PtX Business Opportunities in South Africa

Renewable Hydrogen Market Potential and Value Chain Analysis

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ACRONYMS

BoP	Balance of Plant
CO_2	Carbon Dioxide
COC	Centres of Competence
DHET	Higher Education and Training
DSI	Department of Science and Innovation
DST	Department of Science and Technology
EIA	Environmental Impact Assessment
EPC	Engineering, Procurement, and Construction
FATF	Financial Action Task Force
FC	Fuel Cell
FCT	Fuel Cell Technology
FT	Fischer-Tropsch
GH_2	Green Hydrogen
GHCS	Green Hydrogen Commercialisation Strategy
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GW	Gigawatt
HFC	Hydrogen Fuel Cell
HSRM	Hydrogen Society Roadmap
HYSA	National Hydrogen Strategy South Africa
H_2	Hydrogen
IPPs	Independent Power Producers
KTPA	Kilotonnes per annum
kW	Kilowatt
kWh	Kilowatt Hour
LOHC	Liquid Organic Hydrogen Carrier
MEA	Membrane Electrode Assembly
NWU	North-West University
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
PGM	Platinum Group Metals
PtX	Power-to-X
PV	Solar Photovoltaic
R&D	Research and Development
RDI	Research, Development and Innovation
RE	Renewable Energy
REIPPP	Renewable Energy Independent Power Producer Procurement Programme
SAF	Sustainable Aviation Fuel
SMEs	Small and Medium-Sized Enterprises
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TVET	Technical Vocational Education and Training
UCT	University of Cape Town
UK	United Kingdom
US	United States
UWC	University of the Western Cape
WP	Work Package

EXECUTIVE SUMMARY

South Africa, amongst other countries like Australia, Chile and Morocco, is classified as a potential net exporter of Green Hydrogen (GH_2) and its derivative products (collectively known as power-to-X or PtX) thanks to its abundant and cost-competitive solar and wind resources, land availability, significant resources of platinum group metals (PGM) used in producing electrolysers and hydrogen (H_2) fuel cells, historical experience in industrial-scale Fischer-Tropsch (FT) processing used to produce power fuels, as well as an existing port infrastructure and prime shipping access to the rapidly growing international GH_2 markets.

The government has recognised the potential future opportunities in PtX and, since 2007, has developed and implemented different programmes to support the vision of growing a GH_2 industry that can enhance economic development and reduce greenhouse gas (GHG) emissions. It is against this background that GIZ is implementing the H2.SA project ("Promoting a Green Hydrogen Economy in South Africa") in partnership with the Presidency of South Africa, to support stakeholders in the public and private sector to realise the potential of a sustainable GH_2 economy for South Africa. H2.SA is supporting South Africa to leverage its PtX-related competitive advantages by funding several studies and projects, including the project entitled "Renewable H_2 market potential and value chain analysis", carried out by GFA Consulting Group together with DNA Economics.

This report was developed as one of the deliverables under the abovementioned project, and is titled "Business Opportunities for South African Companies". Its purpose is to assess the most attractive business opportunities across the GH_2 value chain and formulate market entry recommendations for local enterprises. The intent is to prepare those companies for the emerging GH_2 market and equip them to face future challenges related to technologies, demand, logistics, expertise, and regulation, among others. The report includes an analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT) for the identified business opportunities along the value chain and is set against the backdrop of the emerging national and international PtX market. The study also lays out the knowledge and skills required for the emerging GH_2 market and suggests what measures would be required to support companies and research institutes to participate in those future markets.

The analysis in this study builds on the results of previous work packages (WPs) in the broader project in which it is located. Business opportunities were identified and described for each subsegment of the value chain, and the "PtX market potential" estimated as part of the project was used to quantify opportunities in relevant segments for five applications: ammonia for export, ammonia for green fertiliser production, green steel production, methanol for bunker fuels, and sustainable aviation fuel (SAF).

The following priority business opportunities have been identified for further exploration in South Africa:

- Expansion of PGM mining;
- Manufacture of electrolysers and fuel cells;
- Renewable energy (RE) infrastructure development and operation;
- Energy storage to ensure continuous operations during non-/low availability of renewables;
- Desalination plant development;
- GH_2 production;
- GH_2 beneficiation;
- GH_2 storage;

- GH_2/PtX transportation, handling and retail; and
- Cross-cutting opportunities, including advisory and support functions, financing and research and development.

Beyond these areas of opportunity, there are a wide range of other technologies and services that are needed to support the construction and operation of the GH_2 value chain. The production of GH_2 and its downstream products requires, among other things, earthworks, facilities construction, electrical and automation systems, piping, drainage, waste heat recovery systems, compressed gas handling, storage and handling of H_2 and its downstream products, as well as project planning and project management.

During operation, the plants also require maintenance and servicing. These products and services are already well established in South Africa, given its sound industrial base, and will be likely to grow as the GH_2 industry grows. However, this area is not explored in further detail in this report, as the focus is on the opportunities outlined in the priority list earlier.

Based on the projections undertaken by the project, the table below presents estimates of the market potential in various segments of the value chain, including PGM, RE, and electrolysers, all of which is based on the demand for GH_2 and its derivative products.

Table 1: Projected market potential along the PtX value chain in South Africa

NO	ITEM	2030	2040	2050
1	Total GH_2/PtX demand (million tonnes, Mt H_2 equivalent)	1.2	1.8	2.9
2	Electrolyser capacity requirements (GW)	10.9	16.2	24.9
3	RE capacity requirements (GW)	21.8	32.5	48.9
4	Iridium (tonnes)	10.9	11.4	9.8
5	Platinum (tonnes)	4.0	3.8	2.4

Stakeholders and investors across the GH_2 value chain in South Africa are already engaged in the growing GH_2 economy, despite the GH_2 market still being uncertain and characterised by both high complexity and fragmentation in unregulated domestic and international markets. Given the current state of the market, there are some risks to businesses seeking to invest early. Fully integrated solutions and industrial-scale roll-out are still a way off. This is why both the supply and demand of GH_2 product(s) needs to be stimulated. To do so requires support such as blended finance and a range of de-risking instruments. Without this support, market ramp-up remains challenging.

There will be significant demand for various skillsets and training, including for technicians, engineers, and academic professionals of various backgrounds. The GH_2 sector thus represents a substantial opportunity for the creation of new jobs and skillsets. Establishing opportunities across the various value chain segments can potentially act as a powerful engine of growth and development – creating decent job opportunities while driving significant capital accumulation and enhancing economic productivity. As South Africa is transitioning the economy towards GH_2, it will need to invest to provide for adequate skilling and upskilling to support the GH_2 roll-out.

Recommendations are grouped into short-, and medium-term actions to encourage industry players and research institutes to take part in the future GH_2 markets across the value chain, as shown in the table below.

Table 2: Short- to medium-term recommendations

RECOMMENDATIONS	SHORT-TERM	MEDIUM-TERM
Support planned projects and initiatives	• Leverage and market the unique South African technological strengths across the value chain. • Proactively promote the advancement of initiatives that are already in preparation as pilot projects.	• Provide proactive support to increase new opportunities arising across the various sub-chains. • Support industry players and research institutions to engage in the advancement of activities beyond Research & Development and the promotion of their own innovations.
Support to attain cost competitiveness	• Continue to engage with the private sector to secure technical and financial support for GH_2 market development. • Foster a structured approach to identify the best opportunities for funding to mitigate risks for those involved in the value chain via concessional and blended finance.	• Introduce national and industry commitments to be enforced via final product requirements. • Invest in the development of masterplans with specific implementation targets for the various end use sectors. • Introduce supportive policies and create a solid regulatory framework to encourage cost competitiveness (subsidies, taxes, etc.). • Foster multilateral and bilateral sector commitments by importing countries to allow South African enterprises to take a fair share of the long-term supply agreements.
Support entrepreneurship for GH_2 market entry for Small- and Medium-Sized Enterprises (SMEs)	• Design and implement a broader support structure beyond private-sector-led initiatives to develop business opportunities for SMEs. • Consider introduction of dedicated incubation programmes tailored to specific GH_2 value chain segments.	• Develop financing schemes tailored to the specific needs of entrepreneurs in the GH_2 sector (venture capital funds, angel investor networks). • Develop a framework to integrate SMEs (with defined targets) in planned projects and to outline the roles, responsibilities, and contributions of those to be involved.
Promote partnerships and networks	• Invest further in the promotion of partnerships between industry stakeholders, universities, and public institutions. • Ensure continued government commitment to partnerships. • Scale up collaborations globally and locally across the supply chain.	• Foster networks and communities of entrepreneurs in the GH_2 sectors. • Encourage the formation of industry associations, networking events, and knowledge sharing platforms. These platforms can provide entrepreneurs with opportunities to connect, collaborate, and learn from each other. • Engage proactively to support international collaborations and partnerships to promote technology transfer, market access, and knowledge sharing.

RECOMMENDATIONS	SHORT-TERM	MEDIUM-TERM
Promote skills development in GH_2	• Introduce apprenticeship programmes to equip youth with skills. • Build in feedback mechanisms, industry consultations, and collaboration forums. • Collaborate with international partners for knowledge exchange and benchmarking.	• Engage with private sector companies operating in the PtX sector to secure not only financial support for the skills development programmes, but also their long-term commitment to work closely and align on communicating GH_2 skills requirements. • Develop mechanisms to ensure the quality of skills development programmes; consider establishing industry standards for skills assessment and certification.

1 INTRODUCTION

Green Hydrogen (GH_2) and its derivatives, referred to collectively as Power-to-X (PtX), have gained attention among the international community, thanks to their ability to defossilise the so-called "hard-to-abate" sectors such as heavy-duty long-distance transport (comprising long-haul road transport, maritime shipping, and aviation) and industrial processes (steel, cement, ammonia, and chemicals). However, some countries will not be able to produce enough PtX to meet their needs due to limited availability of domestic renewable energy (RE) resources, land, water, and/or other input requirements. Based on their projected demand and production profiles, countries can be classified as "net-exporter", "self-sufficient" and "net-importer" (IRENA 2022).

South Africa, amongst other countries like Australia, Chile and Morocco, is classified as a potential net exporter of PtX because of its abundant and cost-competitive solar and wind resources, land availability, significant resources of platinum group metals (PGMs) used in producing electrolysers and in GH_2/PtX fuel cells, historical experience in the industrial-scale Fischer-Tropsch (FT) process used to produce power fuels, as well as an existing port infrastructure and prime shipping access to the rapidly growing international GH_2/PtX markets.

The country has recognised the potential future opportunities in PtX and has developed and implemented a number of programmes and plans since 2007, including the National Hydrogen Strategy South Africa (HySA) programme, the Hydrogen Society Roadmap (HSRM) released in February 2022, and the Green Hydrogen Commercialisation Strategy (GHCS) approved by the Cabinet in October 2023.

H2.SA, implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, supports South Africa to leverage its PtX-related competitive advantages by funding several studies and projects, including the project entitled "Renewable H_2 market potential and value chain analysis", commissioned by GIZ and implemented by GFA Consulting Group together with DNA Economics. The objective of the study is to improve the conditions for companies to participate in a South African H_2 economy and strengthen the technical capabilities of relevant stakeholders from politics, business, research, and civil society.

Activities in this study are grouped into three Work Packages (WP):

- WP1: Assessment of the PtX market potential of South Africa.
- WP2: Analysis of South Africa's PtX value chains and business opportunities.
- WP3: Job potential analysis along the PtX value chains.

WP2 aims to identify, describe, and analyse the value chains and the specific supply chains of PtX products in South Africa and, based on this analysis, to formulate market participation recommendations for South African companies. WP2 comprises five activities, including one on "Business Opportunities for South African companies" (see Figure 1), which is the subject of this report.

Chapter 2 of this report outlines the objectives of the study and the methodology used to conduct the analysis, while Chapter 3 presents and discusses those market opportunities that are considered as having high potential. Chapter 4 discusses the expertise and skills required per market segment for the high potential opportunities of the value chain, and Chapter 5 provides recommendations on required measures to support companies and research institutes to take part in the emerging GH_2 economy. Finally, Chapter 6 presents a set of conclusions.

2 OBJECTIVE AND METHODOLOGY

The objective of the "Business opportunities for South African companies" study is to assess the most attractive business opportunities across the GH_2 value chain and formulate market entry recommendations for local companies to prepare them for engagement in the emerging GH_2 market and increase robustness to future challenges related to demand, logistics, expertise, regulation, etc.

The analysis builds on results from other work packages in the broader study in which this activity is located, (Figure 1).

WP1	PtX market potential in SA	WP2	PtX value chain and business opportunities	WP3	Job potential analysis
1A: PtX competitiveness analysis	• PtX vs. fossil-fuel alternatives • PtX vs. non fossil-fuel alternatives (e.g., batteries, biomass)	**2A: Stakeholder mapping**	• Database of actors across the PtX value and supply chains	**3A: Job potential**	• Estimates of jobs opportunities • Capacity building needs (public and private)
		2B: Project mapping	• Database of projects/initiatives (existing/announced/planned)		
1B: Dynamic LCOX tool	• Future PtX production costs • Evolution of price gap between PtX and their alternative	**2C: Value / supply chains analysis**	• Description of PtX value and supply chains + their maturity • Strengths, weaknesses, gaps	**3B: Re-skilling needs**	• Potentials for re-skilling the SA work force (WF) • Specific knowledge to be built • Most suitable economic sectors for the re-skilled WF
1C: PtX market potential in SA	• Market quantity per each selected PtX application • Market value per each selected PtX application	**2D: Business opportunities for SA enterprises**	• Best business opportunities • Investments/expertise required • Required support & measures		

Figure 1: Work packages of the study "Renewable H_2 market assessment and value chain analysis"

In accordance with the Terms of Reference, this current analysis covers the following tasks:

- Identification of the most promising business opportunities for South African companies within the emerging PtX market, delivering a "compass" for partners and other relevant stakeholders to support them in deciding where they should focus their activities;
- Presentation of a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the identified business opportunities for South African companies, considering the emerging national and international PtX market;
- Cataloguing of knowledge and skills required by the emerging GH_2 market and the companies that could provide the necessary products and services;
- Identification and implementation of measures to support companies and research organisations to take part in those future markets; and
- Formulation of recommendations to relevant government institutions.

Data and information used to analyse PtX business opportunities in South Africa were obtained from the following sources:

- Literature review used public literature to gather detail on business opportunities and skills requirements in South Africa.

- **Interviews with stakeholders** included those at companies, project developers, research institutions, and public institutions. The interviews served to obtain an understanding of their overall objectives and planned and existing activities and level of maturity of their products and services. The inputs obtained through the interviews helped to provide a deeper understanding of promising opportunities across the value chain segments. Internet searches were used to highlight relevant stakeholders for consultation.

- **Stakeholder and project mapping** (conducted as part of WP 2A&B) provided insights into activities of local and international businesses in the South African PtX value chain. The mapping identified over 300 domestic and international companies, and about 50 PtX related projects/initiatives, spanning several of the value chain components.

- **Value and supply chains analysis** (conducted as part of WP 2C) provided a deep dive into the up-, mid- and downstream value chain segments of the supply chain (Figure 2), providing a more detailed analysis of current and planned activities. The assessment also included a comprehensive analysis of the GH_2 value chain in terms of SWOT and potential business models that could work in different value chain segments.

- **PtX competitiveness analysis** (conducted as part of WP 1A provided guidance on which PtX products and applications are likely to become attractive over time in comparison with their fossil-fuel-based alternatives. The analysis provided estimations of the cost gaps for five PtX applications: ammonia for export and for fertiliser, green steel, methanol and sustainable aviation fuel (SAF).

- **PtX market potential analysis** (conducted as part of WP 1C) estimated the annual PtX market size and market value for the same applications as in WP 1A for three time horizons: 2030, 2040 and 2050, and for three scenarios: realistic, optimistic, and conservative. The realistic scenario (that taken forward in this current document) captured the most likely future based on the available information. The optimistic scenario provided an indication of what the outcome could be if conditions turn out to be more favourable than expected, while the conservative scenario was based on an assumption that conditions may turn out less favourable than expected.

Business opportunities were identified and described for each subsegment of the value chain, and the "PtX market potential" estimated as part of WP 1C was used to quantify opportunities in relevant segments (where possible) for five applications: ammonia for export, ammonia for green fertiliser production, green steel production, methanol for bunker fuels, and SAF. The projected market potential for the above five applications together with the GH_2 equivalent required in each application are presented in the table below.

Table 3: Estimated PtX market potential for five analysed products

PRODUCT/APPLICATION	UNIT	2030	2040	2050
Green ammonia for export				
Annual market potential	KTPA	5,514	7,219	8,925
Equivalent GH_2 requirements[1]	KTPA	973	1,274	1,575
Green fertiliser (ammonia)				
Annual market potential	KTPA	307	1,110	1,733
Equivalent GH_2 requirements	KTPA	55	197	308
Green steel (GH_2)				
Annual market potential	KTPA	106	106	212
Equivalent GH_2 requirements	KTPA	106	106	212
Aviation (SAF or e-kerosene)[2]				
Annual market potential	KTPA	6	170	1,100
Equivalent GH_2 requirements	KTPA	3	74	478
Bunker fuel (methanol)[3]				
Annual market potential	KTPA	174	810	1,511
Equivalent GH_2 requirements	KTPA	42	194	362

[1] Conversion from green ammonia to GH_2 was done using the factor 0.176471 tonnes GH_2/tonnes ammonia.
[2] Conversion from SAF to GH_2 was done using the factor of 0.435 tonnes GH_2/tonnes SAF.
[3] Conversion from green methanol to GH_2 was done using the factor 0.1875 tonnes GH_2/tonnes methanol.

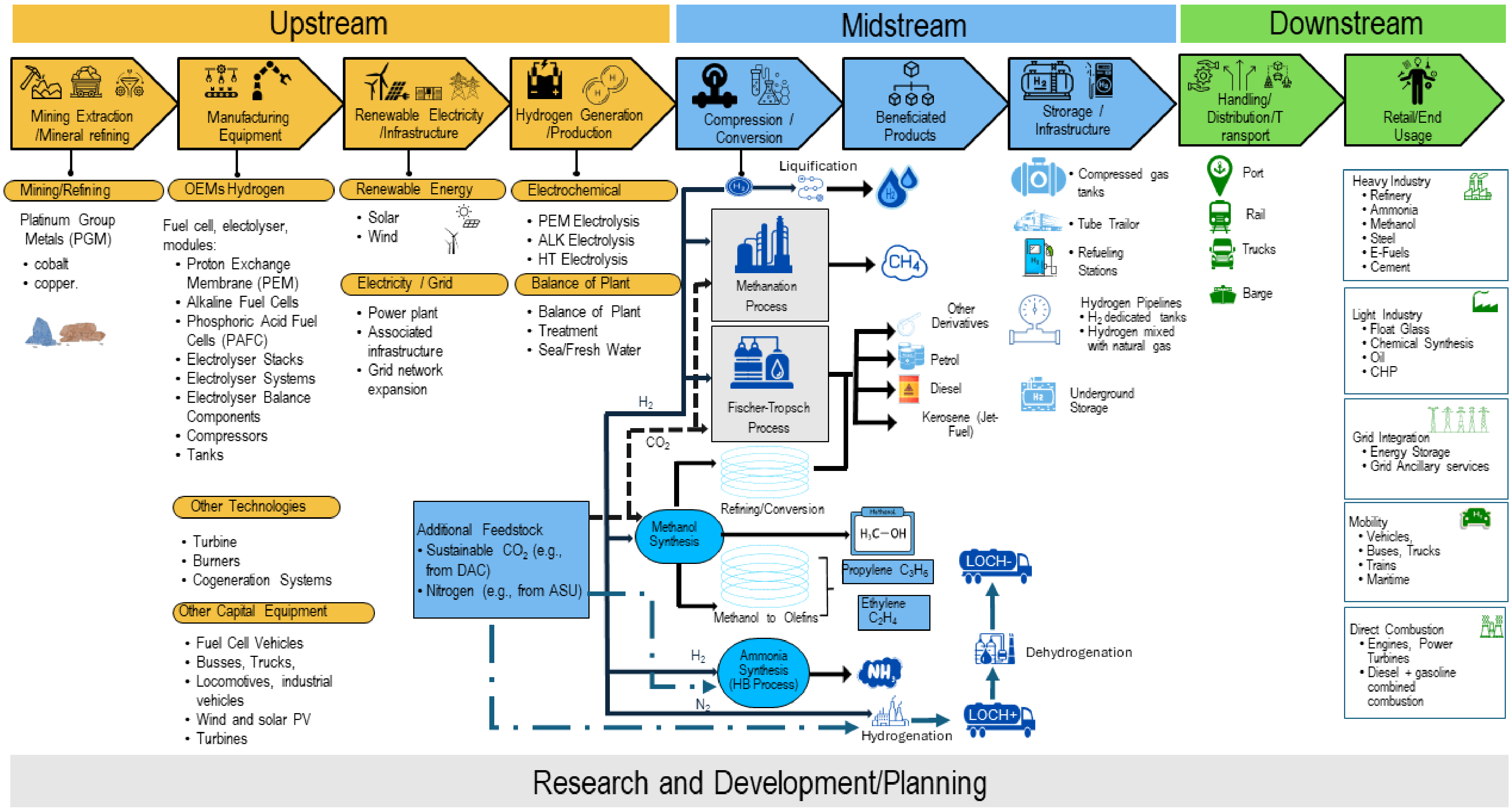


Figure 2: Illustration of the South African PtX value chain

3 BUSINESS OPPORTUNITIES

Production of GH_2 and its derivatives to meet the expected local and export market demands will require an extensive list of technologies, products, equipment, infrastructure, and auxiliary services. Within this context, the following priority business opportunities have been identified for further exploration in South Africa:

- Expansion of PGM mining;
- Manufacture of electrolysers and fuel cells;
- Renewable energy infrastructure development and operation;
- Energy storage to ensure continuous operations during non-/low availability of renewables;
- Desalination plant development;
- GH_2 production;
- GH_2 beneficiation;
- GH_2/PtX storage, transportation and handling;
- GH_2/PtX retail; and
- Cross-cutting opportunities, e.g., advisory, financing, and research and development (R&D).

The opportunities can notionally be grouped as upstream, midstream, and downstream opportunities, in line with the value chain diagram shown in Figure 2. These opportunities are described in the sections that follow, along with a SWOT analysis for each.

3.1 Maturity of the South African PtX value chain segments

Prior to exploring the business opportunities, there is value in providing an overview of the level of maturity of the various PtX value chain segments as illustrated in Figure 3, where products are considered to be mature once Phase 3, the value creation phase, has been reached.

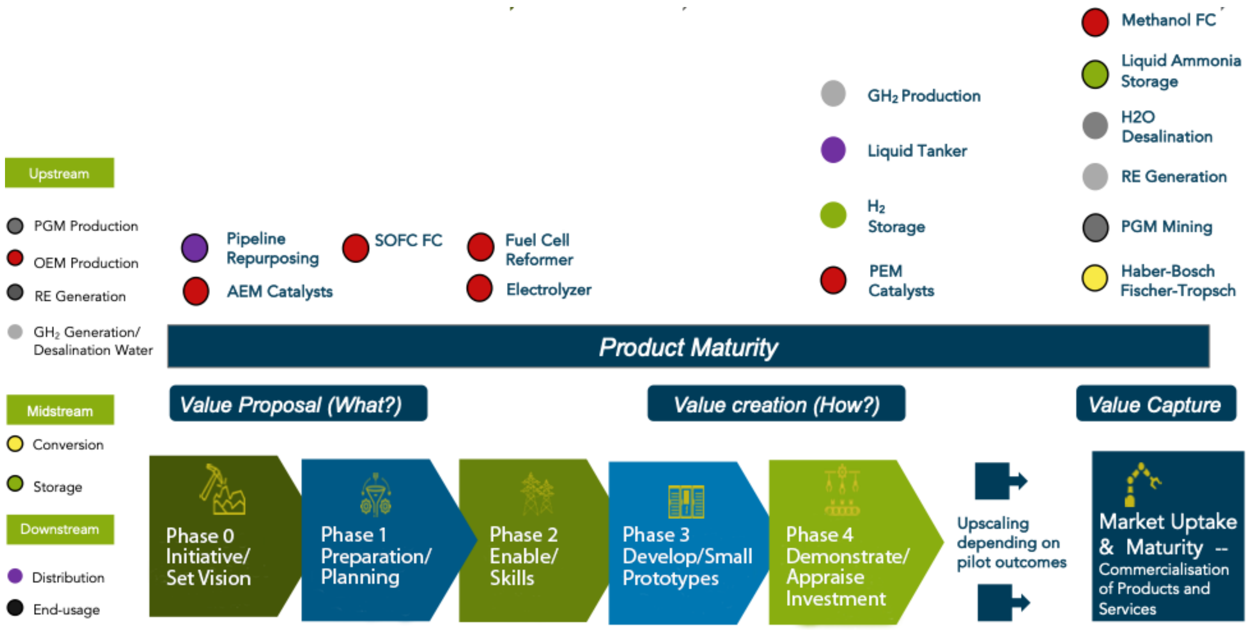


Figure 3: Maturity of various PtX-related business opportunities in South Africa

Source: Adapted from Markets and Markets (2023)

The above figure shows that South Africa has a clear first mover advantage due to the maturity of its GH_2 conversion technologies, notably Sasol's experience in downstream beneficiation of H_2 through its Fischer-Tropsch technology. Sasol's Secunda facility has operated on H_2 that is produced using coal and natural gas for several decades, which provides an opportunity to transition to operations on GH_2, although some investment will be required to retrofit existing infrastructure. It is also well established in ammonia production, using grey H_2, through the Haber-Bosch process.

Similarly, RE generation is mature in South Africa, with those RE companies who are current supplying and operating grid-connected generation infrastructure being readily able to pivot to become active in the GH_2 market. The country's existing PGM mining sector also has potential to engage across the value chain. An example here is Anglo-American who are contributing to developing the downstream GH_2 economy.

Other opportunities, such as investing in manufacturing of original equipment (electrolysers or fuel cells or sub-components thereof), are at early stages, although a few companies have moved beyond exploratory phases and are testing their products in the global market. HyPlat, for example, has invested in manufacturing of catalysts, while CHEM Energy is investing in fuel cell production. However, most business opportunities remain at the early stages.

Beyond these capital-intensive investments, there is a wide range of other technologies and services that are needed to support the construction and operation of the GH_2 value chain. The production of GH_2 and its downstream products requires, among other things, earthworks, facilities construction, electrical and automation systems, piping, drainage, waste heat recovery systems, compressed gas handling, storage and handling of H_2 or its downstream products, as well as project planning and project management. During operation, the plants also require maintenance and servicing. These products and services are already well established in South Africa, given its sound industrial base, and will likely grow as the GH_2 industry grows. These opportunities are not explored in detail further in this report, however, as the focus is on the applications presented earlier.

3.2 Upstream business opportunities

Business opportunities in upstream segments are in mining and extraction of PGMs, OEM such as electrolysers and H_2 fuel cells (HFC), RE production and associated infrastructure, as well as GH_2 production.

For electrolysers and fuel cells, the focus in this study was on polymer electrolyte/proton exchange membrane (PEM) technology, given the country's endowment in PGM (with PEM domination representing a "best case" scenario as it will enable South Africa to add local value to its PGM resource). To estimate the required PEM electrolyser capacities and the corresponding quantity of iridium and platinum that would be required to produce the electrolysers, assuming increased performance and material reduction strategies, the following assumptions were made (IRENA 2020):

- Electrolyser/stack lifetime: 60,000-80,000 hours, increasing to 100,000-120,000 hours in 2050;
- Specific energy consumption: 51.2 kWh/kg H_2 in 2020, improving to 43.8 kWh/kg H_2 in 2050;
- Iridium loading: 1.3 g/kW in 2020, decreasing to 0.4 g/kW in 2050; and
- Platinum loading: 0.5 g/kW in 2020, decreasing to 0.1 g/kW in 2050.

In addition, an electrolyser load factor of 60% and RE plant and capacity factor (hybrid solar and wind) of 50% was assumed. Based on these assumptions together with the project GH_2 requirements for the five analysed applications (see Table 1), the aggregated projected PGM requirements (platinum and iridium) as well as electrolyser and RE capacity requirements between 2030 and 2050 are presented in Figure 4 (more details can be found in Appendix 1).

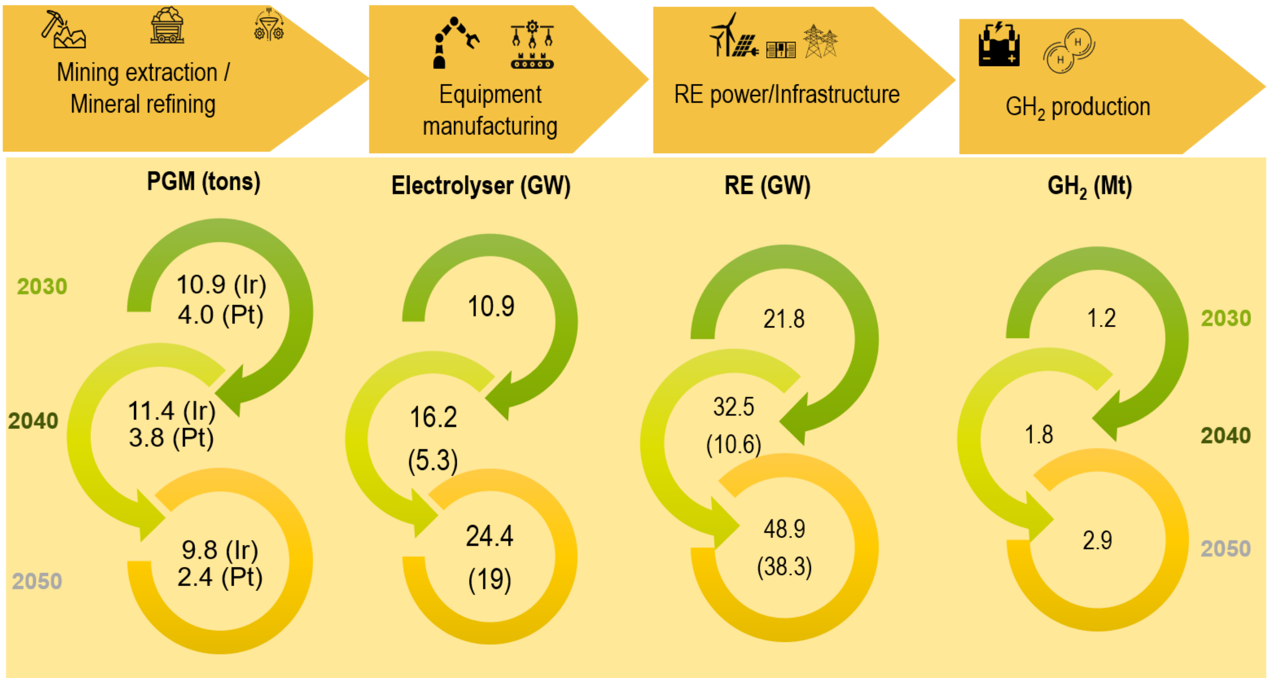


Figure 4: Market potential projections creating opportunities along the value chain for various industries

The above figure shows that total electrolyser capacity of 10.9 GW will be required by 2030, increasing to 24.4 GW in 2050. The renewables sector will need 21.8 GW of capacity as early as 2030, further increasing to 48.9 GW by 2050. This represents a significant roll-out. It is important to mention that for electrolysers and RE, the top figures for 2040 and 2050 represent total installed capacity required for production of GH_2, while the figures in brackets represent the additional capacity that must be built in that year, to account for both growth in demand and end-of-life retirement of equipment.

Further GH_2 applications to those included in WP 1A and 1C can also be identified, based on factors including alignment with national targets, technology/application readiness in South Africa, potential PtX demand, potential for creation and retention, and defossilisation potential. These include:

- HFC powered long-haul trucks, trains or buses;
- Power-to-Power markets, where H_2 is used to generate electricity and where ammonia is used for stationary power generation, partially or completely displacing coal and natural gas in power plants and diesel in off-grid generators; and
- Power-to-Heat, ranging from buildings to industrial heating.

3.2.1 PGM Mining

South Africa holds more than 90% of the global PGM reserves (Garside 2023), and the country typically supplies over 70% of the total global platinum (Material Insight 2023). PGMs are used to produce catalysts in selected electrolyser and fuel cell designs, and increased uptake of these designs would drive the demand for PGMs. The government, through the GHCS, acknowledges the need to develop a dedicated PGM beneficiation strategy, thereby increasing its participation along the value chain to allow the country to leverage value from its PGM resources. Recognising the opportunity, mining companies are being proactive in exploring prospects for growing the GH_2 economy and are already investing across the PtX value chain (details in the WP 2C report).

Based on the findings presented in Figure 4, about 10.9 tonnes of iridium and 4.0 tonnes of platinum will be required to produce 10.9 GW of electrolysers in 2030. The demand is projected to decline to 3.8 tonnes and 1.3 tonnes for iridium and platinum, respectively, in 2040 as electrolysers that will be installed in 2030 will still be in operation in 2040 and so only PGMs for new electrolysers will be required. By 2050, however, annual PGM demand will increase since the electrolysers installed in 2030 will achieve their expected 20-year lifetime and so will need to be replaced in addition to building new capacity. The projected PGM demand in 2050 is 9.8 tonnes for iridium and 2.4 tonnes for platinum. The required iridium and platinum per application for the three time periods (2030, 2040, and 2050) are presented in Figure 5 and Figure 6.

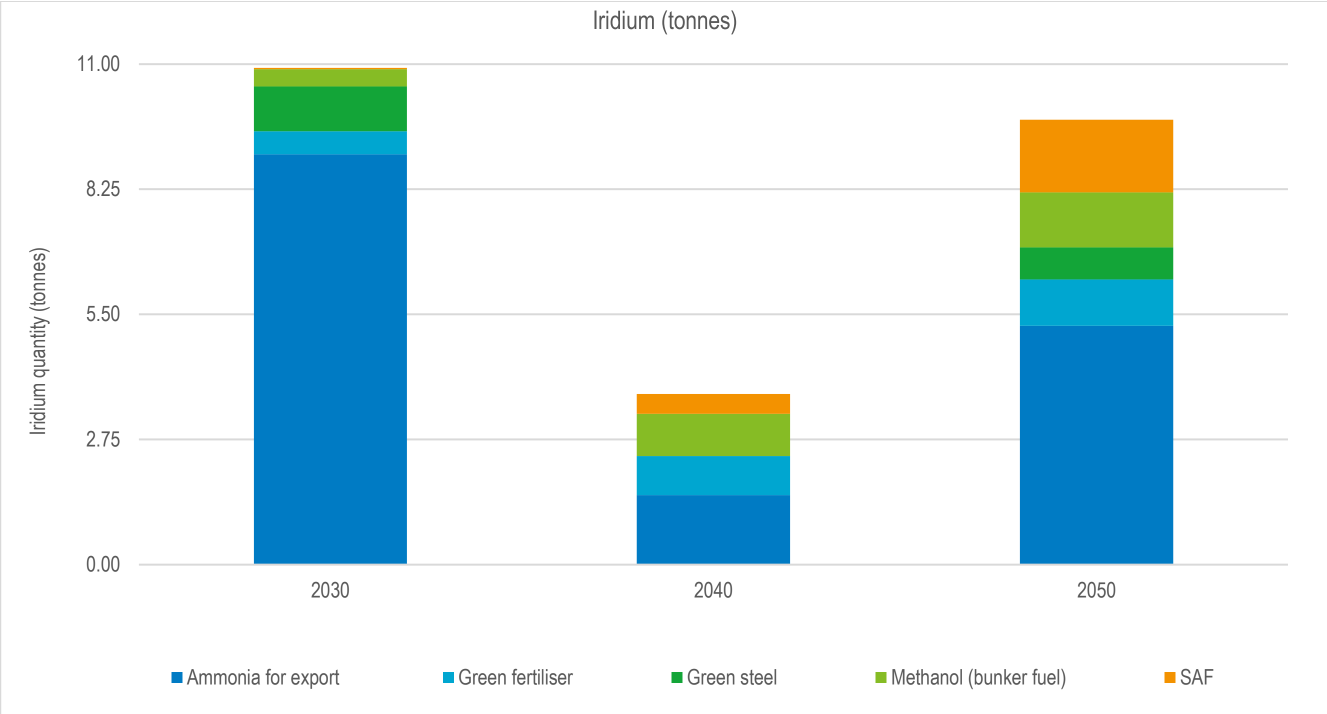


Figure 5: Iridium requirements for electrolyser production

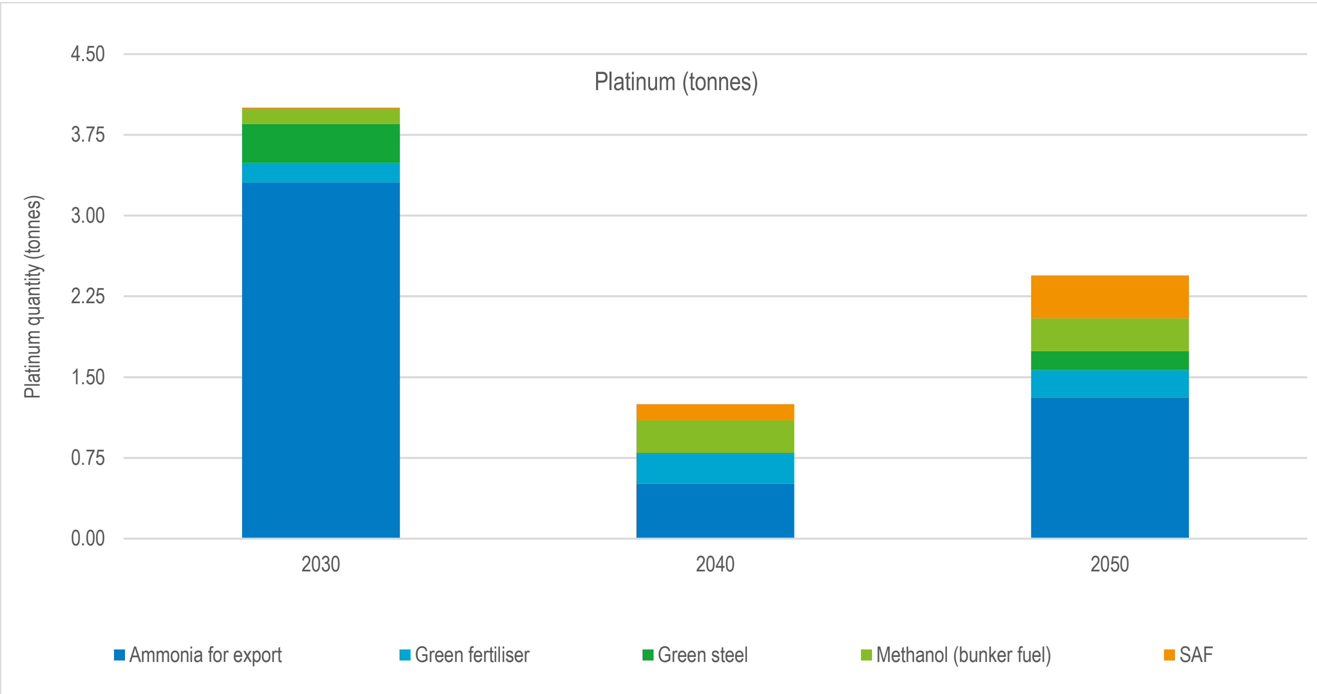


Figure 6: Platinum requirements for electrolyser production

These projected PGM quantities to produce electrolysers provide a range of opportunities for mining houses to continue to grow production. However, it is important to note once again that this growth rate assumes PEM electrolysers (and fuel cells) will dominate the GH_2 industry. In reality, it is recognised that PEM electrolyser and fuel cells will be competing with other technologies, such as alkaline technologies which are already established, as well as solid oxide technologies, which can be operated as both electrolysers and fuel cells.

Apart from supply to the main PGM producing companies operating mines, concentrators, smelters and refineries (i.e., Anglo American Platinum, Impala Platinum, Lonmin Platinum and Norilsk), there are several opportunities for new and existing players, including SMEs, linked to PGM mining (Figure 7).

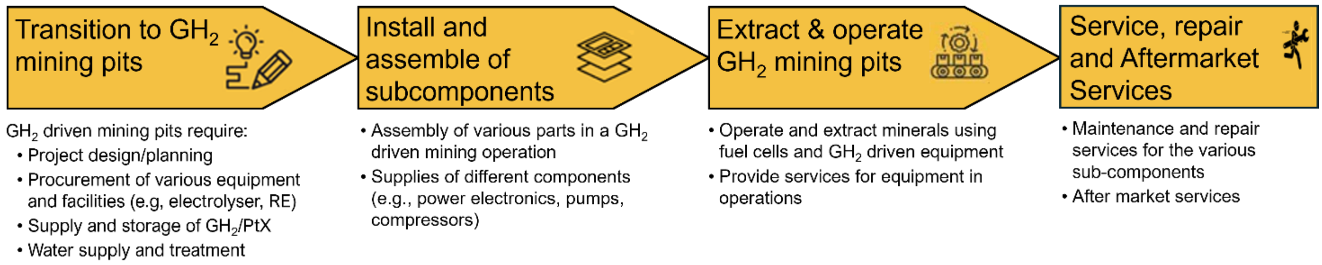


Figure 7: Business opportunities under the PGM sub-chain

Table 4 provides a SWOT analysis for the PGM sector to assist stakeholders in understanding where strengths and opportunities lie, and to highlight potential challenges in market development.

Table 4: SWOT analysis of the PGM Sector in the GH_2 industry

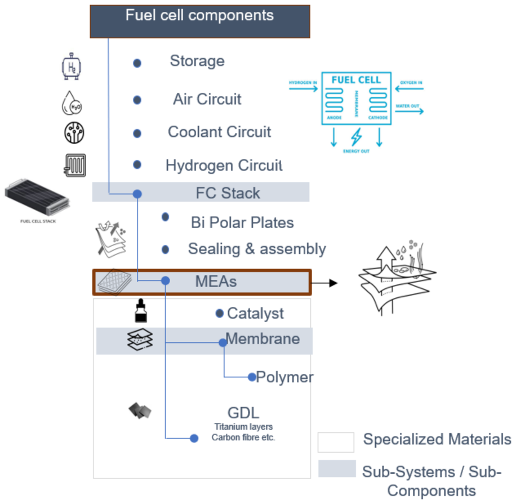
STRENGTHS	WEAKNESSES
• South Africa holds >90% of global PGM reserves. • Technical know-how, skills and experience in PGM mining and beneficiation already exist in the country. • Leading PGM mining companies are active in GH_2-related activities across the whole value chain and can serve as GH_2 industry champions. • Political support for PGM beneficiation exists.	• Required skills may not be available. • Equipment and infrastructure to extract the required tonnages of PGMs may not be available when required.
OPPORTUNITIES	**THREATS**
• Growing global PGM demand as PtX economy grows. • Engagement in other activities of the value chain besides mining (e.g., RE and GH_2 production).	• Frequent and prolonged load shedding. • Volatility in energy and water prices. • Increased mining legislation, regulation and red tape impacting mine development and operation. • Advances in materials science and alternative technology development that may lead to alternatives to PGM-based technologies.

3.2.2 Original equipment manufacturing

The equipment manufacturing value chain segment theoretically offers a business opportunity for companies in both fuel cell and electrolyser manufacturing, and in the supply of sub-components to meet local and global demand. However, despite local availability of PGMs in South Africa, the country will unlikely see large-scale electrolyser and fuel cell production, at least in the short to medium term. Various factors could pose a challenge to local equipment production, notably the high cost of technology licences and high investment costs to establish electrolyser and fuel cell production facilities. However, companies are still seeking opportunities here, such as Mitochondria who plans to licence its technology from the UK-based fuel cell technology (FCT) and engineering company, Ceres Power, to manufacture FC stacks locally.

One of the solutions to the technology licence issue would be cooperation between international and South African companies. A recent study funded by GIZ investigated the appetite of international fuel cell manufacturers to cooperate with suppliers and service providers in South Africa. The study found that a few international manufacturers are already active in country, while others expressed an interest in getting an understanding of the opportunities in the fuel cell businesses locally (Radebe and Hofmann 2023).

More short-term equipment manufacturing-related opportunities lie in the production of components for fuel cells and electrolysis systems. Figure 8 indicates the component manufacturing opportunities for market players to support the localisation of up-stream supply chain components.



MEA	Maturity	Local players
Reformer packages	+	HySA, Isondo Precious Metals
Catalyst for reformers	+	HyPLAT, Bambili Energy
Electrolyte materials	–	-
Stack and Cell Manufacture	+	CHEM Energy, Mitochondria
Stack cooling and thermal management	–	-
Balance of plant components	+	No identified player
Manufacturing equipment & processes	+	Hydrox Holding, CHEM Energy, Mitchondria
Installation/Services (O&M) and other 3rd Party Services	+	24 Solutions
Materials recycling	–	-
Other applications (e.g., backup power, data centres, remote power generation	+	24 Solutions
Manufacturing of fuels cell powered trucks / automotive	+	Anglo-American

Figure 8: Fuel cell component manufacturing and supply in South Africa

The scale of component production in South Africa will likely be driven by a complex interplay among several factors including the speed of development of the GH_2 offtake market, incentives, regulations, and policies to make localisation of facilities attractive for international original equipment manufacturers (OEMs). As market conditions change, the demand for H_2 both domestically and internationally increases, and government policies become more aligned with global and domestic priorities, the localisation of OEMs with various components in South Africa will evolve.

Should the electrolysers needed to meet the projected demand for GH_2 from South Africa be manufactured locally, 10.92 GW of electrolysers would be required in 2030 and an additional 3.8 GW in 2040, before reaching 24.4 GW in 2050. Just like the shift in demand over time for PGMs, demand for electrolyser capacity in 2040 is likely to decline (i.e., electrolysers that will be installed in 2030 will still be operating in 2040), while by 2050 electrolysers would be needed to both meet new demand and replace retiring equipment. The projected electrolyser capacity that is needed to meet the different market demand segments for the three time periods 2030, 2040 and 2050 is presented in Figure 9.

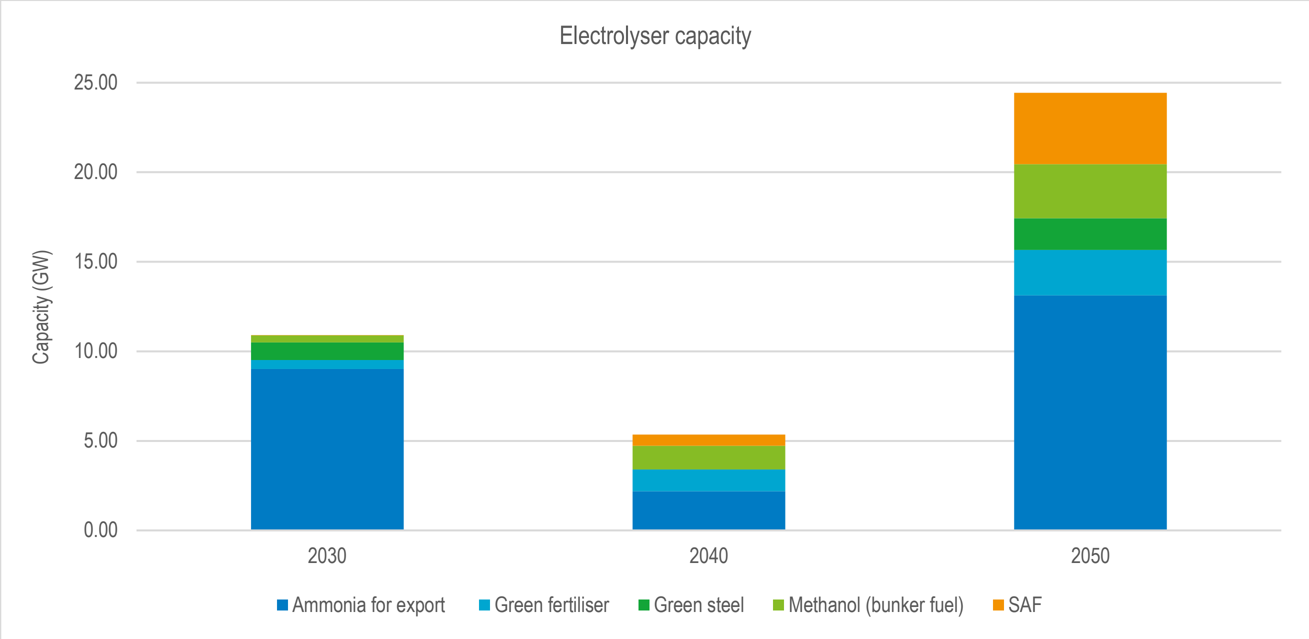


Figure 9: Projected electrolyser capacity per application

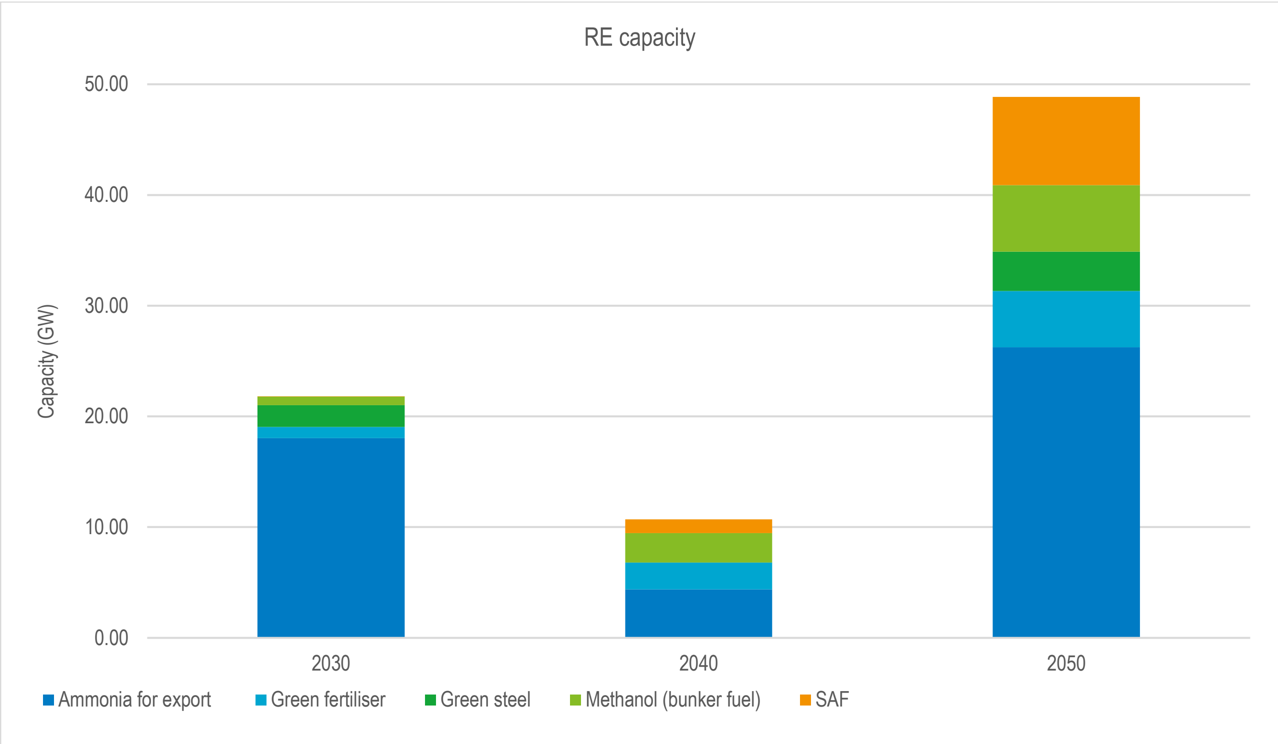


Figure 10: Projected RE capacity per application

In addition to large companies that would be producing electrolysers and their subcomponents, SMEs can play a major contributory role in the success of the equipment manufacturing sub-chain. SMEs can participate by becoming suppliers of components or providing assembly, repair and maintenance services for large-scale fuel cell/electrolyser production facilities. Most Balance of Plant (BoP) components can be sourced locally as there is expertise in South Africa in engineering and after-sales service. A more detailed assessment is required to determine the local content of BoP subcomponents and suppliers. As GH_2 technologies contain critical PGM minerals which have retail salvage/residual value after their useful life, there is also a future opportunity to introduce recycling and circular business models into the end-of-life phase of a GH_2 project and its key equipment components.

The figure below outlines potential business opportunities within the OEM subsegment.

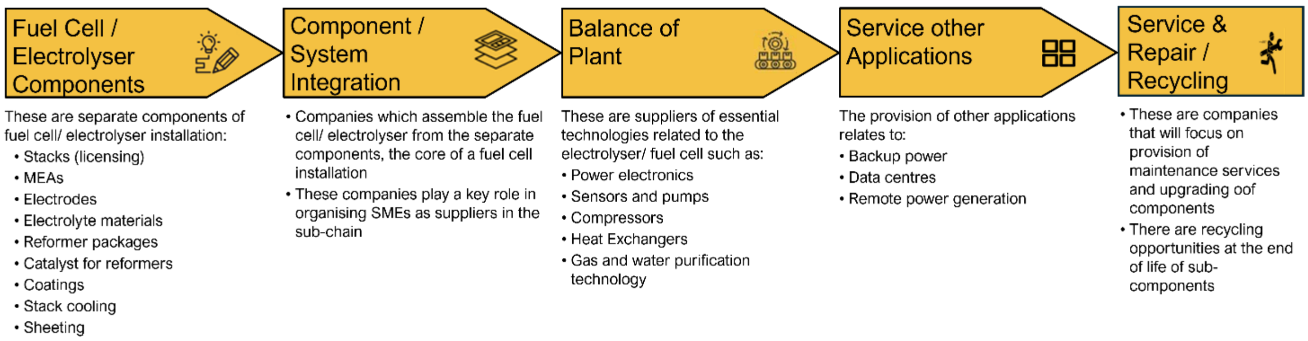


Figure 11: Business opportunities under the equipment manufacturing subsegment in South Africa

Overall, OEM face a "chicken and egg" situation, where increased demand would drive an increased supply of equipment and vice versa. The SWOT analysis in the table below illustrates the challenges and opportunities for OEM and service providers in South Africa.

Table 5: SWOT analysis of equipment and component supply

STRENGTHS	WEAKNESSES
• Strong cooperation between academia, researchers and industry allows for development and testing of new technologies and products. • Well-established R&D for some subcomponents. • Strong government support beyond R&D. • Adequate skills and experience in country. • Electrolysers and fuel cells already in use in South Africa. • Political support for manufacturing equipment and components locally.	• The equipment market remains limited as equipment is still not cost competitive. • No GH_2 equipment manufacturing in the country. • Lack of knowledge and skills in manufacturing of stacks, fuel cells, and electrolysers. • Focus to date remains only on the manufacturing of sub-components. • Procurement processes remain locked into diesel generators in the stationary power generation market.
OPPORTUNITIES	**THREATS**
• Building a strong local component manufacturing industry beyond catalysts. • Licensing of stacks, electrolysers, and fuel cell manufacturing from international technology owners. • Provision of training for the deployment and maintenance of equipment.	• Competitors in other countries possess mature products in the global market. • Competitors in other countries have greater access to funding. • Project financing is still costly due to high interest rates. • Skilled worker retention will pose a challenge due to competition for talent.

3.2.3 Renewable Energy Production

RE is required across the GH_2 value chain, including for water desalination, GH_2 production, beneficiation of GH_2 (including running air separation units and direct air capture systems), and other applications. RE generation is mature in South Africa, although the 2022 SAREM draft (DMRE, dtic and DSI 2022) highlighted the need to scale up the development of local RE supply chains, with a planned target to progressively localise 70% of the components used in solar PV and wind projects procured under the Renewable Energy Independent Power Producer Procurement Programme (REIPPP) by 2030. In addition, there are ambitions to localise 90% of the BoP by that same date, and this could result in the creation of 36,500 new direct jobs. Large-scale GH_2 projects will be linked to large-scale RE projects. Developing GH_2 projects will thus help to signal large future RE investment opportunities, providing certainty to support the development of local RE manufacturing capacity.

As indicated previously, based on the market projections of WP 1C, 21.8 GW of RE would be required in 2030, increasing by 10.7 GW in 2040, and reaching 48.8 GW in 2050 (see Figure 10). Three key business opportunities are presented here: for Independent Power Producers (IPPs); for engineering, procurement, and construction (EPC) contracting services; and for equipment suppliers.

IPPs play a crucial role in the development and operation of H_2 production facilities. The IPP can act as a sponsor or a project developer, and requires expertise in project management, finance, engineering, and regulatory compliance. Key roles include:

- Project identification and feasibility assessment: identifying potential sites or opportunities for power generation; conducting feasibility studies to assess the technical, economic, and environmental viability of the project; analysing regulatory and permitting requirements; and monitoring project performance, both technically and financially.

- Project planning and design: developing a comprehensive project plan that includes technical specifications, construction timelines, and budgets; collaborating with engineers and architects to design the facility; obtaining necessary permits and approvals from regulatory authorities; engaging with various stakeholders, including local communities, government agencies, and environmental organisations; addressing concerns and building positive relationships with stakeholders; and providing regular reports to stakeholders, investors, and regulatory authorities.

- Securing financing: raising capital for project development through various sources, including equity investors, banks, or financial institutions; structuring the financial aspects of the project, including debt and equity ratios; managing financial risk and ensuring the project's financial viability; and developing a project financing and exit strategy.

Offering EPC contracting services is the second business opportunity in RE. This is at both the construction and operation stages of the RE infrastructure life cycle. Finally, the equipment suppliers' responsibility is producing and/or procuring the various components and machinery required for the power generation facility. This includes turbines, generators, transformers, solar panels, wind turbines, and other relevant equipment. Equipment suppliers may also provide engineering support to assist in the design and integration of their equipment into the overall power generation system. They work closely with the project developers and engineering teams to ensure seamless integration. Incumbent RE-related GH_2 businesses are already well placed to move into the GH_2 space, especially those who have participated in the previous rounds of REIPPP and those who have access to capital and deep knowledge about the market and relevant stakeholders.

While opportunities exist for local producers of solar modules, wind turbines, power transformers, inverters, etc., these will have to compete with established international companies, unless South African companies can cooperate with international companies to establish production and assembly facilities in the country. Further business opportunities exist in the production of aluminium module frames and junction boxes, assuming that the cost of aluminium is low enough to be competitive with imports. For inverters, system assembly is a potential opportunity, with some imported products and some local components, including those manufactured locally under license. Local producers need to meet quality standards and have access to local testing and certification.

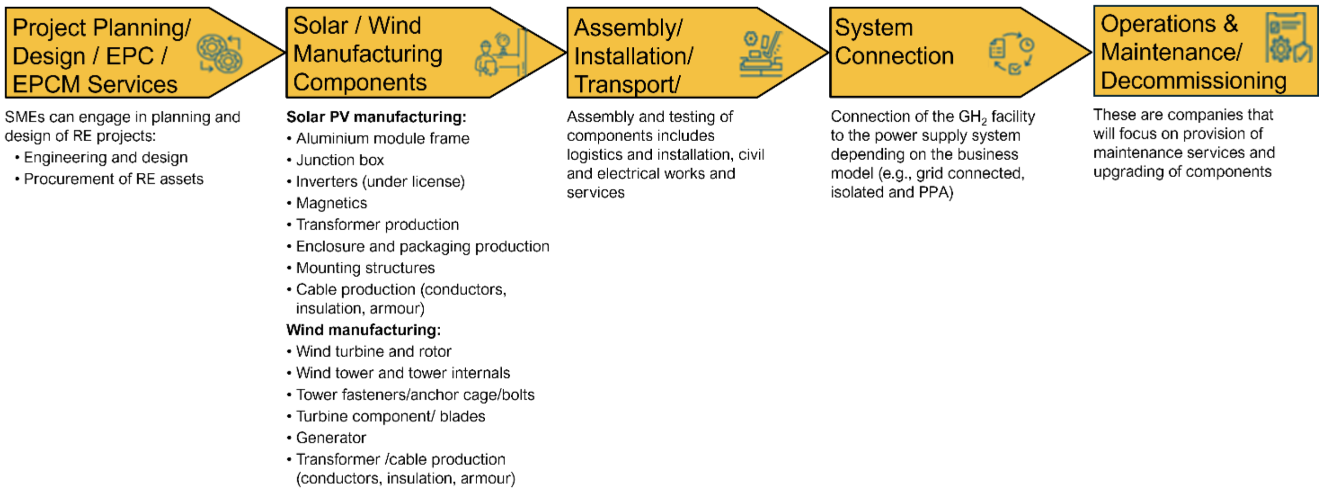


Figure 12: Business opportunities under the RE subsegment

Mounting structures are readily localised and can be expanded due to the expected massive RE capacity, and SMEs have further potential opportunities to get involved in the production of cables including manufacturing of conductors, insulation, and armours, etc.

Table 6 provides an overview of the SWOT analysis of business opportunities in RE.

Table 6: SWOT analysis of the RE industry

STRENGTHS	WEAKNESSES
• High RE resource capacity and land availability. • Well-developed industrial base. • Local RE market is growing exponentially. • Extensive experience in delivering large-scale RE projects. • Financing costs for RE projects are falling. • Engineering and technical expertise is available in the country.	• Insufficient transmission grid capacity. • Lack of an open and transparent power market. • Fragmentation complicates market forecasts. • Limited local capacity to scale up localisation of RE components (e.g., solar module manufacturing).
OPPORTUNITIES	**THREATS**
• Localisation of manufacturing of components. • Large unmet electricity demand in South Africa. • GH_2 projects can consolidate RE demand. • Production and installation of components and plant infrastructure, as well as operating of RE infrastructure.	• Policy uncertainty. • Electricity supply crisis, with a perception that GH_2 production will further impact on supply shortages. • Significant investment needed to support grid access.

3.2.4 Water Desalination

Producing H_2 requires large amounts of pure water. In a country like South Africa, which is increasingly affected by climate-driven droughts, the production of GH_2 cannot depend on bulk water supply; instead, water will need to be supplied primarily through desalination. As outlined in the table below, several business opportunities exist in water desalination in South Africa.

Table 7: Opportunities in South Africa in desalination

COMPONENTS	POTENTIAL OPPORTUNITIES IN SOUTH AFRICA
Intake systems / pre-treatment/ distillation unit / brine disposal / post treatment / BoP	Typically supplied as proprietary equipment by the licensor of the process, since the performance and guarantees for the overall plant are linked directly to the design and performance of the system itself.
Monitoring and control of supply systems	Local companies can develop competencies in monitoring and control of desalination plants to optimise processes, ensure consistency of water quality, and respond to changing conditions.
Membrane monitoring and cleaning	Monitoring and cleaning are critical to maintain optimal membrane performance and extend their lifespans.
Infrastructure and support facilities	Construction of building, intake, and other infrastructure facilities is an opportunity for the local construction industry.

Oversizing of desalination plants is also another opportunity since excess water can be supplied to local communities, thereby enhancing social acceptance of the GH_2 facilities and possibly providing additional revenue streams. Table 6 provides the SWOT analysis of business opportunities in South Africa in the area of desalination.

Table 8: SWOT analysis of the desalination industry

STRENGTHS	WEAKNESSES
• Water demand is high for GH_2 production and auxiliary services, providing an opportunity for a reliable offtake market. • South Africa already has strong experience in engineering related to the water sector.	• Best RE/GH_2 sites may be far away from the coast, putting pressure on water resources. • Skilled personnel may not be available when required.
OPPORTUNITIES	**THREATS**
• Existing water treatment companies could pivot to involvement in the GH_2 industry. • Partnering with service providers and technology partners to offer a full range of software/hardware solutions. • An additional business case exists in the supply of fresh water to local communities and industries.	• Environmental groups and residents may oppose desalination at certain sites, particularly due to brine management concerns. • Obtaining pollutant discharge permits from state authorities could be challenging.

3.2.5 Green Hydrogen Production

Turning now to the production of GH_2, the establishment of GH_2 facilities provides opportunities for industry players. There are already a number of players planning pilot projects to produce GH_2 while simultaneously working on solving the "chicken and egg" dilemma of demand and supply for GH_2 that is developing in parallel. Like RE, GH_2 project implementation requires the involvement of several players along the value chain, including project developers who are typically responsible for identifying, designing, building, and managing the development of H_2 projects. Based on the market projections of WP 1C, 1,178 KTPA of GH_2 would be required in 2030, increasing to 1,843 KTPA in 2040, and further to 2,932 in 2050. As shown in Figure 13, ammonia is likely to be the primary driver of GH_2 demand.

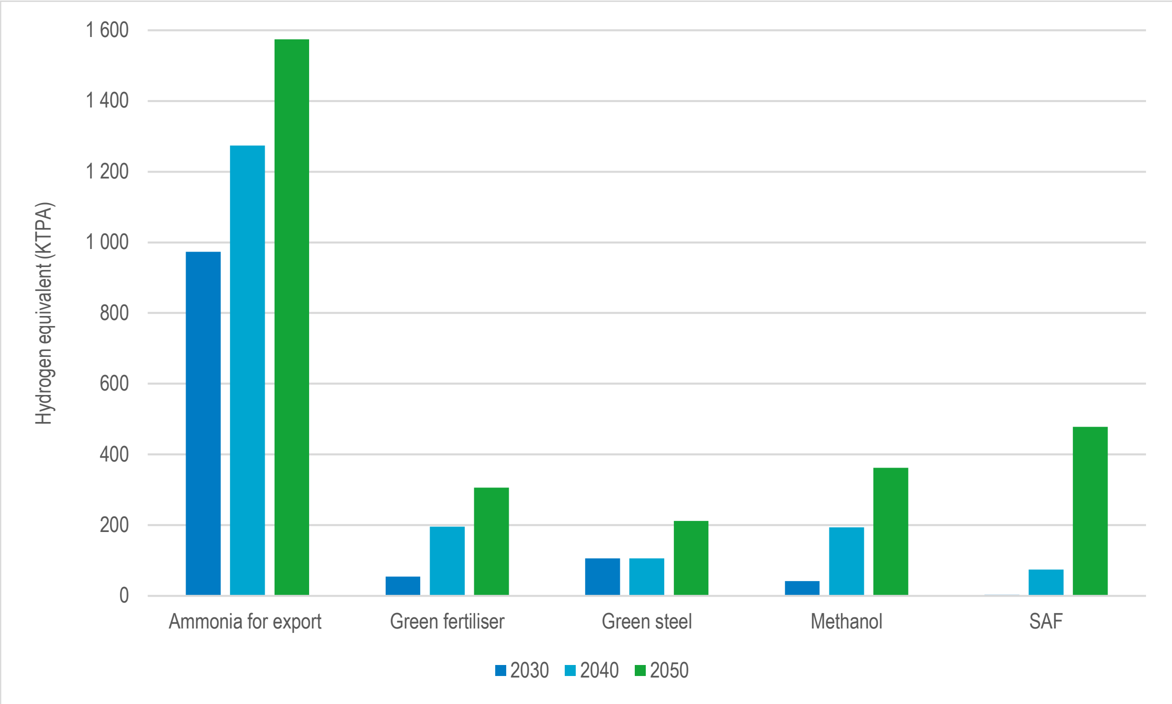


Figure 13: Projected GH_2 needs for the five PtX applications

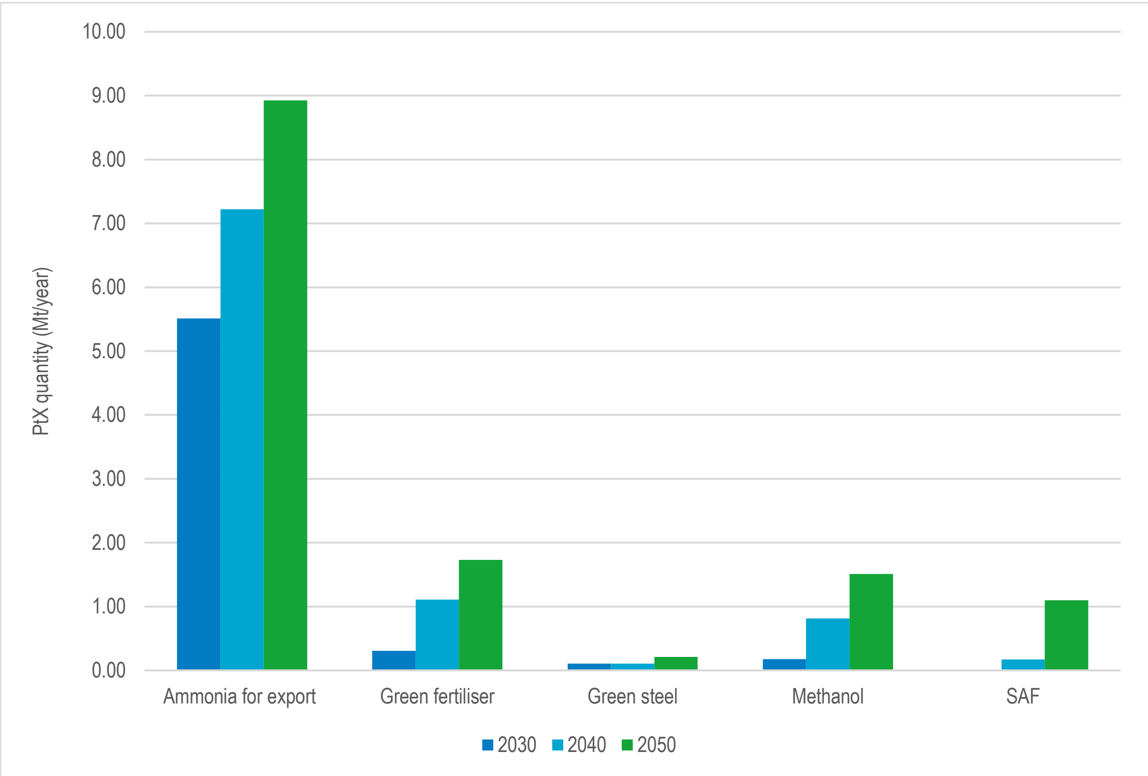


Figure 14: Projected PtX quantities in five applications

The focus of GH_2 production in South Africa is currently on developing pilot scale projects, with no industrial scale production being in place. Most projects or initiatives in South Africa are in the feasibility and preparation stage where sponsors are pooling the competencies of various parties with different skills and experience to prepare the initiatives and test financial and technical viability. Figure 15 provides an overview of potential opportunities in this value chain segment.

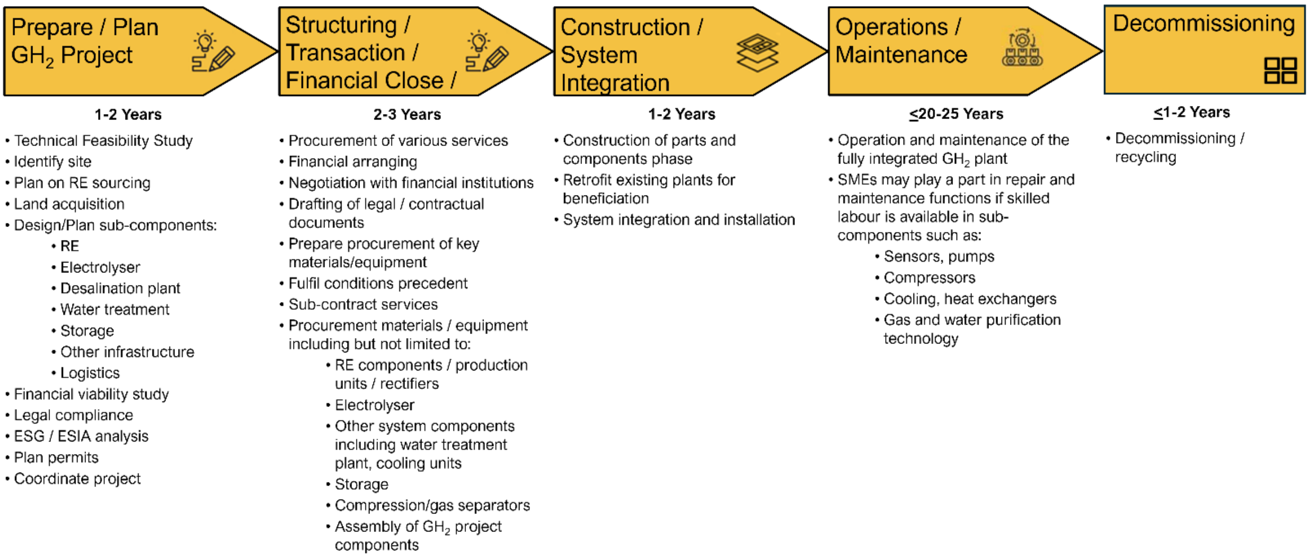


Figure 15: Business opportunities in the GH_2 production value chain segment

Due to the sheer size of this value chain opportunity, there are a range of potential roles to be played by SMEs, including component and system integration services, maintenance and repairs across the various sub-components, supervising storage facilities, as well as transport and logistics services. However, the entry into the GH_2 market involves several challenges and constraints, which vary depending on the location, technology, and scale of the facility. Some of the major constraints to building a business around these types of GH_2 facilities include high initial capital costs, supply of electrolysers, storage, and distribution systems. The table below presents the SWOT analysis of GH_2 production.

Table 9: SWOT analysis of GH_2 production

STRENGTHS	WEAKNESSES
• High technical/engineering skills base in country. • A number of players are preparing pilot GH_2 projects and investing beyond R&D. • Access to PGMs, land, and RE may allow projects to become cost competitive.	• The demand for GH_2 is still emerging, and the market may not yet support large-scale production. • Key components for GH_2 production still have to be imported.
OPPORTUNITIES	**THREATS**
• Collaboration between government, industry stakeholders, and research institutions. • Government incentives, policy support, and R&D efforts can play a crucial role in overcoming the weaknesses.	• Growing competition with producers closer to the global market or with lower GH_2 production cost. • Securing funding for large-scale GH_2 projects can be challenging due to the risks and uncertainties associated with the technology and market. • Fossil-fuel-based alternatives still enjoy subsidies. • Environmental and social requirements may delay projects. • Need for high upfront investments (e.g., electrolysers, RE, infrastructure).

3.3 Midstream opportunities

Business opportunities in the midstream segments can be found in the conversion/beneficiation of GH_2 to a wide range of GH_2 derivatives. Storage and transport are also considered here.

3.3.1 Conversion/Beneficiation

Conversion or beneficiation of GH_2 refers to compressing H_2 or converting it into a range of different products for the purposes of storage, transport to other locations, or final use by end-users. Incumbent South African investors, largely companies with strong credentials, are exploring the use of existing technological knowledge, experience, and infrastructure to convert H_2 into a range of derivatives including methanol, ammonia, and other e-fuels. The technological pathways shown in Table 10 provide various investment opportunities for the conversion of H_2 to its derivatives.

Table 10: Technological pathways for GH_2 beneficiation in South Africa

PATHWAY	DESCRIPTION
Fischer-Tropsch (FT)	Sasol's FT technology for hydrocarbon production is well established in South Africa. Once retrofitted, it can serve as a business opportunity for competitive beneficiation of GH_2 in the move away from producing synthetic fuels, such as gasoline and diesel from coal and natural gas. Downstream products include waxes, lubricants, and specialty chemicals, which have applications in various industries, from automotive to construction.
Hydrogenation	Incorporation of H_2 molecules into organic compounds, such as Liquid Organic Hydrogen Carrier (LOHCs), used for the storage and transport of H_2.
Methanation	Production of green methane by combining GH_2 and sustainable carbon.
Methanol synthesis	Conversion of GH_2 and sustainable CO_2 into green methanol, which can be used as a fuel as well as a chemical feedstock in the production of a wide range of downstream products.
Haber-Bosch	Production of ammonia.

GH_2 conversion and beneficiation requires technological knowledge along with capital investment for new production facilities and/or retrofitting. Sasol clearly possesses a first-mover advantage due to its commercially mature conversion technology. However, there are opportunities for other South African and international companies in the beneficiation of H_2, for example in supplying GH_2 and sustainable CO_2 to Sasol or by entering partnerships. An example here is the HyShiFT project where Linde is responsible for the production of GH_2, Enertrag is responsible for RE generation, and Sasol produces the SAF. Another example is the Keren project for H_2 production, where Keren Hydrogen will be responsible for the GH_2 production, while Namaqua Engineering and Cape Stack will provide engineering support, and Grindrod will add logistics support. External investors can provide off-balance-sheet financing for projects.

The projected market for the five PtX derivatives is shown in Figure 14 (under the GH_2 production section). Although the projected market highlights the dominance of ammonia for export in the future South African PtX industry, significant uncertainties remain. Whereas most of the other application markets are largely domestic focussed, ammonia for export demand relies on how the trajectory of PtX will unfold globally. Developers increasingly find the implementation and scaling up of planned projects to be difficult in the current financial, regulatory, and technology landscape. Independent of these uncertainties, the projections assume that countries such as Germany and Japan will import their announced and planned amount of PtX, and South African players will manage to secure a material proportion of this import demand. This presents a significant opportunity for South African industry which can seize the country's ideal conditions to lower costs and attain a comparative advantage.

Table 11 provides an overview of the challenges and strengths for businesses in this value chain segment.

Table 11: SWOT analysis of conversion and derivative production

STRENGTHS	WEAKNESSES
• High technical/engineering skills base. • Local businesses are already partnering and collaborating across the value chain. • Large appetite to build on the GH_2 opportunity by businesses, especially ammonia for export. • Maturity of FT technology, with its depreciated asset base. • Collaboration between government, industry stakeholders, and research institutions.	• Securing a consistent and cost-effective supply chain for raw materials could be challenging. • Securing funding for large-scale conversion projects can be challenging as investors may be cautious due to the risks and uncertainties associated with the technology and market.
OPPORTUNITIES	**THREATS**
• Consortia of companies are forming around the beneficiation opportunity to gain early-mover advantages and market share (export and local). • Government incentives, policy support, and R&D efforts can play a crucial role in overcoming the weaknesses. • With limited local demand expected, businesses are poised to be key exporters to demand centres in Europe and Asia.	• High local costs of raising finance and trading with global counterparts could increase costs and delay transaction execution. • Achieving cost-competitiveness with GH_2/PtX alternatives remains a challenge. • Competition from other countries (Namibia, Morocco) may provide a threat to scale-up.

3.3.2 Storage and transport

Storage and transport of GH_2 and its derivatives is relevant both mid- and downstream of the value chain. H_2 can be stored and transported by pipeline, by ship or by truck. H_2 can be stored in its original form as a compressed gas (in high pressure tanks and pipelines), as a cryogenic liquid (in super-insulated tanks), as PtX products such as ammonia, methanol, SAF, etc., or bound in LOHC. The choice of mode depends on the delivery distance, the H_2 volume to be transported, and the final use.

For equipment manufacturers, the potential global H_2 distribution market opportunity could total an annual USD 25 billion to USD 30 billion by 2050 (BCG 2021). In South Africa and globally, there will be high demand for components, including robust pipeline materials, and equipment (Figure 16). Leak-proof seals, pumps, gas flow management systems, and heat exchangers, as well as smaller parts like valves, will also be required.

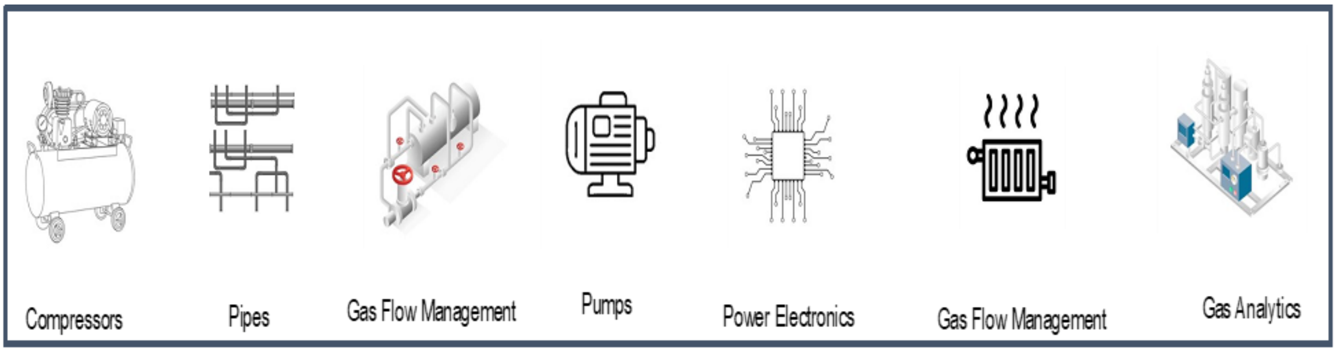


Figure 16: Selected components for conversion/storage

Source: Adapted from (BCG 2021)

Other opportunities relate to the design, manufacture, and operation of the distribution infrastructure, and the tanks and infrastructure required for H_2 refuelling stations where relevant. There are opportunities in:

- Manufacturing of storage- and transport-related equipment and components (e.g., compressors, pipes, storage tanks, pumps);
- Installing and maintaining storage and transportation facilities;
- Transporting GH_2 from production sites to facilities that use it to produce PtX products such as ammonia and FT facilities; and
- Transporting GH_2 and its derivatives from their production sites to consumers or ports for export.

The SWOT analysis of H_2 storage and transport is shown in Table 12.

Table 12: SWOT analysis of the storage and transport sector

STRENGTHS	WEAKNESSES
• Existing industrial base that has plant development and operation experience, which could find applicability in PtX storage and transport. • Existing storage and transport infrastructure and experience linked to current ammonia production, which can be leveraged for the GH_2 industry. • Transnet already plays a central role in promoting intermodal transport. • Several companies are engaged in initiatives (e.g., Hydrogen Valley hubs) that cover transport and storage.	• Lack of skilled personnel with specific experience in this area. • Planning of complex infrastructure, such as rail and ports, not yet done to guide investors. • Lack of refuelling infrastructure is a barrier to the roll-out of H_2-based vehicles. • Existing transport infrastructure has long lifespans, and so current fleets will need to be adapted to future developments in H_2 technology.
OPPORTUNITIES	**THREATS**
• The projected growth in local and export GH_2/PtX demand shows that this segment will grow accordingly. • The wide range of emerging storage and transport options provides multiple business opportunities. • South Africa's main ports' geographic locations present opportunities to develop as H_2 hubs, aggregating	• High dependency on a single entity, Transnet, which has seen delays in build-out of infrastructure in other areas, could hamper development of GH_2 infrastructure. • High capital intensity of infrastructure and long lead times to roll out large-scale investments in ports and rail suggests significant funding will be required, which may not be available in the local context.

demand from on-site operations, land and ocean transport, and local industrial users. • Investing in shared infrastructure provides opportunities for collaboration to de-risk challenges and accelerate investment in infrastructure.	• Availability of specialist materials for construction of storage and transport infrastructure may be limited as global demand grows. • Lack of government policies and safety measures for storage and transport infrastructure provides uncertainty.

3.4 Downstream opportunities

Downstream opportunities of the value chain lie in activities and assets for H_2 transportation and distribution to supply the product to markets for end usage. Transport has been discussed together with the storage in the previous section, and so this section focuses only on retail and end use of PtX. GH_2 opportunities at the retail or end-usage stage relate to getting the final H_2 and PtX products as feedstock or as fuel for use in various applications, such as transportation, heating, and power generation. The various end use applications for South African produced PtX products are presented in the table below.

Table 13: Potential GH_2/PtX applications in South Africa

PTX PRODUCT	APPLICATION		USE	MARKET
Ammonia	1	Energy carrier	Energy carrier	Export
	2	Fertiliser production	Feedstock	Domestic
	3	Marine bunkering	Fuel	Border market
H_2	4	Cement	Fuel	Domestic
	5	Green steel	Feedstock	Domestic
	6	HFC-powered long-haul trucks	Fuel	Domestic
	7	HFC-powered mining trucks	Fuel	Domestic
	8	HFC-powered urban buses	Fuel	Domestic
	9	Power-to-power	Fuel	Domestic
	10	Refineries	Feedstock	Domestic
	11	Production of food & beverages	Feedstock	Domestic
	12	Heating	Fuel	Domestic
Jet fuels (SAF)	13	Aviation	Fuel	Domestic, border and export
Methanol	14	Energy carrier	Energy carrier	Export
	15	Marine bunkering	Fuel	Border market

3.5 Cross-cutting business opportunities

Cross-cutting opportunities span several of the value chain components, and include advisory services, financing, research and innovation as well as other SME services and products.

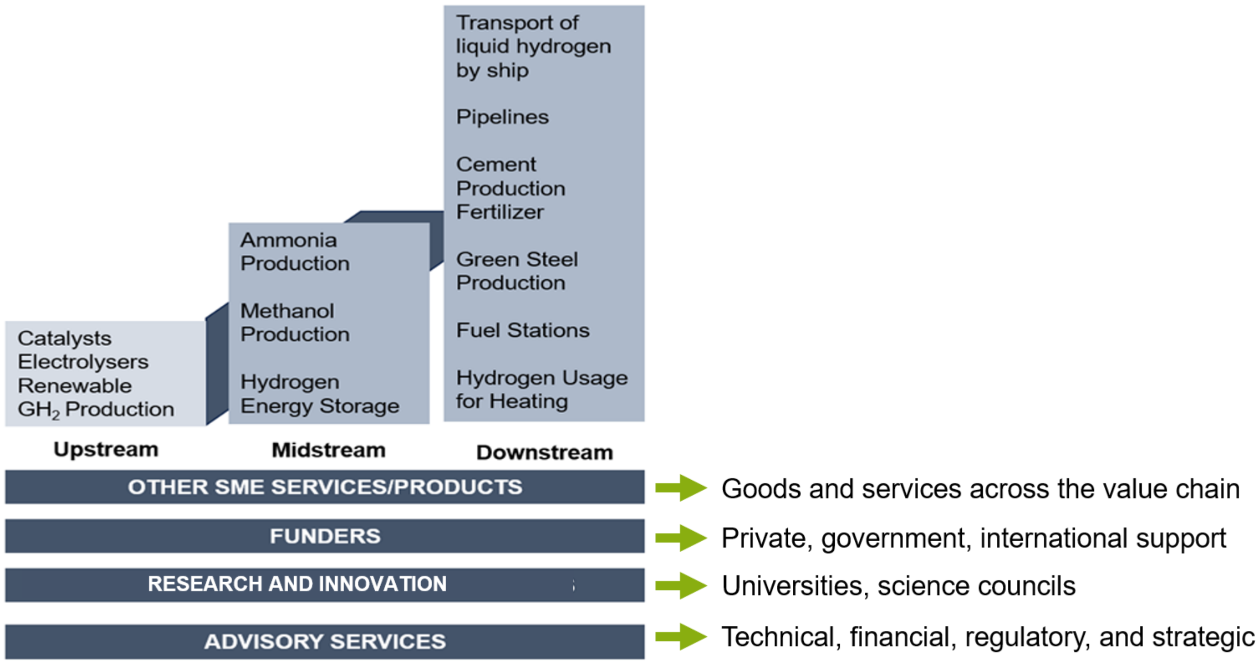


Figure 17: Cross-cutting opportunities

3.5.1 Advisory Support

Advisory support includes service provision to assist planned projects in areas such as GH_2/PtX project finance structuring, design, planning, production, storage, transportation, and utilisation. Within a GH_2/PtX project, advisory support can include, for example, providing technical, financial, regulatory, or strategic advice to help ensure the project's success. This may include analysing project feasibility, identifying potential risks and opportunities, developing business plans, conducting market research, assessing financing options, providing legal or regulatory guidance, and facilitating partnerships or collaborations.

3.5.2 Financing

An increase in GH_2 demand will require financing for the various investment opportunities along the value chain, from OEM development and H_2 generation to H_2 transportation and storage. The capital requirements will vary across the chain, and local financing options will significantly influence investors' choices. Since corporate balance sheets cannot provide all of the necessary funding for projects, low-cost sources of capital, such as infrastructure investors and climate finance, will play a critical role in providing debt and inexpensive equity projects in South Africa.

The South African government is continuing to work with the H_2 industry to overcome the funding barriers to development. However, the current landscape is such that there remains a mismatch between investors' expectations and the risk profiles of current opportunities. Most investors are not willing to invest in projects that have high technology or project risks and commercial or offtake risks. This is why financing for many GH_2 projects is coming from large South African companies such as Sasol, Anglo-American, or oil and natural gas companies who are driven by voluntary defossilisation initiatives with their H_2 related ambitions.

3.5.3 Research and Innovation

There are numerous opportunities across the value chain to advance the various technologies. As early as in 2017, the South African government started to provide long-term support to GH_2 research programmes. The Department of Science and Innovation (DSI) (formerly the Department of Science and Technology (DST)) is the custodian of national research, development, and innovation (RDI) focused on new energy technologies. It assigned the HySA programme to execute the H_2 component of the DSI's RDI strategy of 2008. HySA consists of three Centres of Competence (CoC) which, together, build a national network of research "hubs" and "spokes" through collaboration with institutions and partners from the R&D sector, higher education, as well as industry. In 2021 HySA's RDI support was extended to continue for an additional 10 years.

Table 14: Overview of HySA structure and activities

HYSA CATALYSIS COC	HYSA INFRASTRUCTURE COC	HYSA SYSTEMS COC
Co-hosted by the North-West University (NWU) and the CSIR.	Co-hosted by the University of Cape Town (UCT) and MINTEK.	Hosted by the University of the Western Cape (UWC).
R&D focus: H_2 production, storage, distribution, and codes and standards.	R&D focus: catalyst and membrane electrode assemblies' (MEA) development.	R&D focus: H_2 system(s) development and validation.

The programme cooperates with several research institutions to promote GH_2 related research in South Africa. It also works with private sector and Science Councils researching the beneficiation of PGM resources. Ultimately, the purpose of HySA is to provide the technical expertise that is needed for the implementation of the HSRM, to serve as a national coordinating framework to facilitate the integration of H_2-related technologies in various sectors of the South African economy, and to stimulate economic recovery in line with the Economic Reconstruction and Recovery Plan.

Table 15 provides an overview of the local institutions that have been involved in research and innovation in GH2 technologies.

Table 15: Research and innovation activities in South Africa

Institutions (Research, National, Private Sector)	PGM Mining	OEM Manufacturing	RE Generation	H2 Production	Conversion Technology	Storage	Transport/ Distribution
HySA Infrastrucutre				■		■	■
HySA SYSTEMS	■	■		■		■	
HySA CATALYSIS	■	■		■			
South African Minerals Research Council (Minetk)	■	■		■			
Council For Scientific And Industrial Research						■	■
University Of Pretoria		■					
North-West University		■		■			
University Of Witwatersrand				■		■	
Mangosuthu University Of Technology							
Tshwane University Of Technology		■		■			
Private Sector (Sasol, Anglo, Engie, Total Energies, Enertag, Bambi Energy, Mitochondria, CHEM Energy, etc.)	■	■	■	■	■	■	■
Department Of Mineral Resources And Energy (DMRE)	■						
National Energy Regulator Of South Africa (Nersa)	■		■	■			
Department Of Transport (DoT)						■	■
TRANSNET (Rail/Port Authority/etc.)						■	■
Department Of Public Works And Infrastructure (DPWI)	■		■	■	■	■	■
Department Of Trade, Industry And Competition	■	■	■	■	■	■	■
Department Of Science And Innovation (DSI)	■	■	■	■	■	■	■
Provincial Departments	■		■	■	■	■	■
Indiustrial Developemnt Corporation (IDC)	■	■	■	■	■		■
Development Bank of South Africa (DBSA)			■	■	■		■
South African National Energy Development Institute			■	■			

4 GH_2 SKILL SETS AND CAPACITY-BUILDING OPPORTUNITIES

This section provides an overview of the role of skills and capacity-building in supporting the development and growth of a robust GH_2 industry in South Africa. These considerations are addressed in more detail in the outputs of WP 3.

The skills needed to drive an H_2 economy in South Africa will not be entirely new. South Africa has extensive experience in producing chemicals and liquid fuels. Primarily from natural gas, Sasol produces around 2% of global H_2 demand (DSI 2022, ESI Africa 2023). The skills to enable the GH_2 economy are also not fundamentally different from the skills required in other process industries (Weir, et al. 2023). Thus, while growth in the GH_2 industry will result in job opportunities that may require new skills, training programmes, and qualifications across the value chain, South Africa will not be starting from scratch. Opportunities will include highly-skilled positions (scientists, engineers, designers, chemists, researchers); specialised technicians who can operate, maintain, and optimise equipment; softer skills aimed at communication, teamwork, problem-solving, innovation, and entrepreneurship; and cross-cutting skills like safety, quality control, compliance (environmental and regulatory), finance, accounting and human resources (Green Skills for Hydrogen 2023). These skills can come from training and upskilling the current labour force (including the youth and unemployed or from retraining and onboarding workers in the traditional energy sector (oil, gas, coal, etc.)). The latter already have relevant skills and are at risk of losing their jobs during the energy transition.[4]

Detailed assessments of the skills and occupations needed to develop GH_2 activities across the value chain are available. France Hydrogène (2022), for example, developed a detailed list of skills and competences required to develop the GH_2 economy (Figure 18).[5] With over 84 occupations considered, 27 require specialist knowledge on GH_2, 41 require basic knowledge, and 16 require no specific knowledge.

The results of a study conducted in Australia to identify the skills required to support a GH_2 economy also provides insights into potential education and training needs. More than 70% of the 41 industry participants consulted indicated that education and training on electrolysers, fuel cells, H_2 storage, and refuelling stations is needed (Beasy, et al. 2023). The results are likely to be highly context-specific and, while instructive, are unlikely to be directly applicable to South Africa. It does, however, show the value of undertaking a similar exercise locally given the large variation in responses.

Key to the skills debate, however, is acknowledging that there is significant uncertainty around what, where, and when GH_2 skills will be required in South Africa. Not only is it unclear which segments of the value chain will be established locally, there is also uncertainty around the technologies and process routes that will come to dominate some PtX applications. Furthermore, GH_2 skills will need to be created within the broader South African skills landscape. South Africa is facing acute skills constraints across the economy (Hlapi, Stiglingh-Van Wyk and David 2023) and this is believed to be the second largest constraint on growth after the electricity supply crisis (Sguazzin 2023, Operation Vulindlela 2023). At the same time, however, sufficient numbers of young people are not entering vocational and practical skills training. Furthermore, while the Department of Higher Education and Training (DHET) publishes an annual list of scarce skills based on occupations that are hard to fill, areas where graduates are needed with specific technical skills or experience, and where curricula may be sub-optimal (DHET 2022), a general lack of market intelligence on the exact number, location, and employers of workers with specific skills is lacking in South Africa (SANEA 2023).

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[4] Fossil fuel jobs are at risk from the general transition to energy sources with net-zero GHG emissions rather than a move towards establishing a GH_2 economy, and job losses are expected even if a GH_2 industry is not established in South Africa. See Energy Systems Research Group (2021) for an indication of job losses in the fossil fuel industry that could accompany the development of a GH_2 economy in South Africa.

[5] More details on requirements of the various skill sets are provided in Appendix 2.

The South African Energy Skills Roadmap (SANEA 2023) highlights the need for flexibility when considering skills bottlenecks, given the uncertainty linked to whether the bottlenecks of today will be the bottlenecks of the future. To generate this flexibility, the importance of transversal skills that can be used across various industries is emphasised, as is the importance of establishing a coordinating forum at a national level to drive responsiveness to changing skill and job market requirements. The Green Hydrogen Commercialisation Strategy also acknowledges the importance of flexibility and tasks DSI and the Department of Higher Education and Training (DHET) with developing a training ecosystem that can facilitate this.[6]

In the near term, job candidates in the GH_2 economy are likely to originate from existing technical and manufacturing capacity-building structures, supplemented by foreign skills. It is important to note that the presence of skilled foreigners is likely to help accelerate the local supply of skills via sharing of skills, experience and knowledge, rather than displacing local candidates (Operation Vulindlela 2023). Key to growing the GH_2 industry will be ensuring that partnerships between the private sector and traditional universities, universities of technology, Technical Vocational Education and Training (TVET) colleges, and sector-specific training institutions are fostered to leverage this early knowledge to exponentially increase the type and number of skills generated.

[6] See dtic (2022) for details of the expected roles of both institutions.

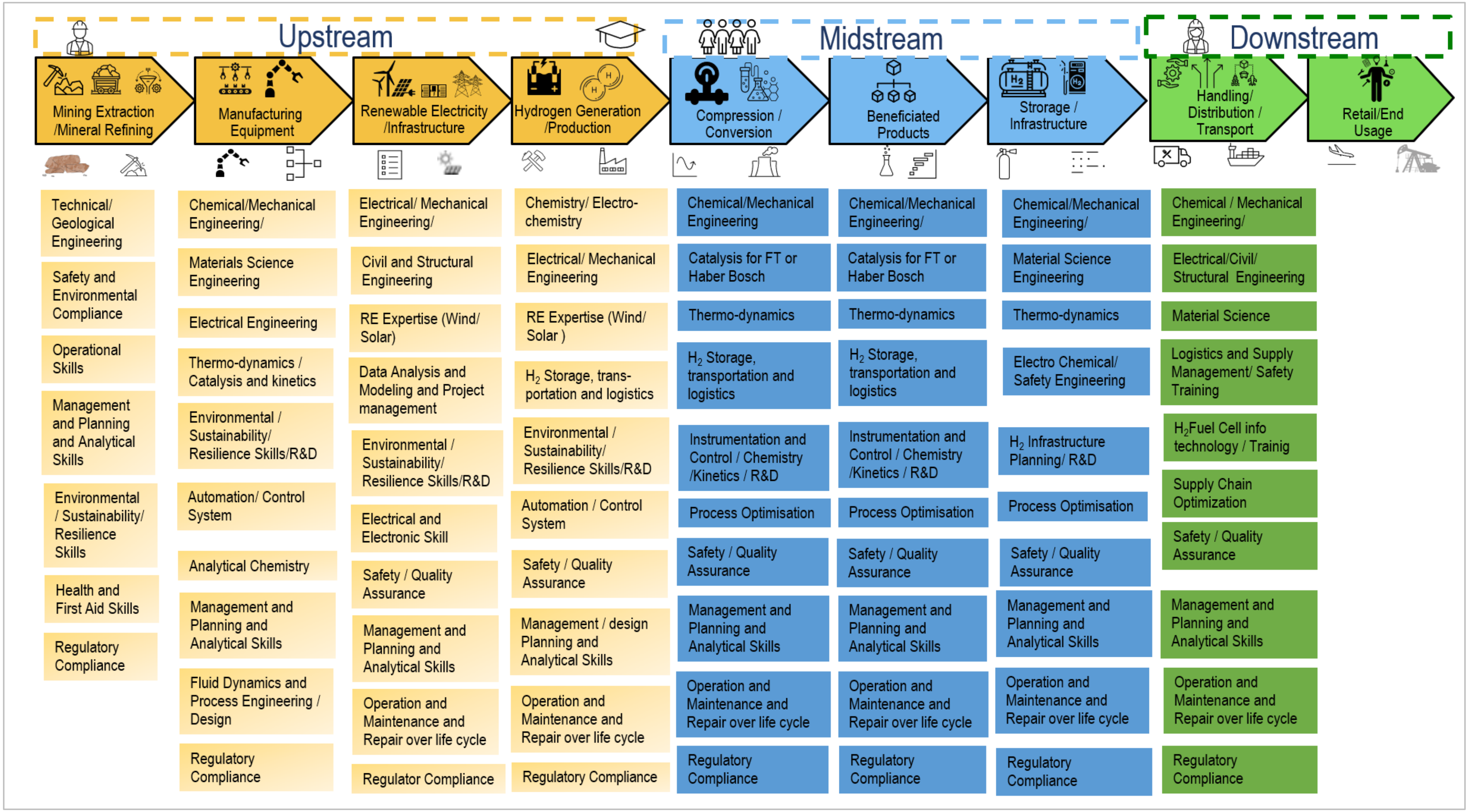

Figure 18: Required skill sets along the PtX value chain

Source: Authors based on France Hydrogène (2022)

5 RECOMMENDATIONS TO RELEVANT INSTITUTIONS

South Africa's GH_2 industry is evolving rapidly with the support of government, private sector, and educational institutions. Nevertheless, more work is still required to ensure that it is successful and delivers the desired outcomes.

The findings of the value chain analysis and business opportunities provide insights on the market entry barriers for businesses seeking to enter the GH_2 space. These challenges are based on a number of factors including the technological complexity of the value sub-chain segments; the current market presence of industry players in South Africa; and their maturity. The latter is, in turn, based on technological readiness, skills preparedness, and R&D readiness.

The figure below shows a high-level assessment of upstream, midstream, downstream, and cross-cutting activities against the indicators of market entry hurdles.

Figure 19: Evaluation of market entry hurdles and South African maturity features along the value chain

- Low market entry barriers and high levels of maturity (yellow background) supported by high levels of technology readiness, skills preparedness, and R&D readiness are seen in the value chain elements relating to PGMs, catalysts, RE, Fischer-Tropsch, and Haber-Bosch production, as well as in construction and O&M. These favourable ratings also apply to policy making and financing as cross-cutting activities. Industry players in these areas with established market presence and low technological complexity are well placed to position themselves in the emerging GH_2 market. They can further be supported by policy making initiatives, such as local content rules and GH_2 regulatory schemes and incentives.

- Those value chain elements considered to have medium market entry barriers and levels of maturity (green background) are characterised by medium levels of technology readiness, skills preparedness, and R&D readiness. This rating applies to OEMs of sub-components, GH_2 production, and downstream refuelling stations, storage, and transportation of liquid H_2. Storage and transportation of hydrogen have traditionally been challenging due to the unique characteristics of the gas – with high flammability, low density, and ease of dispersion. At the same time, technical development and commercial drivers are increasingly enabling more economic modes of storage and transportation. Here, medium levels of market presence are observed with low levels of technological complexity, which allows companies to position themselves in the emerging GH_2 market in the medium term. Players falling into this category can also be further supported with policy making initiatives like other technology deployment and scaling efforts, and government can help make the economics more favourable for early market entrants and producers.

- The final category, shown in red, indicates high barriers to entry and low technology preparedness includes production of electrolysis and fuel cells. The readiness level here is also low for certain conversion technologies including methanation, liquefaction, and methanol synthesis where technological maturity is not yet proven, and few companies are in the market and need to be supported by R&D.

The introduction of favourable policies can provide a degree of near-term demand certainty for private sector players and help address some of the risks associated with investment in early-stage energy technologies. This demand certainty can set the stage for GH_2 to ride the cost reduction curve and be adopted at scale in the long term. In the process, this can lead to decarbonisation, energy and economic security, and growth in local manufacturing. The following sections outline the kinds of potential support measures that would help industry players, policy makers, and research institutes participate in the future GH_2 markets across the value chain.

5.1 Short-term actions

Support planned projects and initiatives

- Leverage and market South Africa's current positioning, including the mature PGM sector and expertise in FT conversion technologies to attract investment in GH_2 beneficiation and localisation of manufacturing of sub-components for the GH_2 economy.

- Proactively promote and advance pilot projects (including those in hydrogen valley hubs) to drive scale-up of the GH_2 market.

Support to attain cost competitiveness

- Scale-up of GH_2 technologies requires costs reductions to allow GH_2 to become cost competitive. Continued engagement between the public sector and private sector companies is required to attract their technical and financial support for GH_2 market development.

- Players in the market need to minimise upfront capital risks, with concessional and blended finance potentially playing a role here. Structuring targeted GH_2 finance instruments will be valuable in bridging the funding gap.

Support entrepreneurship for GH_2 market entry (SMEs)

- A wide range of opportunities for SMEs is identified across the value chain. Growing SMEs to be active in this space could be supported by the introduction of dedicated incubation programmes tailored to each of the GH_2 value chain segments, providing aspiring entrepreneurs with mentorship, business development support, access to funding opportunities, and shared workspace facilities.

- Setting up financing mechanisms tailored to the specific needs of entrepreneurs in the GH_2 sector, including via venture capital funds and angel investor networks, is needed.

- Reducing complexity and costs associated with the licensing and permitting requirements is key to market players' acceptance to enter the nascent GH_2 market.

Promote partnerships and networks

- Further investment and support in promotion of partnerships between universities, public institutions, and industry stakeholders will help companies access new technologies and expertise, while universities will benefit from real-world application of their research.

- Provide structured support to scale up collaboration with relevant players globally and locally across the supply chain to ensure that infrastructure and investments come together in a coordinated manner. This requires the involvement of state-owned enterprises including Transnet.

- The GHCS emphasises the need to consider competition for import terminal allocations and the need to proactively develop relationships with importing countries (government to government relationships) and GH_2 import hubs, such as Hamburg Port Authority. Transnet is already engaging with European port operators to work together on exporting GH_2 via European port terminals.

Promote skills development in GH_2

- Introduce apprenticeship programmes to help equip youth with skills needed in the industry. Coordination with industry is critical here.

- Developing new skillsets and investing in re-skilling of the existing work force across the range of value chain requirements needs to be embedded in a culture of continuous learning and adaptation to keep pace with the evolving needs of South Africa's GH_2 economy. Regular feedback mechanisms, industry consultations, and collaboration forums can be established to gather inputs and adjust the skills development initiatives that need to be fostered in country.

- Collaborate with international partners for knowledge exchange and benchmarking.

- Provide hands-on training in fit-for-purpose labs or in training centres to help bridge the gap between theoretical learning and practical hands-on implementation. Consideration should be given to how educational institutions and the GH_2 private sector can collaborate in locating, designing, building, and using such labs to make investments worthwhile.

5.2 Medium- to long-term actions

Support planned projects and initiatives

- Provide proactive support to ever growing new opportunities arising across the various sub-chains, the nature of which will be determined by how the trajectory of GH_2 evolves in the medium term. Promote investment in localisation as and where appropriate and relevant.

- Engage industry players and research institutions in the advancement of projects beyond Research, Development and Innovation (RDI) to commercialise their innovations.

Support to attain cost competitiveness

- Support is needed to close the gap between supply and demand, as scale-up will be key to attaining competitiveness in the medium term. The introduction of in-country and industry commitments can help bridge this gap, for example, through proactively switching current consumption of grey hydrogen to GH_2.

- Investing in development of masterplans with specific implementation targets for the various end usage sectors (steel, RE, and chemical sectors) will help stimulate the GH_2 economy. This is in line with the HSRM.

- Leverage support from both public sector institutions and the private sector to optimise value chain linkages and lower costs. The introduction of supportive policies and the creation of a regulatory framework that encourages cost competitiveness will allow South African market players to position themselves adequately in the global GH_2 landscape. Interventions could include:

    a. Incentives such as subsidies, taxes, and levies or accelerated depreciation on capital equipment to reduce costs in the long term.

    b. Carbon subsidies – using carbon taxes to subsidies GH_2 production.

    c. Low-cost finance through state-owned development finance institutions, to provide access to low-cost finance for GH_2 projects at preferential interest rates.

- Support to establish multilateral and bilateral sector commitments by importing countries to allow South African enterprises to access a fair share of the long-term supply agreements.

Support entrepreneurship for GH_2 market entry (SMEs)

- Continue and expand short-term financing schemes tailored to the specific needs of entrepreneurs in the GH_2 sector into the medium term.

- Develop a framework to integrate SMEs, with defined targets, in planned pilot projects and to outline the roles, responsibilities, and contributions of those to be involved. This framework could serve as the basis for collaboration and ensure effective coordination among all stakeholders.

Promote partnerships and networks

- Foster networks and communities of entrepreneurs in the GH_2 sectors. Encourage the formation of industry associations, networking events, and knowledge-sharing platforms. These platforms can provide entrepreneurs with opportunities to connect, collaborate, and learn from each other.

- Proactive engagement to support international collaborations and partnerships to promote technology transfer, market access, and knowledge sharing. Engage with global players in the GH_2 industries to explore joint ventures, joint research projects, and technology licensing agreements. Such partnerships will provide South African entrepreneurs with valuable expertise and business opportunities.

Promoting Skills Development in GH_2

- Engage with private sector companies operating in the PtX sector to secure not only their financial support for the required skills development programmes, but also their long-term commitment to work closely and align on communicating the GH_2 skills needs.

- Create specialised training centres or institutes focused on GH_2 technologies, applications, and processes. Invest in GH_2 focused educational programmes at academic institutions to accelerate technology development and to allow for a tailored knowledge transfer process from academia to project developers to local SMEs. This can be achieved through partnerships, joint ventures, and capacity-building initiatives that enable local workers to acquire the necessary expertise and experience in GH_2 technologies.

- Develop mechanisms to ensure the quality of skills development programmes. This may involve establishing industry standards for skills assessment and certification.

6 CONCLUSIONS

Ambitious national and global climate action provides for a range of opportunities in South Africa in the GH_2 and derivatives industry, with GH_2/PtX having the potential for export and to meet local demand. This analysis has provided an overview of estimated end use demand for PtX in five different applications (green ammonia for fertiliser and for export, methanol for marine bunker fuel, green steel, and SAF), based on the demand projections of WP 1C. It has also indicated the demand for crucial minerals (notably iridium and platinum), electrolyser capacity requirements, RE requirements, and the demand for GH_2 to serve these applications.

Under a "realistic" scenario, the market for PtX could grow from 1.2 Mt (in GH_2 equivalent) in 2030 to 2.93 Mt by 2050. More than half of PtX-derived demand for GH_2 in 2050 will be from ammonia for export, with the GH_2 demand being greatest between 2030 and 2040, requiring more than 80% of the projected GH_2 volumes. Production of the required GH_2 in 2030 requires approximately 10.9 GW of electrolyser capacity (requiring 14.9 tonnes of PGM) and 21.8 GW of renewables. The annual H_2 production increases to 9.4 Mt in 2040, requiring 5.3 GW electrolyser capacity (requiring 5.1 tonnes of PGM) and 10.7 GW of RE. By 2050, about 13.8 Mt of GH_2 is projected in the various applications, which will require 12.2 tonnes of PGM, 48 GW of RE capacity and 24.4 GW of electrolyser capacity.

The analysis also provided an overview of the range of GH_2 business opportunities along the GH_2 value chain, focussing on those technologies that have reached the value creation phase and beyond. South African companies demonstrate technological maturity in conversion technologies, including in Fischer-Tropsch and Haber-Bosch technologies. Furthermore, RE generation and PGM mining experience offer market diffusion and commercialisation opportunities for products and services across the GH_2 value chain segments. With roughly 90% of the world's known PGM reserves, South Africa could be well placed for the production of major components and products needed for electrolysers and fuel cells. Desalination technology is also already available and can be integrated into the upcoming pipeline of GH_2 projects, providing for business opportunities to market players in country.

The equipment manufacturing sector theoretically holds the largest opportunities for value creation for businesses, especially when it comes to producing components such as catalysts for GH_2 production and use, which are essential for the growth of the H_2 industry. As the demand for GH_2 is expected to increase, boosting the manufacturing of equipment will be crucial for the future development of new technologies aimed at making the production and utilisation of H_2 more efficient, cost-effective, and accessible. However, the equipment manufacturing segment is still at value creation stage as prototypes have been developed and market testing is taking place. Actual market diffusion remains uncertain, and upscaling will hinge on several factors including reliability of products after pilot outcomes and the uptake of demand in general. Similarly, electrolysers and fuel cell manufacturing, H_2 production, and equipment related to storage and transportation are at an early stage.

The SWOT analysis for each of the opportunities laid out the strengths and weaknesses and the opportunities and risks. Stakeholders and investors across the GH_2 value chain in South Africa are already active in the emerging GH_2 economy, but also are aware of the uncertainties due to the high complexity of the value chains, current lack of cost competitiveness, and fragmented or un-regulated domestic or international markets. Given the current state of the market, there is a risk to businesses. Fully integrated solutions and industrial-scale roll-out are yet to be implemented. First mover risks remain a real challenge to market participants. This is why both the supply and demand of GH_2 product(s) must be stimulated. Here, support is required such as blended finance and a range of de-risking instruments. Otherwise, the market ramp-up will remain challenging.

There will be significant demand for various skill sets and training, including technicians, engineers, and academic professionals in various areas of speciality. The GH_2 sector represents a substantial opportunity for the creation of new jobs and skill sets. Establishing these opportunities across the various value chain segments could act as a powerful engine of growth and development – creating decent job opportunities while driving significant capital accumulation and enhancing economic productivity. As South Africa is transitioning the economy towards GH_2, it will need to invest to provide for adequate skilling and upskilling to support the GH_2 roll-out.

Recommendations were provided with suggestions on short-term and mid-term actions which may be taken to support planned projects and initiatives, requirements to attain cost competitiveness, and assistance for entrepreneurs.

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APPENDIX 1: PROJECTIONS IN INDIVIDUAL GH_2 APPLICATIONS

Parameter	Ammonia for export		
	2030	2040	2050
Annual market potential (KTPA)	5,514	7,219	8,925
Annual H_2 equivalent (KTPA)	973	1,273	1,574
Average H_2 Output per Day (TPA)	2,666	3,489	4,313
Specific energy consumption (kWh/kgH_2)	48.73	46.27	43.80
Actual electrolyser capacity factor	60%	60%	60%
Nominal electrolyser capacity (additional to 2030)	9,022	2,188	13120
RE plant capacity factor: hybrid system	50%	50%	50%
Total Nominal Power Plant Capacity (MW)	18,043	4,377	26,239
Iridium loading (g/kW of electrolyser)	1.00	0.70	0.40
Platinum loading (g/kW of electrolyser)	0.37	0.23	0.10
Iridium loading (tonnes)	9.02	1.53	5.25
Platinum loading (tonnes)	3.31	0.51	1.31

Parameter	Ammonia for green fertiliser		
	2030	2040	2050
Annual market potential (KTPA)	307	1,110	1,733
Annual H_2 equivalent (KTPA)	54	196	306
Average H_2 output per day (TPA)	148	537	838
Specific energy consumption (kWh/kgH_2)	48.73	46.27	43.80
Actual electrolyser capacity factor	60%	60%	60%
Nominal electrolyser capacity (additional to 2030)	502	1,222	2,548
RE plant capacity factor: hybrid system	50%	50%	50%
Total Nominal Power Plant Capacity (MW)	1,005	2,445	5,096
Iridium loading (g/kW of electrolyser)	1.00	0.70	0.40
Platinum loading (g/kW of electrolyser)	0.37	0.23	0.10
Iridium loading (tonnes)	0.50	0.86	1.02
Platinum loading (tonnes)	0.18	0.29	0.25

Parameter	H_2 for green steel		
	2030	2040	2050
Annual market potential (KTPA)	106	106	212
Annual H_2 equivalent (KTPA)	106	106	212
Average H_2 output per day (TPA)	290	290	581
Specific energy consumption (kWh/kgH_2)	48.73	46.27	43.80
Actual electrolyser capacity factor	60%	60%	60%
Nominal electrolyser capacity (additional to 2030)	983	0	1,767

RE plant capacity factor: hybrid system	50%	50%	50%
Total Nominal Power Plant Capacity (MW)	1,966	-	3,533
Iridium loading (g/kW of electrolyser)	1.00	0.70	0.40
Platinum loading (g/kW of electrolyser)	0.37	0.23	0.10
Iridium loading (tonnes)	0.98	0.00	0.71
Platinum loading (tonnes)	0.36	0.00	0.18

Parameter	Green methanol		
	2030	2040	2050
Annual market potential (KTPA)	174	810	1,511
Annual H_2 equivalent (KTPA)	42	194	362
Average H_2 output per day (TPA)	114	531	991
Specific energy consumption (kWh/kgH_2)	48.73	46.27	43.80
Actual electrolyser capacity factor	60%	60%	60%
Nominal electrolyser capacity (additional to 2030)	386	1,321	3,016
RE plant capacity factor: hybrid system	50%	50%	50%
Total Nominal Power Plant Capacity (MW)	772	2,642	6,032
Iridium loading (g/kW of electrolyser)	1.00	0.70	0.40
Platinum loading (g/kW of electrolyser)	0.37	0.23	0.10
Iridium loading (tonnes)	0.39	0.92	1.21
Platinum loading (tonnes)	0.14	0.31	0.30

Parameter	SAF		
	2030	2040	2050
Annual market potential (KTPA)	6	170	1,100
Annual H_2 equivalent (KTPA)	2.7	74	478
Average H_2 output per day (TPA)	7.5	203	1,311
Specific energy consumption (kWh/kgH_2)	48.73	46.27	43.80
Actual electrolyser capacity factor	60%	60%	60%
Nominal electrolyser capacity (additional to 2030)	25	627	3,987
RE plant capacity factor: hybrid system	50%	50%	50%
Total Nominal Power Plant Capacity (MW)	51	1,253	7,974
Iridium loading (g/kW of electrolyser)	1.00	0.70	0.40
Platinum loading (g/kW of electrolyser)	0.37	0.23	0.10
Iridium loading (tonnes)	0.03	0.44	1.59
Platinum loading (tonnes)	0.01	0.15	0.40

APPENDIX 2: SKILL SETS ACROSS THE GH_2 VALUE CHAIN

Skills	Higher Technical Education	PhD	Engineering	Technician	Secondary Education	Level of GH_2 know-how required	Structuring / Finance / Legal	Design / Planning	Production/Manufacturing / Construction	Installation	O&M	Commissioning	PGM Mining	Fuel Cell / Electrolyser	Stack Manufacturing	Catalyst	BoP	MEA	Wind Turbines	Solar PV	RE Generation	H_2 Production	Conversion	Storage	Transportation
CEO / COO																									
Chief Engineer R&D																									
Business Developer																									
Project Management and Planning																									
Project Financing / Modelling																									
Legal / Regulatory Compliance																									
General Engineering																									
Geological Engineering																									
Metallurgical Engineering																									
Climate Engineering																									
Thermal Engineering																									

Skills	Higher Technical Education	PhD	Engineering	Technician	Secondary Education	Level of GH_2 know-how required	Structuring / Finance / Legal	Design / Planning	Production/Manufacturing / Construction	Installation	O&M	Commissioning	PGM Mining	Fuel Cell / Electrolyser	Stack Manufacturing	Catalyst	BoP	MEA	Wind Turbines	Solar PV	RE Generation	H_2 Production	Conversion	Storage	Transportation
Material Science Engineer																									
Hardware / Embedded Systems Engineer																									
Software Engineer																									
Mechatronics Engineer																									
Metrology																									
Modelling of Dangerous Phenomena																									
Power Electronics Engineer																									
Automation Engineer																									
Composites Engineer																									
Mechanical Engineer																									
Process Engineer																									
Plasturgy Design Engineer																									
Construction Design Engineer																									

Skills	Higher Technical Education	PhD	Engineering	Technician	Secondary Education	Level of GH_2 know-how required	Structuring / Finance / Legal	Design / Planning	Production/Manufacturing / Construction	Installation	O&M	Commissioning	PGM Mining	Fuel Cell / Electrolyser	Stack Manufacturing	Catalyst	BoP	MEA	Wind Turbines	Solar PV	RE Generation	H_2 Production	Conversion	Storage	Transportation
Control and Command Engineer																									
Test Engineer																									
Operations Engineer																									
Data Engineer																									
Maintenance Engineer																									
Development Engineer / Smart Grids																									
Electrochemical Engineer																									
Thermodynamics Engineer																									
Gas / Liquid Engineer																									
Project Designer																									
Production Line Operator																									
Technician on Industrial Sites																									
Analytical Chemistry																									

Skills	Higher Technical Education	PhD	Engineering	Technician	Secondary Education	Level of GH_2 know-how required	Structuring / Finance / Legal	Design / Planning	Production/Manufacturing / Construction	Installation	O&M	Commissioning	PGM Mining	Fuel Cell / Electrolyser	Stack Manufacturing	Catalyst	BoP	MEA	Wind Turbines	Solar PV	RE Generation	H_2 Production	Conversion	Storage	Transportation
Heavy Equipment Operator																									
Operator																									
Drilling / Blasting																									
Materials Handling																									
Supply Chain Management																									
Risk Operating Safety Engineer																									
Environmental Sustainability																									
Electrical Technician																									
Assembler																									
Plumber-Heat Engineer																									
ATEX Material Repairer																									
Metalworker																									
Welder																									
Fitter																									

Skills	Higher Technical Education	PhD	Engineering	Technician	Secondary Education	Level of GH_2 know-how required	Structuring / Finance / Legal	Design / Planning	Production/Manufacturing / Construction	Installation	O&M	Commissioning	PGM Mining	Fuel Cell / Electrolyser	Stack Manufacturing	Catalyst	BoP	MEA	Wind Turbines	Solar PV	RE Generation	H_2 Production	Conversion	Storage	Transportation
Certifier																									
Compliance Assessor																									
Works Project Manager																									
Safety Studies Manager																									
Boilermaker																									
Bus Driver																									
Train Drivers																									
Health and First Aid																									
Human Resources																									
Communication / Marketing																									