteristics
o Understanding the solar irradiation and other weather data relevant to solar PV systems
o Site assessment & Shadow analysis
o Energy bill analysis (in case of distributed/rooftop solar)
o System sizing (in case of distributed/rooftop solar)
o AC & DC cable sizing
o Safety equipment sizing
o Electrical codes
o Array layout and system architecture
o Single line diagram
o Bill of Material (BOM) preparation
o Grid integration & Power evacuation
System optimization
o Solar PV system Production modelling and energy estimation
o Battery storage system concepts &technologies
o Sizing of battery systems
o Installation on site- hands on training is a must
System Maintenance & Troubleshooting

o Monitoring system output
o Identifying the faults in the system
o System shutdown procedure
o Safety while fixing system faults

Source: ILO, 2011

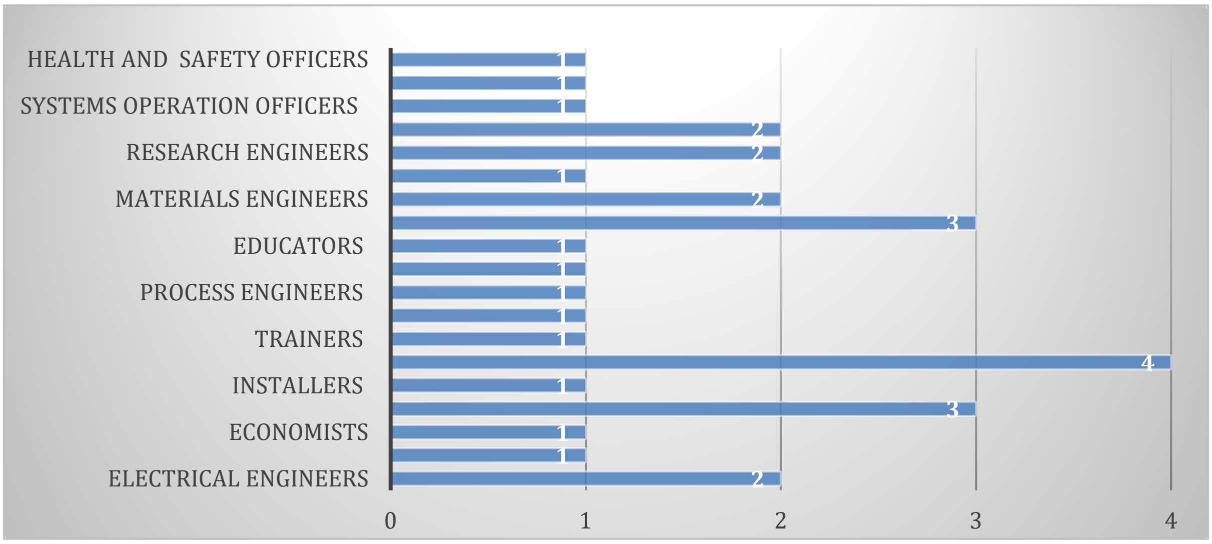
Annex 7- Interview analysis

The interview analysis evaluates the current nature and quantum of curriculum and training offered by the TVET college system that could be useful to the GHE (including grey hydrogen applications where relevant) economy in South Africa. Qualitative interviews were conducted, and a thematic analysis undertaken thereafter. These findings are not generalisable but are useful in understanding context and adding an element of triangulation to the literature review.

Specifically, interviews were requested with key stakeholders in the TVET system including local and international HE and GHE entities, international educational institutions, relevant government departments, relevant research and development entities and international industry associations. Of the 25 interviews requested, fifteen were achieved. Of these, ten related to skills demand- that is, those entities which need GH skills, and five were related to skills supply. Three were conducted with multinational stakeholders, and one was undertaken with a supplier of skills in the US.

Thematic analysis revealed a variety of themes: professional skills needed for the HE, and the subject choices, education levels, skills development programmes and public-private partnership (PPP) investments that are needed to ensure appropriate skills development. The professional skills needed are shown in Figure 36 with strong emphasis on manufacturing capability, as well as engineers and technicians. The lack of infrastructure for the hydrogen economy at present necessitates the need for skilled professionals to design and monitor systems centred on hydrogen utilisation[200]. One research institution identified the highly volatile and flammable nature of hydrogen storage and transport and suggests that properly skilled materials handlers and monitors are important for the safe operation of hydrogen infrastructure.

Figure 35- Professional skills required in the HE

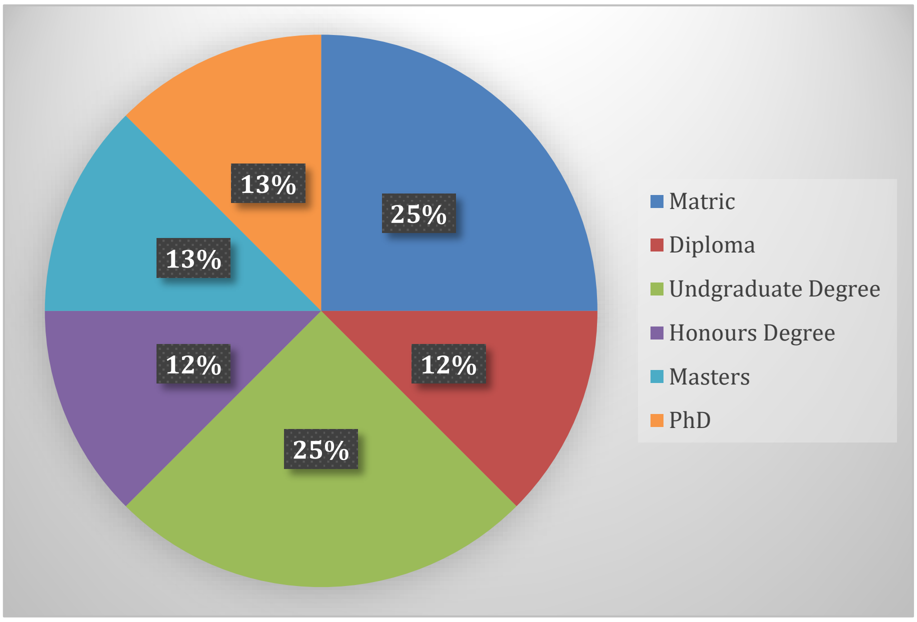


200 Walwyn, D., Bertoldi, A., Gable, C. (2016). Building the hydrogen economy through niche experimentation and digitisation. *Journal of Manufacturing Technology*, 30, 1-17

The transition away from a fossil fuel dominated economy and towards one dominated by hydrogen will have significant economic ramifications. The African Hydrogen Partnership (AHP) notes that the HE will require new technologies, and that the African region lacks skilled individuals who understand the generation of hydrogen and conversion into electricity. One multinational firm noted that HE aware economists will also be significant at the inception of the HE and can help to design systems and approaches to make hydrogen infrastructure and processes economically viable. Another multinational, noting the demand for highly skilled engineers and technicians, also highlighted the need for vocational skills and suggested that it will be critical for the TVET college system to design specific courses to supply skills sooner rather than later.

Skills needed for the HE were largely those that require a diploma, undergraduate degree, or a masters and/or PhD as indicated in Figure 37. Two multinationals specified that its potential professional employees should possess at least a bachelor's degree from a university and stated that South African TVET colleges will need to alter curricula to better equip their graduates and make them employable. While well thought through and quality qualification from a TVET college will be acceptable, higher skilled jobs such as engineers will require bachelor's degrees from universities. Operation of equipment would require at least a matric certificate and further training. The need to include basic fuel cell training at the NDip level was emphasised by a number of respondents. This would not eliminate the need for further training but would facilitate exposure to experienced professionals in the field, enhancing the employability of graduates.

Figure 36- Required education levels in demand for the HE



Source: Interviews, 2021

Respondents felt there is a clear need to design tertiary and vocational courses that will fully equip graduates to enter the hydrogen workspace. The research institutions in particular stressed that there was a need for focused and rigorous training of students. This required the development of curricula that would better prepare students entering the professional world.

All respondents affirm that it is crucial for TVET curricula and quality graduate development that those seeking employment in the HE, even at the artisanal level, to have matriculated in mathematics and physical (preferably chemistry) science. However, some respondents pointed out the shortage of high-level teaching skills in STEM subjects which is a challenge across the education system in South Africa.

As it stands, there are no plans by the TVET college system to develop courses that are specific to the HE. There are, however, existing programmes offered in the TVET college system in engineering and related trades which are aligned to skills needed by manufacturing industries in general, with applicability to the HE. Some respondents felt that the addition of a requirement to complete a trade test would provide an integrated summative assessment for an artisan qualification for the HE.

From the demand perspective, at present, several South African universities offer courses that are well designed to equip students with the knowledge and skills that are required for HE jobs although further investment in tertiary institutions by the public sector would promote the expansion of these courses to allow for a greater number of potential students and employable graduates. However, the TVET system is not yet equipped to provide the sort of vocational skills at a scale that the HE will require. The need to increase the number of research grants was viewed as essential for the tertiary education sector- this was confirmed by international respondents. Investments in infrastructure such as laboratories and associated lab equipment are increasingly identified by universities in the US for example, as a necessity resulting from increased interest and participation in hydrogen related courses. Locally, the DSI noted the need for more investment by the public sector and continues to fund postgraduate students at institutions of higher learning, with the goal of reaching one hundred PhD graduates by the year 2030.

As issues pertaining to clean energy and green economies become increasingly politicised, securing funding for such projects becomes more difficult. Investment from the private sector therefore becomes crucial. Respondents identified the need for investments and projects spanning multiple years to promote the successful development and transfer of skills at all levels. In this regard, the Bambili Advisory Group has collaborated with the University of Pretoria to support the DSI's implementation of the Cabinet approved HySA programme that will span fifteen years. The AHP also stressed the importance of collaboration with the private sector, noting that such partnerships were crucial in developing a "green energy" mind-set amongst the public. The importance of internships cannot be overstated, according to international and local respondents. This is a private sector responsibility, as they alone can provide more internship opportunities.

Annex 8- Sample of international hydrogen economy and fuel cell courses available

Table 39- International (English language) online courses in HE

Canada			
Institution	**Name of Course**	**Focus of Course**	**Website address**
Canadore College	Hydrogen Technician training course	Hydrogen fuel cell systems and technologies.	https://www.canadorecollege.ca/programs/part-time/hydrogen-technician
Compliance Training Online	OSHA Hydrogen Fuel Cell Safety	Hydrogen fuel cells.	https://www.compliancetrainingonline.com/hydrogen_fuelcell_safety.cfm
Canada Safety Training Centre	Hydrogen Sulphide (H2S) Awareness	Hydrogen Sulphide (H2S).	https://www.canadasafetytraining.com/ProductDetails.aspx?ProductID=226
Ontario Petroleum Institute	H2S Alive training	Hydrogen Sulphide (H2S).	https://www.ontariopetroleuminstitute.com/resources-training/training/
Conestoga College	Hydro, Fuel Cell and Biofuel Renewable Energy Concepts and Practices TECH1325	Hydrogen fuel cells.	https://www.conestogac.on.ca/fulltime/renewable-energy-techniques/courses-no-intake?id=11833

Australia			
Institution	**Name of course**	**Focus of course**	**website**
Informa Connect	Live Online Training Course: Hydrogen Industry Fundamentals	The hydrogen industry.	https://www.informa.com.au/event/training/energy-utilities-training/hydrogen-industry-fundamentals/
University of Technology Sydney	Hydrogen Energy Program	Hydrogen energy.	https://www.uts.edu.au/about/faculty-engineering-and-information-technology/civil-and-environmental-engineering/cgt-hydrogen
Smart Energy Council	Hydrogen Australia Webinars	The hydrogen industry.	https://www.smartenergy.org.au/hydrogen-australia-webinars

USA			
Institution	**Name of Course**	**Focus of course**	**Website**
Renewable Energy Institute	Hydrogen Energy Expert Certificate	Hydrogen energy.	https://theect.org/hydrogen-energy-expert-certificate-distance-learning-online/
AIChe Academy	Introduction to Hydrogen Fuel Cell Vehicles for Incident Response	Fuel Cell Electric Vehicles (FCEVs).	https://www.aiche.org/academy/courses/ela261/introduction-hydrogen-fuel-cell-vehicles-incident-response
Udemy	Hydrogen Powered Fuel Cell Electric Vehicle course.	FCEVs.	https://www.udemy.com/course/hydrogen-powered-fuel-cell-electric-vehicle/
Udemy	Green Hydrogen Fundamentals: A Renewable Energy Course	Hydrogen economy fundamentals.	https://www.udemy.com/course/green-hydrogen-fundamentals-a-renewable-energy-course/
Class Central	Hydrogen as an Energy Vector	Hydrogen energy.	https://www.classcentral.com/course/emma-hydrogen-as-energy-vector-19653

EU			
Institution	**Name of course**	**Focus of course**	**website**

European Energy Centre	Hydrogen Energy Course	Hydrogen Energy.	https://www.renewableinstitute.org/training/hydrogen-energy-course/
HY Professionals	Fuel Cell Technology	Hydrogen fuel cells.	https://www.h2euro.org/hyprofessionals/courses/
European Energy Centre	Electric Vehicles Course	FCEVs.	https://www.renewableinstitute.org/training/electric-vehicles-course/
Pure Energy Centre	Hydrogen Technologies Training Course	Hydrogen Technology.	https://pureenergycentre.com/hydrogen-technologies-training-course/

Additional institutions in the EU offering hydrogen and fuel cell related courses can be found here Training programmes | FCHObservatory and in New York here https://cem-nwu.co.za/index.php/introduction-to-green-economy-for-south-africa/

Annex-9- Selection of hydrogen application targets (2019)[201]

Table 40- Hydrogen Application targets by selected countries

Nation	Targets
Spain	• 500 FCEVs and 20 HRS by 2020
Belgium	• 22 HRS by 2020
Finland	• 21 HRS by 2020
United Kingdom	• 65 HRS by 2020
France	• 5 000 FECVs by 2023 and 20 000-50 000 by 2028 • 200 FC trucks by 2023 and 800-2 000 by 2028 • 100 HRS by 2023 and 400-1 000 by 2028 • 10% decarbonised H2 use in industry by 2023 and 20-40% by 2028
Japan	• 200 000 FCEVs by 2025 and 800 000 by 2030 • 1 200 FC buses by 2030 • 10 000 FC forklifts by 2030 • 320 HRS by 2025 and 900 by 2030 • 5.3 million cumulative sales of Micro Combined Heat and Power (micro-CHP) FC units by 2030
South Korea	• 80 000 FC taxis by 2040 • 4 000 FC buses by 2040 • 3 000 FC trucks by 2040 • 81 000 FCEVs by 2022 and 2.9 million by 2040 (plus 3.3 million exported) • 310 HRS by 2022 and 1 200 by 2040 • 1.5 GW of capacity by 2022 15 GW of combined production (7 GW exports, 8 GW domestic) by 2040 • 50 MW of micro-CHP FCs by 2022 and 2.1 GW by 2040
The Netherlands	• 15 000 FCEVs, 3 000 FC heavy-duty vehicles and 50 HRS by 2025 and 300 000 FCEVs in 2030 • 500-800 MW of installed electrolyser capacity by 2025 and 3-4 GW in 2030
Germany	• 100 HRS by 2020 and 400 by 2025

[201] IEA. Hydrogen

Annex 10- Acronyms

Acronym	Full term
4IR	Fourth Industrial Revolution
AHP	African Hydrogen Partnership
APU	Auxiliary Power Units
ASEA/MISI	American Solar Energy Association and Management Information Services, Inc
ATR	Auto Thermal Reforming
BEV	Battery Electric Vehicle
BIM	Building Information Modelling
CAGR	Compound Annual Growth Rate
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CE	Computer Engineering
Cedefop	European Centre for the Development of Vocational Training
CEM10	10th Clean Energy Ministerial
CET	Community Education and Training
CFCs	Chlorofluorocarbons
CHP	Combined Heat and Power
CSIR	Council for Scientific and Industrial Research
CSP	Concentrating Solar Power
DEA	Department of Environmental Affairs
DERO	Desired Emission Reduction Outcomes
DHE	Department of Higher Education
DHET	Department of Higher Education and Training

Acronym	Full term
DMFC	Direct Methanol Fuel Cells
DoD	Department of Defence
DOE	Department of Energy
EC	European Commission
EE	Electrical Engineering
EEC	Energy, Environment and Climate
EU	European Union
EWSETA	Energy and Water Sector Education and Training Authority
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicle
FET	Further Education and Training
GDP	Gross Domestic Product
GE	Green Economy
GED	General Education Diploma
GH	Green Hydrogen
GHE	Green Hydrogen Economy
GHG	Greenhouse Gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatt
HE	Hydrogen Economy
HEI	Higher Education Institution
HLHSRSA	High-Level Hydrogen Society Roadmap for South Africa
HRS	Hydrogen Refuelling Station
HSD	High School Diploma
HVAC	Heating, Ventilation, and Air Conditioning

Acronym	Full term
HySA	Hydrogen South Africa
ICT	Information and Communications Technology
IEA	International Energy Agency
IEA	International Energy Association
IEP	Integrated Electricity Plan
ILO	International Labour Organisation
INDC	Intended Nationally Determined Contribution
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
JET	Just Energy Transition
JLT	Just Labour Transition
JT	Just Transition
JTM	Just Transition Mechanism
LH	Liquid Hydrogen
LOHC	Liquid Organic Hydrogen Carriers
MAHP	Major Accident Hazardous Pipelines
MCFC	Molten Carbonate Fuel Cells
ME	Mechanical Engineering
MEA	Membrane Electrode Assembly
MENA	Middle East and North Africa
micro-CHP	Micro Combined Heat and Power
MINTEK	South African Minerals Research Council
MTSF	Medium Term Strategic Framework

Acronym	Full term
MW	Megawatt
NCCAS	National Climate Change Adaptation Strategy
NCCRP	National Climate Change Response Policy
NCS	National Climate Strategy
NCV	National Certificate Vocational
NDC	Nationally Determined Contribution
NDP	National Development Plan
NESDPF	National Environment Skills Development Planning Forum
NEVA	National Employment Vulnerability Assessment
NGO	Non-Government Organisation
NGP	National Growth Plan
NOC	National Oil Company
NQF	National Qualifications Framework
NSC	National Senior Certificate
NSDS	National Skills Development Strategy
O&G	Oil & Gas
O&M	Operation & Maintenance
OEC	Observatory of Economic Complexity
OFO	Organising Framework for Occupations
OECD	Organisation for Economic Co-operation and Development
OJT	On the Job Training
OTEC	Ocean Thermal Energy Conversion
P2X	Power-to-X conversion
PAFC	Phosphoric Acid Fuel Cells
PEM	Polymer Electrolyte Membrane

Acronym	Full term
PPP	Public Private Partnership
PSET	Post School Education and Training
PV	Photo Voltaic
QCTO	Quality Council for Trades and Occupations
R & D	Research & Development
RD&D	Research, Development & Deployment
RDI	Research, Development & Innovation
RE	Renewable Energy
REIPPP	Renewable Energy Independent Power Producer Programme
RIS	Reinvigorated Industrial Strategy
RPL	Recognition of Prior Learning
SANEDI	South African National Energy Development Institute
SAQA	South African Qualifications Authority
SDG	Sustainable Development Goal
SETA	Sector Education and Training Authority
SJRP	Sector Jobs Resilience Plans
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolyser Cell
SOFC	Solid Oxide Fuel Cells
SSP	Sector Skills Plan
STEM	Science, Technology, Engineering and Mathematics
TS	Technical Supervisor
TSAM	Toyota South Africa Motors
TVET	Technical and Vocational Education and Training
UCT	University of Cape Town

Acronym	Full term
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNIPCC	United Nations Intergovernmental Panel on Climate Change,
US	United States
VET	Vocational Education and Training
WEF	World Economic Forum
WRI	World Resources Institute
WSP	Workplace Skills Plans

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