DNA Economics

sanedi
South African National Energy Development Institute

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

GREEN HYDROGEN SOUTH AFRICA

Green hydrogen research, objectives and needs in South Africa

Final Report

29 November 2023

Making economic sense of common problems

Confidential

This document is the final deliverable for the research study entitled "Review of current green hydrogen research activities, public sector objectives and private sector needs" that was prepared for SANEDI, with the support of GIZ.

Author

DNA Economics.

For more information, please contact Brett Cohen via e-mail at brett@thinka.co.za.

Citation

Not to be cited. Only for internal use.

DNA Economics

Hillcrest Office Park, Lourie Place, 2nd Floor, 179 Lunnon Street
Hillcrest, Pretoria, 0083

PO Box 95838, Waterkloof, 0145, South Africa

Tel +27 (0)12 362 0024 | **Fax** +27 (0)12 362 0210
Email contact@dnaeconomics.com | www.dnaeconomics.com

DNA is accredited as a level 2 (125%) B-BBEE contributor in terms of the Broad-Based Black Economic Empowerment Act (2003)

Contents

BOXES

FIGURES

TABLES

Abbreviations

CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CHIETA	Chemical Industries Education and Training Authority
CHP	Combined Heat and Power
COP	Conference of the Parties
CRES	Centre for Renewable and Sustainable Energy Studies
CSIR	Centre for Scientific and Industrial Research
DFFE	Department of Forestry, Fisheries and the Environment
DMRE	Department of Mineral Resources and Energy
DRI	Direct Reduced Iron
DSI	Department of Science and Innovation
dtic	Department of Trade, Industry and Competition
EWSETA	Energy and Water Sector Education Training Authority
GH_2	Green Hydrogen
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HRTEM	High Resolution Transmission Electron
HSRM	Hydrogen Society Roadmap
HYENA	Hydrogen Energy Applications
HySA	Hydrogen South Africa
IDZ	Industrial Development Zone
IRP2019	Integrated Resource Plan 2019
JET-IP	Just Energy Transition Investment Plan
LOHC	Liquid Organic Hydrogen Carrier
LPG	Liquefied Petroleum Gas
MEA	Membrane Electrode Assembly
Mintek	Council for Mineral Technology
NDC	Nationally Determined Contribution
NDP	National Development Plan
NMMU	Nelson Mandela Metropolitan University
NRF	National Research Fund
NWU	North-West University
PEM	Proton Exchange Membrane
PGMs	Platinum Group Metals
PtX	Power-to-X
RE	Renewable Energy
REIPPPP	Renewable Independent Power Producer Programme
R&D	Research and Development
SA	South Africa
SAIIA	South African Institute of International Affairs
SANEDI	South African National Energy Development Institute
SAPVIA	South African Photovoltaic Industry Association
SARChI	South African Research Chairs Initiative
SAWEA	South African Wind Energy Association
SASSCAL	Southern African Science Services Centre for Climate Change and Adaptive Land Management
SEERU	Sustainable Energy and Environment Research
SEZ	Special Economic Zone
SMME	Small, micro and medium sized enterprise
SOFC	Solid Oxide Fuel Cell
TETA	Transport Education and Training Authority
TIA	Technology Innovation Agency
TIPS	Trade and Industrial Policy Strategies
ToR	Terms of Reference

TUT	Tshwane University of Technology
TVET	Technical and Vocational Education and Training
UCT	University of Cape Town
UFS	University of the Free-State
UJ	University of Johannesburg
UNISA	University of South Africa
UWC	University of the Western Cape
VUT	Vaal University of Technology
Wits	University of the Witwatersrand
WSU	Walter Sisulu University of Technology

1. Introduction

One of the mandates of the South African National Energy Development Institute (SANEDI) is to help catalyse sustainable energy innovation, transformation, and technology diffusion, including in the emerging and potentially transformative green hydrogen (GH_2) sector. To help support their work in this area, SANEDI, with support from GIZ under the H2.SA project, commissioned DNA Economics to conduct a review of the status quo and gaps in GH_2 research in South Africa (SA). The project sought to achieve five high-level outcomes, as outlined in the Terms of Reference (ToR):

1. Provide an overview of current GH_2 research activities that are underway at SA Universities, Universities of Technology, Science Councils, and other research institutions
2. Outline the alignment of current GH_2 research activities with public sector GH_2 policy objectives and private sector needs/ priorities
3. Identify common themes and priorities in the research, towards identification of possible future research gaps
4. Compile a profile of the GH_2 researchers actively working in the field
5. Make recommendations on future GH_2 research focal areas for SA

It is intended that the project findings will enhance collaboration between the public sector, private sector, academia, and industry associations regarding research, innovation, and commercialisation of the GH_2 research portfolio within SA. The findings will also support informed decisions on guiding the focus of future research activities to meet both public sector objectives and private sector needs.

A desktop review of publicly available information was developed as the first deliverable under the project. It was then used as a basis from which to engage in extensive consultations with relevant stakeholders to gather further information on current research themes, priorities, and gaps and make recommendations for future GH_2 research. This final review report combines the information collected via both the desktop review and the stakeholder consultations, and is structured as follows:

- Section 2 outlines the GH_2 value chain and the approach to collating and structuring the review
- Section 3 provides an analysis of public sector policies and strategies to identify GH_2 objectives towards identifying how these might guide research activities
- Section 4 collects information on current GH_2 research activities at South African Universities, Universities of Technology, Science Councils, and other Research Institutions
- Section 5 provides an analysis of private sector needs in terms of supportive research requirements.
- Section 6 identifies gaps in the research using the literature review and stakeholder consultations
- Section 7 concludes, making recommendations for future GH_2 research

2. The GH_2 value chain and review approach

2.1 Overview of the GH_2 value chain

The review considers the entire GH_2 value chain as shown in Figure 1, which is notionally divided into upstream, midstream and downstream activities. These activities include not only the process inputs and the production of GH_2 and its derivative products, but also consider technology development and deployment, and transport and storage infrastructure, amongst others. Furthermore, to drive investment in GH_2 production it is critical that markets for the products are considered.

Some specific examples of the activities along the value chain include:

- Large-scale renewable energy (RE) generation, primarily wind and solar, and supporting electricity transmission infrastructure
- Development, manufacture and roll-out of electrolysers, which are the process units at the core of the process that splits water into hydrogen and oxygen for hydrogen production. Global scale up of efficient electrolyser production to meet growing GH_2 demand requires significant research and development, engineering expertise, and investment. Linked to this activity is the production of platinum group metals (PGMs) which are used as catalysts in some electrolyser designs
- Conversion of GH_2 to a range of beneficiated products for downstream use or to facilitate decarbonisation of industrial sectors such as transport, steel, ammonia, and aviation
- Development and operation of transport and storage infrastructure. Hydrogen has different characteristics to other energy carriers, requiring specialised infrastructure for storage, distribution, and handling. Developing an extensive network of hydrogen pipelines, storage facilities, and filling stations is a complex and capital-intensive endeavour
- Development of and integration into different market applications

The complexity of the value chain highlights the need for collaboration and coordination among various stakeholders including governments, industry players, and financial institutions across production, technology development, infrastructure, end-use applications, and market development. Furthermore, activities need to be underpinned by supportive policies and regulatory frameworks, research and development (R&D), and incentivising investment.

2.2 Methodology

For the purposes of compiling this research review, information was sourced from a desktop review and interviews with stakeholders.

Desktop review: In compiling the desktop review, information on current GH_2 research activities across the value chain was obtained from the following sources, with the full list of literature consulted being included in Appendix A:

- Reports and status updates on proposed GH_2 projects as found in the public domain, including those identified in the speech by Minister of Public Works and Infrastructure (Patricia De Lille) at the South African Green Hydrogen Conference Summit on 29 November 2022 (Department of Public Works and Infrastructure, 2022a)
- Public sector policies and strategies, as well as related documentation downloadable from web pages of government departments

- Internet searches to identify research activities at South African Universities, Universities of Technology, Science Councils, and other Research Institutions
- Annual reports and other online information on private sector stakeholders

Google and Google Scholar were used to highlight any research not identified through the previous steps[1].

Stakeholder interviews: Stakeholder consultations were used to complement the desktop research, towards providing a comprehensive review of current GH_2 research activities and results. Stakeholder consultations were in the form of semi-structured interviews. The consultations were used to collect information on the current GH_2 research activities, and the alignment of current GH_2 research activities with the public sector GH_2 policy objectives and private sector needs/ priorities. **This allowed the team to identify common themes and priorities in the research, as well as identify possible gaps that are not being covered. It also allowed the team to compile a profile of the GH_2 researchers actively working in the field and to make recommendations on future GH_2 research focal areas for South Africa**.

The data gathered through the desktop review and interviews was then organised into three categories: Public sector policies and strategies; Current GH_2 research activities; and Private sector research and supportive research requirements.

Information was then further analysed to both highlight common research topics being pursued across the country, and to help identify where possible gaps may lie. This was done by colour coding activities according to where they are located in the value chain as follows (see also Figure 1 for full value chain):

GH_2 Production – Equipment – Electrolysers

GH_2 Production – Equipment – Membranes

GH_2 Production – Equipment – Balance of Plant

Fuel and fuel cell usage – Equipment – Fuel cell catalysts

Fuel and fuel cell usage – Equipment – Other

Hydrogen beneficiation – processes and products (e.g., production of ammonia using the Haber Bosch process and hydrocarbons via Fischer Tropsch)

Storage, transport and safety - Research

Storage, transport and safety - Pilots

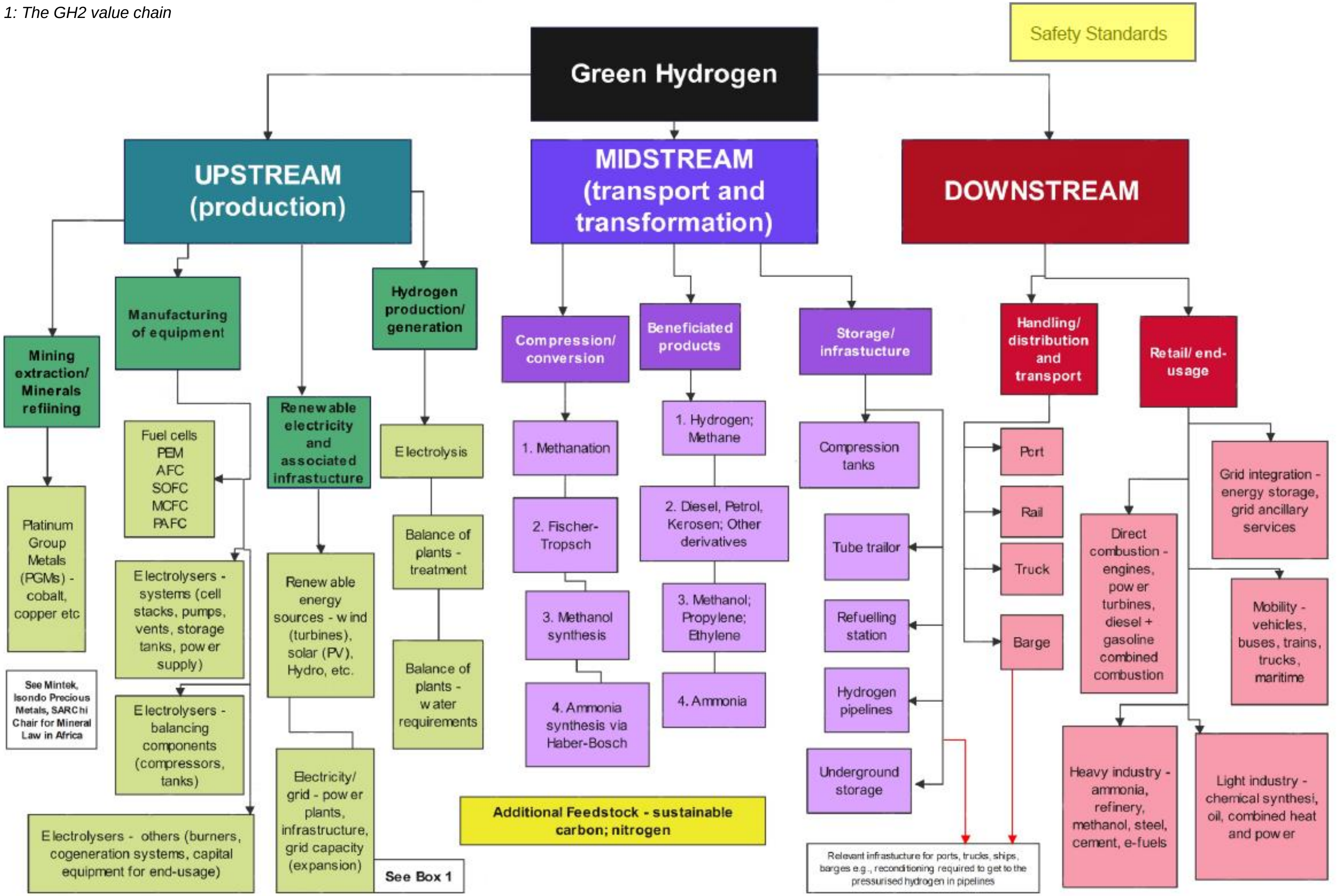
Commercialisation

Policy and overarching support

---

[1] *Search terms used here included: "green hydrogen research South Africa", "green ammonia research South Africa", "hydrogen research in South Africa", "green hydrogen South Africa", "fuel cell research in South Africa", "electrolyser research in South Africa", "sustainable aviation fuel research in South Africa", "PtX research in South Africa", "hydrogen component manufacturers in South Africa", and "green steel research in South Africa".*

Figure 1: The GH2 value chain



Three sectoral workshops: Used to engage with stakeholder groupings:

- Workshop 1: A kick-off workshop for the project was held online on 19 September 2023. At this workshop, the project team presented an introduction to the study and some initial findings from a desktop review based on publicly available literature. Feedback from attendees on the initial findings of the review, as well as suggestions on how best to leverage maximum benefit from the project was recorded. Attendees were also encouraged to engage with the project team during the interview process
- Workshop 2a and 2b: Once the draft research review was finalised, workshops 2a and 2b were conducted. Workshop 2a was held online on 27 October 2023, with stakeholders from research institutions and the public sector. Workshop 2b was held online on 9 November 2023, with stakeholders from the private sector. Both these workshops were used to present the study's preliminary findings and obtain stakeholder inputs on these findings, which were then integrated into the draft research review
- Workshop 3: With the findings from workshops 2a and 2b adding useful insights into the preliminary findings, a final hybrid (in-person and online) workshop was held on 17 November 2023 in Pretoria. At this workshop the draft results were presented, and final inputs obtained from attendees

More information regarding the attendance, discussions, and findings from these workshops can be found in Appendix F.

3. Review of public sector policies and strategies and links to research

A range of public sector policies and strategies that have direct or indirect implications for the GH_2 value chain in South Africa have been developed, including a number which have direct implications for research. From Table 1 it can be seen that these policies and strategies focus on energy security, decarbonisation of the energy system, environmental sustainability, economic growth, job opportunities, and harnessing pre-existing industrial capabilities.

Table 1: Analysis of public sector policies and strategies

Strategy / Document	Author/ Entity	Year	Relevance to this study
South Africa's Nationally Determined Contribution (NDC)	DFFE	First published in 2015 and updated in 2021	Provides targets to support decarbonisation of the SA economy, with emissions to be within the range of 398-510 Mt CO_2-eq for 2025, and 398-440 Mt CO_2-eq for 2030. Notes the aspiration to set a 2050 net zero commitment as presented in the country's Low Emission Development Strategy (SA LEDS) (DFFE, 2021). GH_2 could potentially play a role in meeting emissions targets.
The Just Energy Transition Investment Plan (JET- IP)	The SA Presidency	2022	Response to a commitment of USD 8.5 billion from the United States, the United Kingdom, France, Germany and the European Union, to be used for the country's transition to a green economy, with a focus on the phase out of coal. Aims of the JET-IP include establishment of a long-term partnership to support low emissions and climate resilient development in SA, acceleration of the just transition, decarbonisation of the electricity system, and development of new economic opportunities (The Presidency, 2022). A ZAR 319 billion funding requirement is identified for GH_2 between 2023 and 2027[2], representing 21.6% of the overall JET funding requirements.
Integrated Resource Plan (IRP2019)[3]	Gazetted by the DMRE	2019	Electricity infrastructure development plan that is based on least-cost electricity supply and demand balance to 2030 (DMRE, 2019). Supports a diverse energy mix, setting out nine policy decisions to ensure the security of electricity supply. The plan considers environmental concerns associated with carbon emissions and water consumption. Although RE is included, GH_2 is not mentioned explicitly in this plan.
Renewable Energy Independent Power Producer Programme (REIPPPP)	SA Government initiative	Bid Window 1 in 2011 to Bid Window 6 in 2022.	Aimed at bringing additional RE capacity onto the country's electricity system through private sector investment (DMRE, DBSA, National Treasury, 2023). Supports the development of the RE value chain.

[2] See: https://www.climatecommission.org.za/publications/sa-jet-ip

[3] An updated IRP2023 has been announced but was not available at the time of writing this report

Strategy / Document	Author/ Entity	Year	Relevance to this study
The 2030 National Development Plan (NDP)	The SA Presidency	2012	The NDP seeks to eradicate poverty and decrease inequality by 2030. The strategy envisions harnessing the efforts of its citizens, fostering a comprehensive economy, developing skills, strengthening governmental capabilities, and encouraging leadership and collaboration across all of society (National Planning Comittee, 2012). The NDP foresees a scenario where, by 2030, SA's energy industry will deliver dependable and effective energy services at competitive prices. This energy sector will also exhibit social fairness by extending energy accessibility at affordable rates, while maintaining environmental sustainability through decreased emissions and pollution. Although not mentioned explicitly, GH_2 could potentially play a role here.
Government strategies related to IDZs / SEZs. Including Atlantis, Coega, Dube Tradeport, East London, Maluti-A-Phofung, Musina/Makhado, Nkomazi, OR Tambo, Richards Bay, Saldanha Bay, Tshwane and Vaal.	A dedicated unit at the dtic is responsible for policy development around IDZs.		SEZs/ IDZs are hubs for fostering innovation, research, and development. They also seek to encourage collaboration between businesses, universities, research institutions and manufacturing start-ups (GTAC, 2021). The Vaal SEZ Centre of Excellence is focusing specifically on the hydrogen economy knowledge and skills in partnership with VUT, FETs (Labs & Testing Facilities). The aim is to provide skills upgrades to about 1000 job seekers to be employed in the Valley together with the Department of Labour/ SETA's (Mitochondria, 2022). Other SEZs/ IDZs focusing on GH_2 include Coega, Dube Tradeport, OR Tambo and Saldanha Bay.
HySA Strategy	HySA	2008	HySA is a long-term (15-year) Hydrogen and Fuel Cell Technologies Research, Development, and Innovation National Flagship programme that focuses on the country's large PGM resources. HySA comprises of 3 Centres of Competence: HySA Catalysis, HySA Infrastructure and HySA Systems. These Centres have all produced their own research. The aim is to develop SA intellectual property, knowledge, human resources, products, components, and processes to support participation with international platforms in hydrogen and fuel cell technologies.
The South African Hydrogen Society Roadmap (HSRM)	DSI	2021	A national coordinating framework, approved by cabinet, to facilitate the integration of hydrogen-related technologies in various sectors of the economy. The Hydrogen Valley Feasibility Study Report is an essential component of the HSRM. The core objective is to stimulate economic recovery, in line with the Economic Reconstruction and Recovery Plan (ERRP). The HSRM signals an objective of producing 500,000

Strategy / Document	Author/ Entity	Year	Relevance to this study
			tonnes per annum of GH_2 by 2030 and deploying 10 GW of electrolysis capacity in the Northern Cape region by 2030 and 15 GW by 2040 (GH2, 2023).
South African GH_2 Commercialisation Strategy	DSI	2022	Describes opportunities and benefits that can be derived for SA from GH_2, seeks to align to national objectives and be responsive to competitive market drivers and success factors. It also suggests options and focused actions. Builds on the findings of the interim report of the HSRM and the Hydrogen Valley Feasibility Study (DSI, Anglo American Platinum, Bambili Energy, Engie, 2021), looking into opportunities to transform the Bushveld complex and larger region around Johannesburg, Mogalakwena and Durban into a Hydrogen Valley.

4. Current GH_2 research in South Africa

This section now considers the current GH_2 research activities at South African Universities, Universities of Technology, Science Councils, and other Research Institutions. Information is provided on where the research fits into the value chain (see Figure 1), research outputs, and local and international collaborations. Information was acquired from publicly available sources and further confirmed in the stakeholder engagements held with some of these entities.

4.1 Research groups

4.1.1 HySA Catalysis

Upstream: Manufacturing of equipment (fuel cells and electrolyser systems).

HySA Catalysis is a Centre of Competence co-hosted by Mintek and the University of Cape Town's (UCT's) Department of Chemical Engineering. It is an application-driven research institute focusing on the development of materials, components, and units in the early part of the fuel cell and hydrogen generation value chain, from research through to the development of prototypes (UCT, 2023a). The Centre has three current and potential future focus areas:

1. **Fuel cells**: Research on non-carbon support materials and nanofiber-based catalyst and support structures. Development of advanced catalysts, electrode structures, and membrane electrode assemblies (MEAs) - for low temperature polymer electrolyte fuel cell applications (stationary and back-up power). Customer-specific stack development work for niche applications (e.g., aerospace, UAV, and rural electrification)
2. **Fuel to hydrogen**: Research on advanced platinum group metal (PGM) catalysts and high throughput catalyst experimentation. Development of integrated fuel processors, microchannel based reactor modules, and catalyst coated methods for microchannel reactors. Fuels being considered are propane, LPG, and methanol
3. **Proton exchange membrane (PEM) electrolysis**: This is a future research pipeline

Technologies which show potential move to product development and commercialisation at HyPlat, the commercialisation arm of HySA Catalysis (Section 4.1.2 below). Opportunities (including funding) are available for international and local students for postgraduate study, across a wide range of disciplines and topics, as well as for industry involvement through active research collaborations.

Research outputs

Between 2013 and 2020, HySA Catalysis published 31 research papers in various academic journals. A full list is available on their website.

Collaborations

HySA Catalysis has partnered with FlyH2 Aerospace, the University of the Western Cape (UWC), the University of KwaZulu-Natal (UKZN), North-West University (NWU), Nelson Mandela Metropolitan University (NMMU), Mintek, the Centre for Scientific and Industrial Research (CSIR), Greenlight Innovation, Hot Platinum, the Paul Scherrer Institute, Powertech, and the Western Cape Tooling Initiative.

4.1.2 HyPlat

Upstream: Manufacturing of equipment (fuel cells and electrolyser systems).

Hyplat is a specialist fuel cell technology company that is a 100% owned subsidiary of HyPlat IP (Pty) Ltd, and is the commercialisation arm of HySA Catalysis. Hyplat is focused on delivering MEAs and platinum-based catalysts to the low temperature PEM fuel cell industry (HyPlat, 2023). The vision is to not only develop fuel cell supply chains in SA with local manufacturing partners, but also establish SA as major global exporter of catalysts and fuel cell components.

Research outputs

Exclusive licences for Intellectual Property (owned by UCT and Mintek).

Collaborations

HyPlat has partnered with the DSI and Bambili Energy and Bambili Group (HyPlat, 2023), and aims to be a global supplier of fuel cell components to the industry by providing innovative technology at competitive prices.

4.1.3 HySA Infrastructure

Upstream: Manufacturing of equipment (fuel cells).

Midstream: Compression/conversion (electrochemical hydrogen compression and separation); Storage/infrastructure (systems integration, LOHC, reticulation, delivery, safety and codes).

HySA Infrastructure is a HySA Centre of Competence co-hosted by North-West University (NWU) and the CSIR. Objectives include the development of hydrogen production systems and prototypes as well as hydrogen storage and distribution technologies. Research and development at HySA Infrastructure is focused on product development, including activities related to (HySA Infrastructure, 2023):

- PEM electrolysers and electrolyser systems
- Electrochemical hydrogen compression and separation
- Hydrogen storage (other than metal hydride systems) with a focus on liquid organic hydrogen carriers (LOHC)
- Hydrogen reticulation, delivery, safety, and codes
- Systems integration (solar-to-hydrogen production, delivery and storage)
- Providing GH_2 for fuel cell testing
- Assessment of risks of storage of hydrogen for use in underground mining and tunnelling

Research outputs

HySA Infrastructure has published a range of research papers in the academic literature, books, chapters in books, online encyclopaedia articles, dissertations, and conference and workshop presentations – with a full list being available on their website. The Centre currently has four patents (activation compounds for hydrogen generation, method and apparatus for hydrogen generation, a microchannel reactor and method for decomposition of ammonia, and membrane electrode assembly comprising a catalyst migration barrier layer), one patent application, one trademark, and three trademark applications (HySA Infrastructure, 2023).

Collaborations

- **Research:** CSIR, and a collaboration on micro-channel reactors with the Fraunhofer Institute (Germany)
- **Industry**: Anglo American Platinum (Amplats), Hydrogenous LOHC Technologies (stationary LOHC infrastructure - Germany), and Areva engineering and design (Germany)
- **Funding:** DSI and Amplats

4.1.4 HySA Systems

Upstream: Manufacturing of equipment (fuel cells); Manufacturing of equipment (electrolyser systems – cell stacks).

Midstream: Storage/infrastructure (metal hydride tanks); Compression/conversion (metal hydride hydrogen compressors); Beneficiated products

HySA Systems is a Systems Integration and Technology Validation Centre of Competence hosted by UWC at the South African Institute for Advanced Materials Chemistry (SAIAMC) (UWC, 2023a). The main objectives of HySA Systems are to (UWC, 2023b):

- Develop hydrogen fuel cell systems, demonstrators, prototypes and products
- Explore technology validation and system integration
- Conduct system-oriented material research and design (R&D) to support two key HySA-programmes - combined heat and power, and hydrogen fuel cell vehicles

Research activities include those focusing on high temperature MEAs, high temperature PEM fuel cells, metal hydrides for hydrogen storage and compression systems, hydrogen fuel cell/battery power modules, palladium membranes, and lithium-ion batteries.

HYSA Systems has laboratories to conduct hydrogen research, with fuel cell testing stations; a membrane electrode assembly manufacturing facility; a bipolar plate manufacturing for fuel cell stacks using computer numerical control (CNC) milling and etching facilities; a hydrogen storage facility including materials synthesis and compressors using metal hydride technology; and a fuel cell vehicle testing platform (SAIMM, 2023).

Research outputs

HySA Systems has published research in international and peer-reviewed high impact factor journals and has successfully implemented pilot plant manufacturing facilities/ capabilities for hydrogen fuel cell components and systems (Pollet, et al., 2014). Their innovation has resulted in the generation of Intellectual Property in key hydrogen fuel cell technologies.

HySA Systems prototypes include a 1 kWe high temperature PEM fuel cell combined heat and power system that delivers electrical power and thermal energy for households, a 2.5 kW fuel cell generator, and a fuel cell-battery hybrid powered golf cart. In addition, HySA Systems has produced several demonstrators including an e-Bike with fuel cell range extender, an educational kit, a fuel cell motorbike, high temperature MEAs, a high temperature PEM fuel cell stack, and the MellowCab.

Collaborations

HySA Systems is supported by the DSI and has partnered with key international hydrogen fuel cell and local industries, established a local supply chain of small, micro and medium enterprises (SMMEs), and set up industrial/commercial agreements with national/international hydrogen fuel cell players.

Within HySA Systems, SAIAMC collaborates with Sasol, PetroSA, Keren Energy, Sakhumnotho, Cape Stack and Namaqua Engineering. SAIAMC is involved in a joint venture with Keren Energy, Sakhumnotho, Cape Stack and Namaqua Engineering, acting as the lead technology and skills development partner on a GH_2 proof of concept project in Vredendal (UWC, n.d.).

4.1.5 Centre for High Resolution Transmission Electron Microscopy (HRTEM)

Upstream: Manufacturing of equipment (fuel cells).

This research centre at the Faculty of Science at NMMU is a facility for advanced electron microscopy research of materials from the micro to atomic scale (NRF, 2023). The centre engages in three activities - human capacity development (training for post-graduate students, staff and students from other institutions and private companies), basic and applied research, and contract research. One of the key areas that it is focused on is fuel cell and catalyst research for use in the hydrogen economy.

Research outputs

The centre has published a range or research papers in various academic journals – a full list is available on their website (NMMU, 2023).

Collaborations

The centre was established through a DSI and NRF grant at the NMMU, with additional funds from various other sponsors. Founding sponsors include the Department of Higher Education and Training (DHET), Sasol, and GHO Ventures. The centre undertakes multi- and cross-disciplinary, grant-funded research in co-operation with local and international collaborators.

4.1.6 Hydrogen Energy Applications (HYENA)

Upstream: Manufacturing of equipment (fuel cells); Hydrogen production.

HYENA is a spin-off company from the Department of Chemical Engineering at UCT. Their focus is on applications of hydrogen-based electric power, including integrated hydrogen generators and fuel cells that produce electricity in the range of 5 to 20 kWe (small to medium-sized standalone systems). Their POWER POD product is a diesel generator replacement technology that produces on-site and on-demand electricity using existing LPG infrastructure – although this could transition to using "green" gas made from hydrogen. Electricity generation takes place in two steps. In the first step, HYENA's proprietary technology is used to produce a hydrogen-rich stream and in the second step, the hydrogen is converted into electricity by the in-built fuel cell.

HYENA is the commercial partner in the project GreenQUEST – which is the R&D project to make green Liquefied Petroleum Gas (LPG) from GH_2. This project is looking to produce a sustainable replacement for LPG gas (short and small hydrocarbons mainly used for cooking fuel). The company is developing a process that would produce LPG replacements (green liquified fuel gases) directly from CO_2 and GH_2. LPG is a versatile fuel that can be used in a wide range of applications, not only in industry but also for cooking, heating, and hot water for households.

Collaborations

There has been interest shown by commercial gas companies in the GreenQUEST project, but at this stage these industrial partners act more as an observer, as the product has not reached technology readiness. The team is also working with the CSIR on the storage containers need to be developed for this gas to replace current cooking fuels, as well as NMMU, SASSCAL, and several research groups at UCT.

4.1.7 c*change

Midstream: Compression/ conversion (Fischer Tropsch).

c*change is a NRF and DSI Centre of Excellence hosted by the Catalysis Institute in the Department of Chemical Engineering at UCT. It consists of a national network of 10 higher education institutions and over 14 research groups. c*change focuses on three research areas that potentially have relevance in the emerging GH_2 industry (c*change, 2023):

- **Paraffin activation** - the potential to use large volumes of carbon-based feedstock in the form of linear alkanes
- **Synthesis gas conversion** - Fischer-Tropsch synthesis, methanation, and preferential CO oxidation (with an emphasis on product formation)
- **Olefins** – development of mainly homogeneous catalytic processes to tap into the large volume stream of even and unevenly chained primary olefins originating from the Fischer-Tropsch process

Research outputs

Even though not all directly relevant to GH_2, as of 2020 c*change had published numerous peer reviewed journal publications (203 with an impact factor > 2 and 78 with an impact factor < 2), 33 published conference proceedings, 6 books or book chapters, 645 un-published conference proceedings, and 36 provisional or granted patents produced (c*change, 2020). For example, patents on the in-situ X-Ray Reaction Cell have been licensed to Cape Catalytix (Pty) Ltd and the product is now commercially available. c*change is also involved in the development of schools' curriculum teaching materials and content.

Collaborations

NRF and DSI Centre of Excellence - 10 partnering universities nationwide including UCT, Stellenbosch University, UWC, UJ, UKZN, University of Limpopo, University of Witwatersrand, University of the Free-State (UFS), University of South Africa (UNISA), and NWU.

4.1.8 CSIR hydrogen storage facility

Upstream: Renewable electricity and associated infrastructure; Hydrogen production.

Midstream: Storage/infrastructure; Beneficiated products (power fuels used in industry applications).

The CSIR is a scientific and technology research organisation that conducts research, development, localisation, and diffusion of technologies towards contributing to industrial development and accelerating socioeconomic prosperity. The CSIR is co-host of HySA Infrastructure, where they are developing porous materials-based hydrogen storage technologies and high-pressure composite cylinders for lightweight applications (CSIR, 2023).

Research activities

Research activities and pilots include (CSIR, 2023):

- Combustion and gasification pilot plant: Studying and piloting cleaner energy alternatives for industry
- Hydrogen storage facility: Equipped for innovative hydrogen storage technologies
- Battery research centre: Developing materials-based technologies for energy storage systems
- Photovoltaic testing facility
- Photovoltaic power plant

Research outputs
Outputs can be found on the organisation's website, including for example, the Powerfuels[4] and GH_2 programme study (Roos & Wright, Powerfuels and Green Hydrogen (public version), 2021), commissioned by the EU-SA Partnership, as well as 'The cost of production and storage of renewable hydrogen in South Africa and transport to Japan and EU up to 2050 under different scenarios' published in the International Journal of Hydrogen in 2021 (Roos, 2021).

Collaborations
30% of the CSIR funding comes from Parliament grants through the DSI. Specific to GH_2 related research, collaborations include those with HySA Infrastructure, EU-SA Partnership, SASSCAL, and KfW. The CSIR and ArcelorMittal South Africa have signed a memorandum of understanding on developing strategies for GH_2 as well as green innovative direct reduced iron (DRI) and low carbon intensity steel based on GH_2 (ArcelorMittal, 2023).

4.1.9 Sustainable Energy and Environment Research Unit (SEERU)

Upstream: Manufacturing of equipment (fuel cells); Hydrogen production.

Midstream: Compression/conversion.

Located at the University of the Witwatersrand (Wits), this research team's objective is to advance knowledge by conducting research required for the production of clean and/or renewable energy (Wits, n.d.). Working within the chemical, energy and environmental sectors, the aim is to promote both the development and the commercialisation of local technology solutions. A number of the research areas have relevance to the GH_2 industry.

Research outputs
The group has established itself in the following research areas:

- Clean and/or renewable Energy Production (biofuels, hydrogen for fuel cell)
- Catalysis and Reaction Engineering (Catalyst design, synthesis, characterisation and testing, reactor design and optimisation, Fischer Tropsch synthesis)
- Sustainable Environmental Technology (wastewater treatment, bio-desulphurisation & CCUS)
- Waste-to-Energy and Waste-to-Resources (waste beneficiation and the bio-based economy)
- Novel Separation Technologies (membrane-based and hybrid/ reactive separation processes)

Collaborations
SEERU collaborates with the CSIR (Energy and Process Unit), NWU, the University of South Africa (UNISA), and the Wits School of Chemistry.

4.1.10 Council for Mineral Technology (Mintek)

Upstream: Mining extraction/minerals refining; Manufacturing of equipment (fuel cells); Manufacturing of equipment (electrolysers)

The Council for Mineral Technology, known as Mintek, is a national mineral research organisation that specialises in mineral processing, extractive metallurgy, and related fields. Mintek is also the co-host for HySA Catalysis, discussed above. Mintek focuses on the following research, technology, and innnovation:

[4] *Fuel based on H_2 from the electrolysis of water using RE*

- Mineral processing and characterisation support the initial stages of the mineral value chain
- Extractive metallurgy focuses on efficiency and sustainability in mining
- Mining, materials, and automation provides services in mining, beneficiation, process control and automations, and post-mining

Relevant to GH_2, Mintek has focused on platinum-based catalysts with applications in PEM fuel cells and some electrolysers (on the cathode side). Historically, Mintek has done testing on fuel cells and UCT have researched electrolysers – specifically the anode catalysts using SA's iridium stores. Through the Catalysis Group, specifically HyPlat, Mintek has pursued opportunities to commercialise its fuel cell intellectual property by building capacity for fuel cell manufacturing and scaling production to commercially relevant quantities (Mintek, n.d.).

Looking ahead, Mintek aims to enter commercial scale production of MEAs, having secured private funding, and are currently engaging with the Technology Innovation Agency (TIA) on the production opportunity. Mintek is currently at the early stages of this project but hope to be running the facility for commercial production by 2030. MEAs can be used in both fuel cells and electrolysers, with Mintek expecting to produce the capacity required for local demand, so as to be able to supply any local manufacturer of fuel cells or electrolysers.

Research outputs

Mintek has published a range of research papers, books, and book chapters – a full list is available on their website and in their annual reports. As discussed above, Mintek is also planning to open a commercial-scale MEA production plant building on their research.

Collaborations

Mintek is overseen by the DMRE. It collaborates with UCT as co-hosts of HySA Catalysis. Mintek's clients include other state enterprises, large multinational mining companies, junior mining companies, engineering contractors, and SMMEs locally and internationally (Mintek, 2022).

4.1.11 Tshwane University of Technology (TUT)

Upstream: Manufacturing of equipment (fuel cells); Hydrogen production.

Midstream: Storage/ infrastructure.

TUT has introduced a project focused on hydrogen energy research and 4IR curriculum development (Tshisikhawe, 2023). This project will include research on hydrogen production, hydrogen storage, fuel cell technologies, system optimization, energy integration as well as the decarbonization of the value chain to produce GH_2.

Collaborations

Tshwane University of Technology will partner with the Technological Higher Education Network South Africa (THENSA) and Irish Universities.

4.1.12 Vaal University of Technology (VUT)

Upstream: Manufacturing of equipment (fuel cells).

Downstream: Heavy industry (green steel)

VUT's Centre for Alternative Energy has a focus on fuel cells research and has grown to a point that a novel membrane has been developed and manufactured (Vaal University of Technology, 2023). VUT believes that this research will pay an important role in green energy generation, GH_2, and green steel.

Collaborations

A Memorandum of Understanding has been signed between VUT, NWU and the Vaal Special Economic Zone (SEZ).

4.1.13 Walter Sisulu University of Technology (WSU)

Upstream: Hydrogen production (water requirements).

WSU engages in research activities that focus on the development of hydrogen fuels from salt water (Hermans, n.d.).

4.2 Private advisory and consultancy services

Independent consultants and research advisories engage in various research activities associated with the SA GH_2 value chain (from an analytical and advisory perspective). The list shown in Table 2 is not comprehensive, but includes some of the important research outputs.

Table 2: Private sector advisory and consultancy services research output

Entity	Overview	Published research	Value chain relevance
GreenCape	Non-profit working with business, government, and academia.	Market intelligence reports - Large-scale Renewable Energy & Supplier Database for Renewable Energy Stakeholders (GreenCape, 2022a; GreenCape, 2022b). Annual market intelligence reports and databases for large-scale renewable energy and supplier database for stakeholders.	RE (see Box 1).
PwC	PwC is involved in a wide range of GH_2 research	Research report - Unlocking South Africa's hydrogen potential (Metcalfe, Burger, & Mackay, 2020), which considers SA as an exporter of cost-competitive GH_2.	RE (see Box 1), hydrogen production, beneficiation, and end-usage.
Rebel Group	Dutch-headquartered advisory and consultancy – has worked on fuel cell technologies with HySA and done hydrogen economic impact work with the DSI. Collaboration with LBST (German producer of sustainable energy).	Scoping study - Promoting the development of a hydrogen economy for South Africa (Rebel Group, 2023). This study aims to create specific recommendations on standards and norms that would be advantageous for the SA hydrogen economy.	Strategy.
Genesis Analytics	Genesis Analytics is a global economic consultancy.	Project - Making South Africa's Just Energy Programme a reality (Genesis Anlaytics, 2022-2023). Strategic advice and recommendations regarding the resource mobilisation and coordination function for the JET IP. This includes the implementation and financing of the electricity, electromobility and GH_2 sectors.	Strategy.
TIPS	An independent, non-profit, economic research institution. Partners in the dtic, GTAC, and the City of Johannesburg.	Research report - Green hydrogen: A potential export commodity in a new global marketplace (Patel, 2020). Emerging export opportunities for SA in the development of GH_2, as well as trade-related risks.	Hydrogen production and end-usage.

DNA Economics and GFA Consulting Group	GFA and DNA Economics are independent consulting companies.	The report entitled "Renewable H2 market potential and value chain analysis" was commissioned by GIZ, and implemented by GFA Consulting Group and DNA Economics. It forms part of the overall project "Promoting the development of a hydrogen economy in South Africa (H2.SA)".	Strategy along the value chain - market potential, business opportunities and job potential.
South African Institute of International Affairs (SAIIA)	SAIIA is an independent public policy think tank.	The South African GH_2 TVET Ecosystem Just Transition Strategic Framework - models the potential employment impacts of GH_2 in SA, using four quantitative scenarios for employment in the GH_2 economy. These include 'Business as usual', 'Value-added manufacturing', 'Status quo with domestic hydrogen use', and 'All-inclusive portfolio' (SAIIA, DSI, DHET, 2022). Presents policy recommendations and strategic actions toward developing the desired GH_2 economy.	Strategy.

Box 1: RE research in South Africa

Over the past two decades, costs of RE technologies have declined considerably due to technology improvements and economies of scale, which are linked to incentive-driven market growth. This observation, along with drivers associated with load shedding and decarbonisation, have resulted in increasing RE activity in SA as evidenced in GreenCape's supplier database of RE stakeholders (GreenCape, 2022b), which provides information on 14 designated local content categories and includes manufacturers, wholesalers, associations, and services. The non-exhaustive database identified 377 entities active in South Africa. Various local industry associations are also present in the RE space: South African Photovoltaic Industry Association (SAPVIA), South African Renewable Energy Council (SAREC), South African Wind Energy Association (SAWEA), and the South African Energy Storage Association (SAESA).

SAWEA's activities include (SAWEA, 2023):

1. Advocating for increased investment in wind power
2. Promoting socio-economic development and transformation through wind power
3. Ensuring excellent operational practices in wind power generation
4. Providing relevant information about the South African wind power market
5. Encouraging the adoption of renewable power in both large and small-scale applications
6. Facilitating wind and renewable power investments across Africa

This includes research related to wind as a RE input for GH_2. SAWEA has published a range of research papers and studies on wind energy – a full list is available on their website and in their annual reports. SAWEA has various collaborations including but not limited to SAPVIA, CSIR, Deloitte, the International Renewable Energy Agency (IRENA), the American National Renewable Energy Laboratory (NREL), Eskom, Trade and Industrial Policy Strategies (TIPS), DSI, dtic, DMRE, GreenCape, Cosatu, the South African Energy Storage Association (SAESA), and the Black Energy Professionals Association (BEPA).

SAPVIA aims to promote, develop and grow the photovoltaic industry and photovoltaic deployment as part of the wider RE sector in South Africa (SAPVIA, 2023). SAPVIA engages in and supports research related to solar as a RE input for GH_2. For example, the South African Renewable Energy Grid Survey was conducted during Q1 of 2023 with the aim of collecting data on current and future renewable energy projects being developed in South Africa. SAPVIA has published a range of research papers and studies on solar energy– a full list is available on their website and in their annual reports. SAPVIA represents the interests of almost 700 members across country's photovoltaic value chain, and is in partnership with government departments, development agencies and some of the world's leading players in the photovoltaic sector. They have also collaborated with both SAWEA and Eskom, as well as TIPS, DSI, dtic, DMRE, GreenCape, Cosatu, SEASA, and BEPA.

Also, of relevance to this current research mapping report, **the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University** was established in 2007 to facilitate and stimulate activities in RE studies and research (Steyn, 2023). They offer short courses including one focussed on the principles of designing, funding and successfully implementing fit-for-purpose projects based on GH_2. CRSES not only provides training, but also initiates flagship projects, tests and reviews technology, drives product awareness and commercialisation, provides advisory services, and unlocks research and funding opportunities. CRSES has published a range or research papers in various academic journals – a full list is available on their website.

4.3 Research support

In this study, research support includes that provided by institutions engaging with and creating spaces for an enabling GH_2 research environment. This includes governance, workforce and sector skills plans, as well as tools (see for example the H_2 Atlas) that all support the advancement of research across the GH_2 value chain. A selection of institutions playing this role is highlighted here.

4.3.1 South African Institute of International Affairs (SAIIA)

Upstream, Midstream and Downstream.

SAIIA aims to provide independent, evidence-based options for Africa's future development, as an independent public policy think tank. Research topics include social development, foreign policy, governance, the environment, and economic policy, and linking local experiences with global debates (SAIIA, 2023). SAIIA's work includes research on the GH_2 economy workforce, which is relevant to this study as it forms part of the enabling environment for the GH_2 economy. Furthermore, the institute conducts research related to the minerals supply chain, RE, and the Just Transition.

Research outputs

Research and outputs are made available freely in the form of publications, policy briefs, videos, articles, workshops, and conferences. Relevant to the GH_2 economy is the study titled "'South African GH_2 TVET Ecosystem Just Transition Strategic Framework' (SAIIA, DSI, DHET, 2022). There is also an open platform for the public to engage with and discuss these issues.

Collaborations

The South African GH_2 TVET Ecosystem Just Transition Strategic Framework study has been co-developed by SAIIA and project consortium partners, alongside the DSI and DHET.

4.3.2 DSI/ NRF - SARChI Chairs at UJ, UCT and Stellenbosch University

DSI/ NRF - Sasol SARChI Chair in GH_2 at UJ and Stellenbosch University

Upstream: Manufacturing of equipment (fuel cells); Hydrogen generation.

Midstream: Storage/ infrastructure.

The focus of the SARChI Chair in GH_2, based at the University of Johannesburg (UJ) and Stellenbosch University, is the advancement of the GH_2 economy from production to application (UJ, 2023). This Chair is led by Professor Tien-Chien Jen (Faculty of Engineering and the Built Environment at UJ), Professor Reinout Meijboom (Faculty of Science at UJ) as co-Principal Investigator, and Professor Prathieka Naidoo (Department of Chemical Engineering at the Faculty of Engineering, Stellenbosch University). The scope includes development of capacity for innovation and technology development in selected focus areas, including GH_2 production (photovoltaic electrochemical, photocatalytic, photoelectrochemical, solar thermochemical, etc), hydrogen storage and transport, and hydrogen fuel cells (NRF, 2022). The GH_2 Chair requires engagement in research programmes that complement and demonstrate the implementation of the HSRM and HySA programme, as well as the development of novel technology options with patenting and commercialisation potential.

DSI/ NRF SARChI Chair for Mineral Law in Africa at UCT

Upstream: Mining extraction/minerals refining.

The work of the Mineral Law SARChI Chair focuses on improving the understanding of the mineral law and governance aspects of African legal systems (UCT, 2023b). Research interests of Chair participants cover a wide range of issues surrounding extractive industries (including PGMs of interest in the GH_2 value chain) –

seeking solutions to the problem of balancing competing interests in the mining industry (UCT, 2023b). Research areas include environmental concerns, socio-economic matters, transformation of mining industries, mining tax, mining waste, investment interests, and land issues. The current and inaugural holder of the Chair is Professor Hanri Mostert at the Faculty of Law at UCT.

4.3.3 South African Agency for Science and Technology Advancement (SAASTA) ■

Upstream, Midstream and Downstream.

SAASTA is a business unit of the NRF with the mandate to advance public awareness, appreciation and engagement of science, engineering, innovation, and technology in SA (SAASTA, 2023). SAASTA supports a range of research programmes and activities, including conferences, webinars, competitions, science centres, and science festivals. SAASTA is closely associated with the HySA Public Awareness, Demonstration, and Education Platform (HySA PADEP) - established to promote hydrogen technology on both local and global scales. The primary objective of HySA PADEP is to foster understanding, prominence, and endorsement among the general public, industrial sectors, business innovators, and the public sector. This initiative aims to identify the hurdles, advantages, and safety considerations linked to the adoption of hydrogen fuel cell technology within the alternative energy sector.

Research output

A full list of research programmes SAASTA supports can be found on their website. In terms of their work with HySA PADEP, SAASTA presented a webinar on Hydrogen Regulations, Standards, Codes and Certifications.

Collaborations

A business unit of the NRF, SAASTA collaborates with the DSI and HySA PADEP, in alignment with the 2030 National Development Plan (NDP).

4.3.4 Southern African Science Services Centre for Climate Change and Adaptive Land Management (SASSCAL) ■

Upstream: Renewable electricity and associated infrastructure.

SASSCAL is a joint initiative of Angola, Botswana, Namibia, South Africa, Zambia, and Germany in response to the challenges of global change (SASSCAL, 2023) and located in Windhoek, Namibia. SASSCAL has three main goals: conducting research on climate change adaptation and sustainable land management; delivering valuable products, services, and information to support decision-making; and fostering a knowledge-based society by offering capacity development programs for both academic and non-academic spheres. The centre was formed to complement the existing research and capacity development infrastructure and research initiatives in the region. SASSCAL is involved in the H_2 Atlas Africa initiative, hence its relevance to this study (H2 Atlas, 2023). The project is a joint initiative of the German Federal Ministry of Education and Research (BMBF) and partners in Sub-Saharan Africa to explore the potentials of hydrogen production from the regions RE sources.

Research outputs

SASSCAL focuses on a wide range of research areas, and all publications are available on their website. SASSCAL is involved in the H_2 Atlas Africa initiative (H2 Atlas, 2023) which explores the potentials of hydrogen production from the regions RE sources. On the H_2 Atlas website, there is an interactive mapping tool that allows the user to view production "hot spots".

Collaborations

SASSCAL actively maintains a wide network of partner universities and research institutions, including the CSIR, as well as funding and service organisations, including the German BMBF.

4.3.5 Saldanha Bay Industrial Development Zone (SBIDZ) / Freeport Saldanha

Freeport Saldanha is located within a port and is the only sector-specific SEZ in SA (oil and gas, maritime fabrication and repair industries and related support services) (Freeport Saldanha, 2022). The GH_2 economy is seen as a long-term opportunity, in which Saldanha can play an important enabling role. Through their Innovation Campus Programme, the aim is to support the GH_2 ecosystem with testing facilities for scaling and commercialisation.

Collaborations

The dtic, Transnet, Department of Labour, Department of Economic Development and Tourism, as well as multiple entities in the private sector who are located (or will be located) in the SEZ.

4.3.6 Sector Education Training Authorities (SETAs)

Upstream, Midstream and Downstream.

The 21 SETAs work with sectors in the economy to develop and implement sector skills plans in response to the skills needed in that sector. They also promote and administer learning programmes, and liaise with the National Skills Authority on policy, strategy and sector skills plans. In particular, the Chemical Industries Education and Training Authority (CHIETA) aims to support the GH_2 economy by identifying growth areas for skills and economic development. They are also pursuing a GH_2 research chair position in collaboration with public institutions to advance research and innovation in GH_2 for the future supply of certain scarce skills (Burger, 2022).

CHIETA will collaborate with the Transport Education and Training Authority (TETA) on R&D programmes (Creamer Media, 2023). They will also collaborate on skills development and training initiatives[5], including digital programmes, supporting the implementation of smart skills centres, collaboration on science, technology, engineering, and math (STEM) projects and working jointly on SMME development and support projects (with a Memorandum of Understanding being in place until 31 March 2025).

The Energy and Water SETA (EWSETA) has also indicated that they are planning to work closely with the hydrogen sector (Slater, 2021) to ensure that the knowledge and capacity required in the GH_2 economy is available.

4.4 Government department enablers

The government recognises the importance of fostering a conducive environment for GH_2 research activities and plays an important role as an enabler through funding, research prioritisation, public-private partnerships, education and training, research infrastructure, and the facilitation of information sharing.

4.4.1 Department of Science and Innovation (DSI)

The DSI is the custodian of national research, development and innovation focused on new energy technologies. The Energy Secretariat sits under the DSI and within SANEDI, and are responsible for the DSI's flagship programmes. The DSI's two GH_2-related flagship programmes are (SANEDI, 2022):

- Coal CO_2-X

[5] *Skills identified include hydrogen fuel technicians, systems engineers, power plant managers, power system electricians, storage specialists, electrolysis engineers, pipeline installers and safety specialists.*

- Hydrogen South Africa (HySA)

These flagship programmes are located at Universities and Science Councils, where centres of excellence have been established.

The DSI drove the Hydrogen South Africa Energy Research, Development, and Innovation Strategy (HySA Strategy), approved by Cabinet in 2008, as well as led the Hydrogen Society Roadmap (HSRM) development in partnership with government and industry stakeholders. The HSRM focuses on national ambitions, sectoral prioritisation, the overarching policy framework, and the macro-economic impact of the hydrogen economy throughout South Africa. The DSI also supported the publication of the Hydrogen Valley Feasibility Study Report (DSI, Anglo American Platinum, Bambili Energy, Engie, 2021), as part of the HySA strategy. This report identifies three catalytic GH_2 hubs in South Africa.

The DSI funds SARChI, where Research Chairs, administered by the NRF, are established at public universities in South Africa (see Section 4.3). The DSI also provides funding to the Technology Innovation Agency (TIA), who act as the implementing agency for this funding. TIA awards applicants GH_2 focused funds based on illegibility and alignment with the HSRM.

Collaborations

The DSI funds and supports a range of GH_2 research activities, including but not limited to those at HyPlat, the three HySA Centres of Competence, DHET, the South African Institute of International Affairs (SAIIA), c*change, the centre for HRTEM, and Mintek.

The Hydrogen Valley Feasibility Study Report was published in partnership with the DSI, Anglo American Platinum, Bambili Energy and ENGIE.

4.4.2 Department of Trade, Industry and Competition (dtic)

The dtic's core mandate is to promote structural transformation in the country, towards a dynamic industrial and globally competitive economy. This means providing a predictable, competitive, equitable, and socially responsible economic environment, broadening participation in the economy, coordination of government departments, state entities and civil society, and improving the alignment between economic policies, plans of the state, its agencies, and government's political and economic objectives. The dtic has nine main programmes, including research, which aims to develop and roll out policy interventions that promote transformation and competition issues through effective economic planning, aligned investment and development policy tools. Part of this includes research on various areas of industry, including GH_2 – see the South African GH_2 Commercialisation Strategy (dtic, 2022). This focuses on the export of GH_2, stimulating domestic markets, supporting localisation, securing financing, proactive socioeconomic development, and policy and regulatory support.

A dedicated unit at the dtic is responsible for policy development around Industrial Development Zones (IDZs)/ Special Economic Zones (SEZs) (GTAC, 2021).

Collaborations

According to the GH_2 Commercialisation Strategy (dtic, 2022), the dtic intends to attract investment into establishing equipment manufacturing facilities for electrolysers, fuel cells, ammonia crackers and balance of plant components along the GH_2 value chain. This will mean significant incentives, such as tax breaks and infrastructure support, as well as collaboration with a number of stakeholders in the public sector, private sector, and both local and international financial intuitions to attract investment support into the industry. The dtic's investment promotion agency (Invest SA) will be an important player here.

4.4.3 Department of Forestry, Fisheries and the Environment (DFFE)

DFFE is mandated to manage, protect, and conserve South Africa's environment and natural resources and are the custodians of the country's decarbonisation agenda through the implementation of the NDC and SA-LED. In order to achieve this, the DFFE has developed an environmental management legislative/ regulatory framework. This includes environmental laws, regulations, policies, norms and standards, and other regulatory tools – including guidelines for environmental impact assessments (DFFE, 2015).

The DFFE have announced support for the green grid, electrolyser park and green hydrogen-related special economic zone (SEZ) in the Northern Cape (Arnoldi, 2021). This would mean working closely with the Northern Cape Department of Agriculture, Environmental Affairs, Rural Development and Land Reform.

4.4.4 Department of Mineral Resources and Energy (DMRE)

The DMRE is mandated to regulate, transform and promote the minerals and energy sectors (DMRE, DMRE Annual Report 2020/21, 2021). The 2023 South African Renewable Energy Masterplan (SAREM) was published for public comment in July 2023, and the DMRE was part of the project steering committee (DMRE, 2023). Together with SANEDI, the DMRE has recently published the DMRE Green Hydrogen Framework Document entitled "Roadmap towards cleaner fossil fuels in South Africa Phase 2 (Coal Oil and Gas Decarbonisation Technology and Strategies)".

Collaborations

DMRE has a variety of collaborations including but not limited to Mintek, SAPVIA, TIPS. DSI, dtic, DMRE, GreenCape, Cosatu, SAESA and BEPA.

4.4.5 Department of Higher Education and Training (DHET)

The mandate of DHET is to provide national strategic leadership in support of the country's post-school education and training system. In this regard, DHET engages in and supports research related to the skills requirements of the economy–upstream, midstream, and downstream GH_2 value chain.

The South African GH_2 technical and vocational education and training (TVET) Ecosystem Just Transition Strategic Framework study (SAIIA, DSI, DHET, 2022) provides policy recommendations and strategic actions toward the development of the desired TVET ecosystem for the GH_2 economy - targeting various public and private stakeholders.

Collaborations

DHET collaborated with SAIIA and project consortium partners, alongside the DSI and other government stakeholders, on the South African GH_2 TVET Ecosystem Just Transition Strategic Framework study.

4.4.6 Eskom

Eskom is a state-owned entity that is mandated is to provide electricity in an efficient and sustainable manner, including its generation, transmission, and distribution and sales. Eskom has expressed their support for a Just Energy Transition and the move towards a lower carbon economy (Eskom, 2023).

The research, testing and development (RT&D) team at Eskom provides technical energy and related research, investigation, demonstration, testing, development & innovation at their centre in Johannesburg. The Eskom RT&D team is interested in a GH_2 pilot study linked to the potential opportunities for Eskom in decommissioning coal-fired power infrastructure and transforming them into chemical hubs for GH_2 production (Phillips, 2021). Additionally, research is conducted with regards to RE sources, for example, the South African Renewable Energy Grid Survey was conducted during Q1 of 2023 with the aim of collecting data on current and future renewable energy projects being developed in South Africa.

4.4.7 South African National Energy Development Agency (SANEDI)

SANEDI is mandated to supervise and conduct research and development in the field of energy, encourage innovation in energy research and technology, and implement actions to enhance energy efficiency across the economy (SANEDI, 2022). The Energy Secretariat sits under the DSI and within SANEDI, they are responsible for ensuring effective monitoring of energy policy specific to the energy landscape and the DSI's flagship programmes, of which two are specifically GH_2 focused (SANEDI, 2022). A full list of publications supported can be found in the SANEDI Annual Reports.

Collaborations

SANEDI supports both the DSI, and the DMRE, with the implementation of the DSI HSRM. SANEDI also collaborates with the Department of Employment and Labour (DoEL) and the Department of Public Works and Infrastructure (DPWI). SANEDI has partnered with several institutions of higher learning, including Technical Vocational Education Training (TVET) colleges, and seven Universities for research and capacity building initiatives (SANEDI, 2022).

4.4.8 The Technology Innovation (TIA)

TIA is a government agency that provides financial and non-financial support to innovators and inventors in South Africa. More specifically, TIA is the implementing agent for DSI funding and aims to provide institutional support in bridging the gap between R&D at higher education institutions, science councils, public entities, and private sector, and the commercialisation of these outputs. TIA have recently released a call for proposals on natural resources and energy technologies, including technology for e-mobility, hydrogen, lithium-ion batteries and fuel cells (TIA, 2023).

4.5 Researcher profiles

The ToR for this project included a task that focused on compiling a profile of the GH_2 researchers actively working in the field. The list of researchers identified during the study is presented in Appendix C. Information to compile this list was collected through the interviews and publicly accessible information from LinkedIn, ResearchGate, Google Scholar, university and faculty websites, and other webpages. Whilst an attempt was made to be as comprehensive as possible, the list is unlikely to be exhaustive.

5. Private sector research activities and needs

To complement the information provided in the previous section, an assessment of publicly available information on private sector actors along the value chain was conducted to attempt to gather information on their priorities and research needs.

The entities chosen for inclusion in the review were based on their involvement in proposed GH_2 projects in SA (see Appendix A). This includes the nine projects to be gazetted as GH_2 Strategic Integrated Projects (SIPs) in line with the Government's Infrastructure Development Act (Department of Public Works and Infrastructure, 2022a):

1. The Prieska Power Reserve in the Northern Cape
2. The Ubuntu Green Energy Hydrogen Project in the Northern Cape
3. Boegoebaai GH_2 Development in the Northern Cape
4. Atlanthia GH_2 in the Western Cape
5. Upilanga Solar and GH_2 Park in Northern Cape
6. Sasolburg GH_2 60MW in the Free State
7. Sasol HySHiFT (Secunda) in Mpumalanga
8. Hive green ammonia in the Eastern Cape
9. Hydrogen Valley Programme (Anglo-American and along the Limpopo, Gauteng to KwaZulu-Natal corridor)

The following further GH_2 projects were also considered as part of the review:

- Mainstream Renewable Energy Hydrogen project in the Western Cape
- ArcelorMittal Saldanha Steel Hydrogen project in the Western Cape
- Enertrag Postmasburg Project (Ammonia) in the Northern Cape
- HDF Energy and Isondo Precious Metals, building RE in Mpumalanga
- Enertrag Indigen Project (e-methanol) in the Eastern Cape
- Isondo Fuel Cell MEAs Manufacturing in Gauteng
- Isondo / NCP Vehicles project in Gauteng
- Saldanha Bay GH_2 project
- Project Phoenix fuel cell manufacturing in Free State (Mitochondria)
- Cape Stack in the Western Cape (Keren and Grindrod's Vredendal project)

The Table in Appendix B presents full details of the private sector stakeholders involved in the above projects. From the Table it can be seen that although there is wide private sector interest in the GH_2 economy, only some are engaging directly in research activities, as discussed further here. In terms of the private sector's research needs, these are typically not explicitly stated in publicly available literature, but will be considered in Section 6, where research gaps that were identified through stakeholder consultations are discussed.

Anglo American, Amplats, EDF, Envusa Energy, Engie – nuGen™ Zero Emission Haulage Solution (ZEHS)

Downstream – End-usage (mobility)

The consortium has worked together to develop a 2MW hydrogen-battery hybrid truck prototype which uses multiple fuel cells for usage in mining. The truck can carry 290 tonnes, and has a fully integrated GH_2 system including production, fuelling, and haulage components, with GH_2 produced at the mine site. nuGen™ has been developed under FutureSmart Mining™, Anglo American's approach to sustainable mining and part of their overall goal of achieving carbon neutrality across by 2040 (Anglo American, 2022). The end plan is to retrofit 40 of the haul trucks at Mogalakwena, before rolling out the technology to the global fleet of 400 trucks (Viljoen, 2022).

ArcelorMittal South Africa and Sasol - Saldanha GH_2 and derivatives study

Midstream – Beneficiated products (ammonia)

The Saldanha GH_2 and derivatives study (Sasol, 2022) will explore the region's potential as an export hub for GH_2 and derivatives, as well as green steel production. The CSIR, ArcelorMittal SA and Sasol are working on developing strategies for GH_2 as well as production of low carbon intensity steel based on GH_2 in DRI (ArcelorMittal, 2023). This initiative would mean the potential for ArcelorMittal SA to become the first African green flat steel producer, using GH_2 to produce direct reduced iron (DRI) via the Midrex facility at its Saldanha Works.

ArcelorMittal's Saldanha works has been mothballed for the last 3 years, and research is being done to recommission the facility to initially produce lower carbon steel and then convert the steelworks to a DRI steel plant. The DRI steel plant would be supplied by GH_2 that would be generated at or near the Saldanha port, producing green steel that could be shipped to Europe for export (Roos & Wright, Powerfuels and Green Hydrogen (public version), 2021). This would establish a new business model for this facility, which previously struggled to match the cheap Chinese steel supply. Moreover, it would align with the overall transformation of the Saldanha port into a hub for GH_2 exports.

Enertrag, Earth & Wire, 24Solutions – e-methanol

Midstream – Beneficiated products (e-methanol)

This consortium has conducted a feasibility study of zero-carbon e-methanol for commercial sale locally and for export (Creamer, 2021). Instead of using fossil fuels, as conventional methanol does, e-methanol will be produced using GH_2. This will be produced through an electrolyser using RE and desalinated seawater, with a synthesis gas, derived from a mixed feedstock of locally sourced biomass and unrecyclable municipal solid waste fed into a gasifier.

Hydrox Holdings – local IP development

Upstream - Manufacturing of equipment (electrolysers)

Hydrox is involved in Intellectual Property (IP) development, being producers of Divergent-Electrode-Flow Through (DEFT) and Advanced Alkaline Electrolyser (AAE) technology (alkaline-based water electrolysis system) (Hydrox Holdings, 2023). Technologies appear to still be at the development/pilot stage.

Implats

Upstream - Manufacturing of equipment (fuel cells)

Implats has invested around R25 million in targeted fuel cell development in SA in collaboration with government and academic institutions (Implats, n.d.).The aim is to help promote local technology development, as well as develop local skills and fuel cell manufacturing and deployment activities.

Linde[6], Enertrag, Hydregen and Sasol - HySHiFT SAF research

Midstream – Beneficiated products (SAF/ e-kerosene)

The HySHiFT Consortium aims to produce SAF (e-kerosene), using GH_2. Each partner contributes differently:

---

[6] *Linde is the parent company of Afrox (Afrox, 2023)*

- Hydregen is the project developer and funder
- Enertrag produces RE from wind and solar resources
- Linde produces GH_2
- Sasol converts these two inputs into green aviation fuel through its Fischer Tropsch reactor

HySHiFT has an overall target of producing 50,000 tons/day of PtL Kerosene, fuelling two flights between Germany and South Africa per day (Sasol, 2022a).

Mitochondria

Upstream - Manufacturing of equipment (SOFC fuel cells)

Mitochondria has an interest in acceleration of fuel cell development with early testing on AVL's Engineering's site (their Austrian engineering services partner). The company collaborates with IDC, the Development Bank of Southern Africa (DBSA). dtic, AVL, Ceres Power, MegaMillion, the Gauteng Growth and Development Agency (GGDA), Vaal SEZ, Emfuleni Municipality, and Anglo Belgian Corporation (Mitochondria, 2022).

Mitochondria's Project Phoenix is working on the development of a bankable feasibility study which includes the design of a Solid Oxide Fuel Cell (SOFC) system, construction of a facility to commercially manufacture the SOFC units, and commercial manufacturing and sale of the SOFC units (DBSA, 2020). However, electrolyser stacks are currently supplied by Ceres Power (UK-based company), and so progress is required on the local manufacturing of electrolyser equipment (stacks).

Omnia

Midstream – Beneficiated products (ammonia)

Downstream – End-usage in light industry (chemicals)

Omnia is a diversified chemicals group that caters for the agriculture, mining, and manufacturing industries. Innovation and green technology development form an integral part of Omnia's strategy. Investments by the company in research and development are anticipated to create new product opportunities (Omnia, 2023). This will include the onsite production of GH_2 at their Sasolburg site, as well as the production of green ammonia. The roll-out of this opportunity will depend on green ammonia becoming cost competitive and customers being willing to pay a green premium on fertiliser and explosives made using green ammonia.

PowerCell

Upstream – Manufacturing of equipment (fuel cells)

PowerCell develops and produces fuel cells, fuel cell systems and services that aim to lower the environmental impact from energy generation. In order to maintain high product efficiency and durability, the group conducts research and development on fuel cell platforms and fuel cell systems (PowerCell Group, 2023).

Isondo Precious Metals

Upstream – Mining extraction / mineral refining

Upstream – Manufacturing of equipment (fuel cells, electrolysers and balance of plant)

Isondo manufactures high-tech PGMs-based components for fuel cells and electrolysers, and are establishing an industrial scale, high-tech, fuel cell and electrolyser component manufacturing facility within the OR Tambo SEZ (Bulbulia, 2021). This project is supported by the dtic.

Isondo is also developing PGM recycling capabilities for metals like iridium and platinum, using molecular recognition technology. Iridium recycling in particular is important to sustain PEM electrolyser based GH_2

production, because there is limited iridium mined in SA, and this process would mean high yields in shorter times (Bulbulia, 2021).

Sasol and ArcelorMittal SA - Vaal Carbon Capture and Utilisation (CCU) study

Upstream – Hydrogen production (electrolysis)

Downstream – End-usage (heavy industry)

Midstream - Compression/conversion – Fischer Tropsch (additional feedstock e.g., sustainable carbon)

A joint agreement was signed between Sasol and ArcelorMittal SA to advance the Vaal CCU study (Sasol, 2022), which aims to develop CCU technology to capture unavoidable industrial CO_2 produced from ArcelorMittal SA Vanderbijlpark's steel plant and combining it with GH_2 to produce sustainable fuels, chemicals, and green steel using RE. The CO_2 will be transported from Vanderbijlpark to Sasol's Sasolburg and Ekandustria operating facilities for processing.

This project is part of the Pilot CO_2 Storage Project that was initiated by the South African Centre for Carbon Capture and Storage (SACCCS), a division of SANEDI (Green Economy Media, n.d.).

Sasol ecoFT

Midstream – Beneficiated products (SAF/ e-kerosene)

German aircraft manufacturer Deutsche Aircraft and Sasol ecoFT have signed a memorandum of understanding to advance technology used for GH_2 based SAF production (Sasol ecoFT, 2022). The two companies will not only work on technology and production aspects of SAF, but also aim to support the certification of sustainable drop-in and non-drop-in jet fuel. The South African Air Force (SAAF) has offered to test this fuel in a collaboration facilitated through SANEDI.

For this, Sasol ecoFT will be leveraging Sasol's Fischer Tropsch experience, proprietary technology, and catalysts to produce sustainable fuels and chemicals via Power-to-X (PtX) processes.

Sasol and Toyota – GH_2 mobility ecosystem

Downstream – End-use (mobility)

Sasol and Toyota South Africa have formed a partnership to explore the development of a GH_2 mobility ecosystem in SA (Sasol, 2021). Sasol will draw on their experience in the production, use and marketing of grey hydrogen, and Toyota will use their experience as a leading global supplier of zero-emission hydrogen fuel cell vehicles. The aim is to develop a proof-of-concept demonstration mobility corridor and then expand this to a pilot project using one of SA's main freight corridors, such as the N3 route between Durban and Johannesburg. This will be used for hydrogen powered heavy-duty long-haul trucks, for which Toyota have started investigating the introduction into SA as soon as they become available from its principals in Japan.

Sibanye-Stillwater and Heraeus Precious Metals

Upstream - Manufacturing of equipment (electrolysers). Sibanye-Stillwater and Heraeus Precious Metals have agreed to jointly collaborate on R&D of novel ruthenium and iridium containing electrocatalysts with high activity and stability for PEM electrolysers, as well as developing more sophisticated metal oxide structures (Heraeus Precious Metals, 2022).

Iridium, used alongside platinum in the manufacturing of PEM electrolysers, is a relatively scarce metal. If there is to be widespread adoption of PGM PEM electrolysers, reducing iridium usage is essential to sustainable and cost competitive PEM technology (Heraeus Precious Metals, 2022). Thus, the research to reduce or replacing iridium with other metals (e.g., ruthenium) offers significant potential for a sustainable GH_2 economy (Heraeus Precious Metals , 2023).

Thyssenkrupp

Upstream – Hydrogen production (electrolysis)

Upstream – Manufacturing of equipment (electrolyser systems and balance of plants)

Research and development work concentrates on the development of the electrolyser module and the cells for GH_2 production based on alkaline water electrolysis, and on improving and automating the production and assembly process (African Petrochemicals and Energy, 2022)

6. Stakeholder consultations

6.1 Introduction

Consultations were held with stakeholders from research groups, research support, independent consultants and research advisories, government department enablers, and the private sector in the form of semi-structured interviews. The consultations were held from the 29th September to the 23rd October, and in total 20 interviews were conducted as shown in Table 3.

Table 3: List of interviewees

Institution within South Africa	Number of interviews	Stakeholder
Research groups	7	CSIR, Mintek, Department of Chemical Engineering at SU, HySA Catalysis at UCT, Mike Levington (Navitas, SAREM, GH_2 panel), Department of Chemical Engineering at UCT, HySA infrastructure at CSIR
Research support; Independent consultants and research advisories	6	Green Cape, Rebel Group. TIPS, Freeport Saldanha, TIA, Atlantis SEZ
Government department enablers	4	DSI, dtic, Eskom, IDC
Private sector	3	Mitochondria, Enertrag, Hydrofuel Solutions
Total	**20**	

The information collected through the interviews was used to complement that collected via the desktop review, and was used to synthesise common themes and priorities in the research as discussed in the sections that follow, as well as identify possible research gaps. It also allowed the team to compile a profile of the GH_2 researchers actively working in the field (see Appendix C) and to make recommendations on future GH_2 research focal areas for SA (see Section **Error! Reference source not found.**). The full interview guides can be found in Appendix D.

6.2 High-level observations

Prior to identifying specific research gaps, two high-level observations from the interviews are presented.

6.2.1 The definition of research and development (R&D)

As expected, stakeholders had different interpretations of what constitutes R&D. On one hand, there is technical R&D which focuses on advancing technology, scientific knowledge, and innovation. Its purpose is to create new products, improve existing ones, localise products developed elsewhere, and enhance technical processes. This R&D thus aims drive economic growth through technological innovation. The nature of technical R&D work involves scientific experimentation, prototyping, testing, and engineering activities. It is a creative and iterative process focused on producing tangible outcomes.

On the other hand, stakeholders considered policy and strategy development to also fall under the broad banner of R&D. This area focuses on shaping rules, regulations, and guidelines that govern various aspects of society, such as public health, environment, economics, and technology, all of which are relevant to the GH_2

industry. The primary goal here is to create a framework that promotes societal well-being, fairness, and order. This area involves deliberative and analytical processes that include research, data analysis, stakeholder engagement, and legal or regulatory drafting. The outcome is the formulation of policies, strategies laws, and regulations.

These two areas are closely interdependent. Policies often influence the direction and funding of technical R&D, as they can provide incentives, regulations, and standards for innovation. Technical R&D outcomes can inform and shape policies, especially in the fields of science, technology, and the environment. Therefore, both are essential for societal advancement, and their interplay is crucial for achieving balanced progress.

6.2.2 The need for prioritisation of local R&D activities

Some of the interview participants highlighted that rather than focusing on R&D activities across the entire value chain, research in the country should target developing specialist knowledge and technologies in areas of the GH_2 production chain where the country could become a global leader. Realising the prioritised opportunities to leverage South Africa's limited R&D resources and key strengths[7] requires critical prioritisation to justify the business cases for investment[8].

Continuing along this line of thinking, research topics could essentially be grouped into three themes:

1. Direct knowledge transfer from international R&D
2. Localisation of international technologies e.g., using international desalination R&D and customise it to the South African context
3. Primary R&D, e.g., research on the South African grid, research on acid-mine drainage for GH_2 production

With regards to the last theme, consideration needs to be given to which of the value chain elements show the greatest potential for local development and production, towards ultimately reducing the local GH_2 production costs. Interviewees noted that a result of SA having a relatively small overall spend on R&D, is that its local research institutions are typically global followers rather instead of global leaders. Moreover, the R&D portfolio is predominantly driven by the funds researchers can secure – in other words, the focus is on research topics that the funding sources offer to support. Despite pockets of coordinated research through the HySA programme, research institutions and commercial companies often ending up working in silos and so may not ask questions like "What do you need?" and "What research have you already done?". Shifting this approach to setting of coordinated research agendas, including through enabling engagement with commercial companies and between research institutions, is critical to ensuring the direction for R&D is coordinated, focused on key opportunities for SA, and driven by what is needed on the ground.

This current report will partially serve to further facilitate alignment, through mapping the research needs within the country and promoting collaboration between the public sector, private sector, academia, and industry associations regarding research, innovation, and commercialisation of the GH_2 research portfolio. However, bridging the gap between academic and pilot-scale R&D, and commercialisation, will require further support. One suggestion to bridge this gap is the creation of demonstration hubs or technology/ innovation parks where

---

[7] For example, beneficiation - Sasol can pivot their Fischer Tropsch and Haber Bosch experience, meaning there is a lower level of research required here, although commercialisation will require more time and effort.

[8] For example, when considering methanol synthesis, there may be little to no strategic advantage in pursuing R&D in this space - international knowledge can instead be used or adapted for the local context and local methanol production to support the bunker fuel industry.

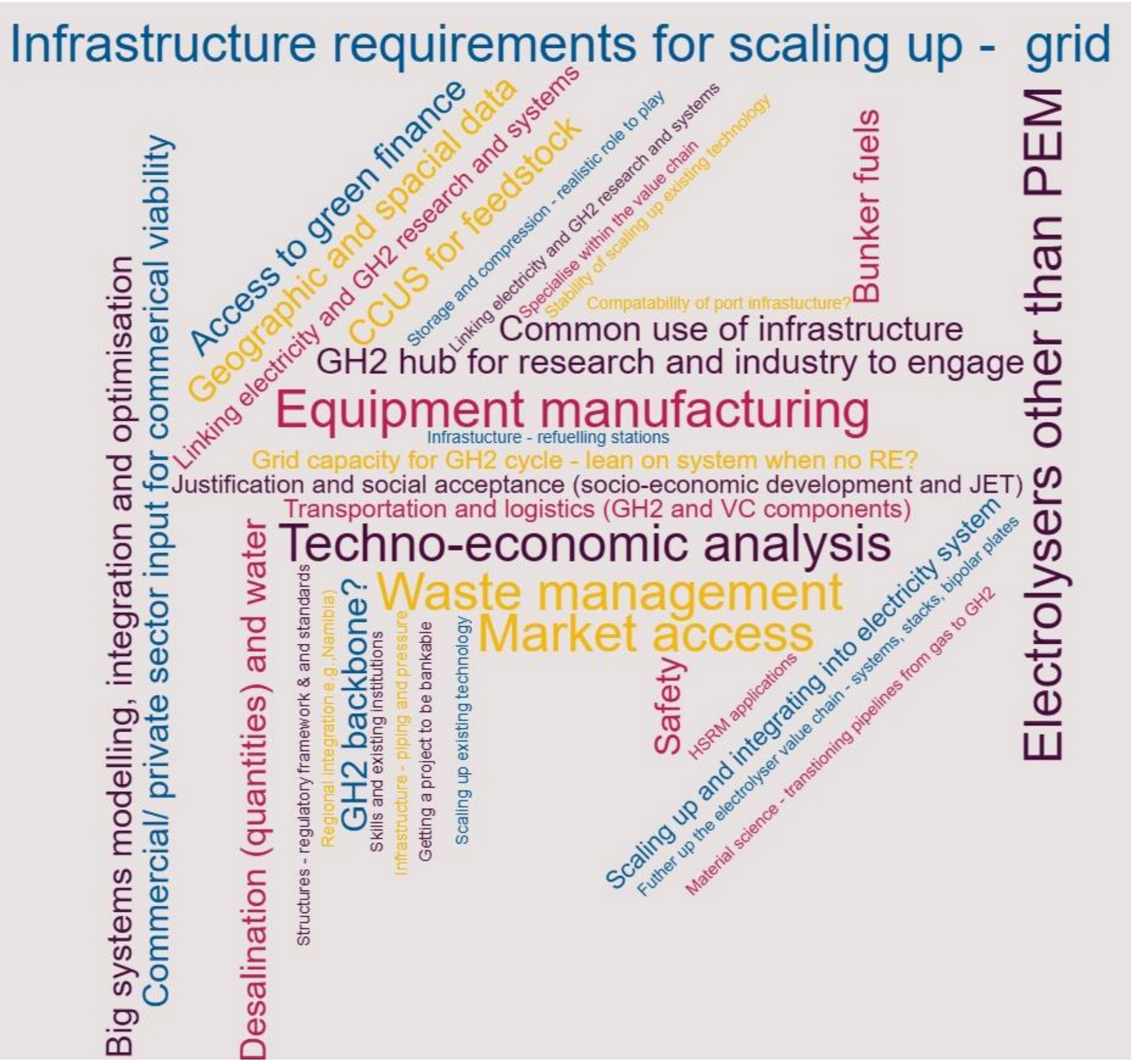
companies (such as HyPlat and HYENA) can find a home within which they can engage with both industry and research institutions ("academic bridging").

In such hubs or parks, industry would be able to express their R&D needs, local research capacity would have the opportunity to fulfil these needs at the laboratory scale, and local companies housed in the hubs could take the laboratory-scale research and provide demonstrations on a commercial scale. Industry could thereafter become offtakers of proven technologies they can trust. If local R&D is unable to demonstrate technologies at a commercial scale, industry will instead import what they need, and this opportunity will be lost. The hub would thus be a place where research institutions, funders, entrepreneurs, and industry off-takers could communicate and collaborate. **The GH_2 start-up hub being implemented by GIZ at Saldanha one example of where this is happening already.**

6.3 Research gap analysis

Figure 2 provides a world cloud summary of the research gaps identified by the stakeholders through the interview process, with further information on these gaps being presented in the sections that follow.

Figure 2: Word cloud summary of the gaps identified through stakeholder consultations



6.3.1 Gaps | Upstream value chain segments

Original equipment manufacturing (OEM) – fuel cells and electrolysers

SA is home to 75% of the world reserves of PGMs (Salma & Tsafos, 2022), and so the R&D focus in fuel cells and electrolysers in South Africa to date has largely been on PEM catalysts. However, some of the stakeholders interviewed felt that the PGM-focused approach taken under the HySA programme has not been fully effective. Their view is that this focused approach narrows the research focus, thereby limiting the range of opportunities that are explored (for example, R&D related to fuel cells other than PEM). There is uncertainty regarding which fuel cell systems will be demanded by the market in the future, noting that the most efficient fuel cell differs between applications (Leo, 2023). **Alternative catalysts, such as those in alkaline fuel cells, thus represent a research opportunity.**

It was noted that there are no local commercial manufacturers of fuel cells and electrolysers. This speaks to the upscaling challenge presented by the gap between small-scale laboratory and pilot demonstrations and commercial-scale production of these products. For example, for Sasol alone to fully convert from grey to green hydrogen, large installations electrolysers and RE will be required, which the local market cannot supply. As discussed above, **support thus needs to be provided to bridge the gap between laboratory and commercial-scale production**.

During the interviews it was highlighted that Mintek are pivoting from a focus on fuel cells to electrolysers and expect to be able to start local commercial-scale production to supply the local market by 2030. However, they are still situated early on in the value chain, converting PGMs into catalysts and electrode structures. They suggest that there is an immediate need for **R&D to start happening further along the value chain – into the electrolyser stacks and systems themselves. Balance of Plant (BoP)[9] of the electrolyser system and bipolar plates were specifically mentioned as important opportunities in the near term.** The reason given is that compared to other components[10], they do not need to be manufactured at such a large scale to be produced cost effectively and compete with global competitors.

There is an opportunity for R&D to look at **how existing technology will be able to handle large-scale GH_2 production.** An example mentioned by one stakeholder was that of electrolyser membranes - larger scale electrolysis will require larger membranes, and the stability of membranes operating at scale has not been researched in enough detail (specifically in the South African context).

Renewable electricity and associated infrastructure

The costs of RE technologies have declined considerably over the past two decades due to technology improvements and economies of scale, which are linked to incentive-driven market growth (see Box 1). This observation, along with drivers associated with load shedding and decarbonisation, have resulted in increasing RE activity in SA. Despite these recent advances, many of the stakeholders interviewed expressed their concerns regarding a shortage of **grid capacity** – although this is more likely an infrastructure build-out issue than a research issue. More relevant to R&D are the more technical elements behind grid balancing when GH_2 is added to the system, which need to be researched in more detail. There is also not yet a full understanding of the capability of the GH_2 production cycle to support the grid and in what way. Some of the questions that interviewees raised included:

---

[9] Including containers, pumps, valves, piping, tanks, casings, current collectors.

[10] For example, for local membrane production to be financially viable, they need to be manufactured on a very large scale. The same applies to gas diffusion layers (porous carbon cloth/paper), where the product needs to be manufactured on a very large scale to be cost effective and competitive in the global market. This will take more time and local capacity building.

- Will the grid need to be further strengthened to be able to supply to large scale GH_2 projects?
- What facilities and infrastructure do we need to build to make that possible?
- When would GH_2 projects be coming online and require the relevant grid support?
- When there is no wind or sun and RE is not being produced, will GH_2 also stop being produced or will production draw on the grid system?
- Will there be capacity charges for grid use?
- If the grid is not fully green, what then?
- PtX does not use the grid but rather provides support to the network, but technically can the grid be completely bypassed for the process of GH_2 production?
- Can GH_2 be produced as a way to avoid curtailment?
- What would a GH_2 backbone look like when it comes to infrastructure needs?

There are clearly a number of gaps in research and understanding when it comes to how the electricity system and GH_2 fit together, with R&D work being done in the electricity sector largely happening in isolation of that of the GH_2 sector. This suggests, for example, that the grid operator (Eskom) may not fully understand GH_2, and Sasol may not necessarily understand the grid and its constraints. Spatial distribution also becomes important here, particularly considering that by 2050 the country will need a national grid capacity of around 300GW for RE alone. There is a need for systems level optimisation of the electricity sector and RE, alongside GH_2. For this, it is important that a **proper techno-economic analysis is completed, that seeks to answer the questions posed above.**

GH_2 production

As mentioned, for companies such as Sasol to convert from grey to green hydrogen, extensive electrolysers and RE infrastructure will be required. **R&D in the electrolysis space will need to look at what further technology evolution is required to support this scale of production**, in such a way that GH_2 production processes remains stable.

Another theme that was mentioned on multiple occasions was how the country could **capitalise on the common use of infrastructure** when it came to the production of GH_2. For example, Namibia is looking at planning for GH_2 projects that do not work in silos but instead make use of pooled desalination plants and shared grid infrastructure. This is specifically important for SEZs, an issue that was raised when speaking to Freeport Saldanha. Representatives felt that there is a gap when it comes to the research relating to shared infrastructure. *Will transmission be shared, or will developers have to put in their own transmission lines? What else will be shared and what will be the onus of the developers?*

In terms of BoP and the water requirements, Freeport Saldanha felt that even though desalination as a process is well established and the technology is known, there is a gap when it comes to understanding the water volumes that will be required for the projects in Saldanha. Furthermore, in a water stressed region, more research needs to be done on water-related issues, as well as how waste brine is to be managed – *is it treated before being discharged or could concentrated brine have other uses*[11]*?* The SARChI Chair in GH_2 also stated this as being an important research area.

Some of the other water-related questions that need to be explored include:

- What volumes of water will projects require and can these be projected going into the future?

[11] *Highlighted here is the partnership between Hive and Cerebos, where Cerebos will be the offtakers of brine from desalination.*

- Where will this water come from (specifically for inland GH_2 production) - natural sources, aquafers, acid mine drainage, treated waste water?
- Does the drinking water from desalination fit the water purity required by GH_2 plants?
- What is required in terms of techno-economic analysis of desalination, given that although the technology is not new, but the costs will be large?
- Is water from acid-mine drainage an option, and could this be treated to achieve the required water purity?[12]

Other feedstock

On the subject of other feedstocks, stakeholders discussed the need for more R&D in the CCUS space, specifically in sourcing sustainable carbon as a feedstock for e-methanol and SAF. Furthermore, it is important to note that there is also a lot of uncertainty regarding what is going to happen if/when produced made using carbon captured via CCUS can no longer be classified as fully green. As it stands, GH_2 derivatives can use industrial carbon, but EU regulations indicate that after 2035 this carbon will not be "sustainable". The question was then raised of where the carbon necessary as a feedstock for the production of GH_2 derivatives will then come from.

6.3.2 Gaps | Midstream value chain segments

Compression/conversion and the beneficiation of hydrogen

This part of the value chain relates to activities that convert GH_2 gas into products that are relatively easier to store and transport, and that can be used in a wide range of applications as fuels and feedstocks. SA already has expertise in many of the processes involved here (including in ammonia production and production of hydrocarbons through the Fischer-Tropsch process), with **methanation and methanol synthesis** appearing to be research gaps. If methanol is used over ammonia for bunker fuel, this may be an area of interest for research, although as indicated previously, fundamental methanol production research is perhaps not a priority for South Africa.

Storage and associated infrastructure

Again, the topic of the GH_2 backbone was brought up, as well as whether existing and operational storage infrastructure could be used as is or modified and expanded for GH_2 (for example, the gas-to-liquids facility operated by PetroSA) (Salma & Tsafos, 2022). Or alternatively, would completely new infrastructure be required? These are important themes that research would need to consider.

The country has experience when it comes to the storage of ammonia, methanol, and liquid fuel etc., and research is being pursued at HySA at UWC, but there is a need to focus on the compression and storage of GH_2.

Research has been done when it comes to the use of metal hydrides for hydrogen storage and compression systems, which have been demonstrated in fuel cells**. But there is a gap when it comes to R&D on GH_2 storage and management at refuelling stations required for commercial vehicles.** UWC has done pilots for forklifts and scooters, but there needs to be testing at a commercial level. Moreover, the compression technology being integrated into hydrogen refuelling structures needs to be tested for performance.

---

[12] *An attendee at the final workshop felt that research on GH_2 production using acid-mine drainage will require primary R&D within South Africa*

6.3.3 Gaps | Downstream value chain segments

Handling, transport, and distribution

In this segment of the value chain, it was noted that research needs to focus on **infrastructure requirements when moving from natural gas to GH_2.** Shifting to GH_2, pipelines results variable pressure[13] and so more R&D will be required on material sciences, welding technology etc. More broadly, the question still remains whether or not natural gas pipelines could be repurposed in the first place, or if new pipelines for specifically GH_2 will be required. There was mixed feedback on this discussion point and so it remains an open question warranting further research.

South Africa has historically had experience in building and operating gas pipelines, including those used by Sasol, which suggests that the skills to build new pipelines could be locally available, but they would need to be **applied to much larger and cross-cutting infrastructure required for the transportation and distribution of GH_2.** Furthermore, if new pipelines are to be built it will be important to consider the different routes and the costs involved for those options. All of these could be topics for research.

Lastly, it is important to note that transportation and logistics within the SA context will in general pose challenges. This goes beyond the transportation of GH_2, as various components in the value chain will also have to be moved to where they are needed. For example, there has been difficulties when it comes to getting RE components (e.g., wind turbine blades) on-site in Coega.

Retail/ end usage

The priority applications for GH_2 identified in the HSRM include SAF, green steel, ammonia, fuel cell vehicles and bunker fuel. Of these, bunker fuel was specifically highlighted in interviews as a potential area for research, including focused on topics such as comparing the use of ammonia to methanol, and safety-related considerations related to on-board use of ammonia - considering the International Maritime Organisation's (IMOs) regulations. Questions were also related to how best port infrastructure can be utilised here.

Stakeholders also expressed a need for GH_2 deployment into applications that match the markets in the country, specifically transport. This would also mean looking at domestic use cases and the creation of serious demonstration projects in the form of mobility corridors or within cities. In other words, there is again a need for commercial-scale demonstrations that are able to integrate into local systems on the ground.

6.4 The need for overarching support

The need for overarching support was highlight by almost all the stakeholders as being critical to supporting the overall R&D space.

Skills and training requirements

At-scale production of GH_2 and its derivatives will require increased production capacity, along with new skills and expertise. Opportunities may include those in operations, maintenance, transportation, construction, and industrial manufacturing (dtic, 2022). The skills required today may not necessarily be the same as those needed in 5 to 10 years. Many job responsibilities are yet to be defined and will evolve over time, making it necessary to identify training needs through ongoing research.

Planning to meet the evolving skills requirements will include considering how best to engage with existing institutions, such as the South African Renewable Energy Technology Centre (SARETEC), which expedites

[13] *Pipelines for natural gas cannot be directly used for GH_2 transport, with varying pressure and buffering feedstock potentially being required for GH_2 pipelines.*

specialised industry-related and accredited training for the RE industry (SARETEC, 2023). SARETEC also holds strong partnerships with government, academia, industry, associations, and private sector companies within the RE sector and aims to make locally developed technologies more accessible to the RE industry in partnership with education and research institutions.

Safety skills were seen to be particularly important in the context of GH_2 economy and enforcing the Occupational Health and Safety Act - which will become increasingly important due to the higher risks associated with the GH_2 industry. Such skills could be built through on-the-job training. Upskilling workers who already have a better understanding and appreciation of industry (such as those in the gas, chemicals, and mining sectors) reduces risk and training costs.

Policy alignment

There was a call for GH_2 to be explicitly integrated into energy policy and plans, with these considering GH_2 projections and requirements. It was felt by certain workshop attendees that the IRP2019, and upcoming update, should be split to understand RE generation to be used on the grid versus the RE used for producing GH_2. The hydrogen industry needs growth plans and allocations, so that RE and transmission plans can be aligned with these. This is particularly important when it comes to infrastructure, which takes time to build. The main comment here is that policy documents, including the Integrated Energy Plan (IEP) and related plans (such as the IRP), as well as water allocation plans, need to account explicitly for GH_2 and its growth projections.

At the same time, a caution was raised in the final workshop on integrating GH_2 into the IRP. Stakeholders suggested that if it were to be integrated into IRP, other criteria that are relevant to the electricity sector which might then apply to GH_2 industry would come into play, such as local content requirements, which could negatively affect GH_2 ambitions. These stakeholders suggested that GH_2 projections should be included in the transmission development plan, but not the IRP.

Socio-economic development and the JET

Socio-economic and socio-technological research is required to work towards getting buy-in from the country and creating political will with regard to the enablement and advancement of the GH_2 R&D space. Topics of interest here include discussions around the JET, local capacity building, local value addition, and the role that SMMEs can play in the local GH_2 economy.

Social acceptance of GH_2 in communities becomes imperative – not only in communities where GH_2 production takes place, but throughout the country. Social acceptance by the population is necessary when it comes to adopting the use of GH_2, not only in industry but also for consumer usage. Without it, the success of the GH_2 economy is less likely in South Africa.

Making the financial case for SA in the global GH_2 value chain

The financial case for GH_2 and its derivatives depends on whether GH_2 will be able to compete with the cost of grey hydrogen, specifically in the context of heavy industry. To determine how GH_2 pricing could evolve, research will need to consider the local pricing of technology and components, and local OEMs will need to secure offtakers to produce at a scale that allows them to be financially competitive in the global market. Consideration will also need to be given to how premiums that can be attained for green products over the competing products impact the financial case for GH_2.

Achieving local competitiveness requires support from both the private and public sectors to initially build capacity. This means striking a balance between learning from international experience and deciding which knowledge, technologies, and processes should be outsourced, versus what aspects of the value chain SA should focus on and develop itself.

Finally, when it comes to competition and accessing markets, it needs to be recognised that South Africa is not the only country striving to compete in the global GH_2 economy. There are other GH_2 producers who may be closer to the market demand, making transportation of GH_2 and derivatives more convenient and cost-effective. It is therefore crucial to determine which markets to target and where in the value chain South Africa should concentrate its efforts to develop the necessary capabilities.

This highlights the importance of conducting and regularly updating a future GH_2 market analysis, including the projected demands and requirements for both local and global market. Certain countries have signalled their demand and willingness to pay a premium for GH_2 - so does South Africa capitalise early and profit from this export demand, or rather channel the GH_2 to local development first (i.e., build up domestic capabilities then move to exporting)?

Waste and recycling

Waste management is an important research topic, specifically when it comes to the critical minerals found in PV, wind turbines, fuel cells, lithium-ion batteries etc. These minerals have value at the end of life of equipment, but as it stands there are no explicit waste recovery plans. Questions therefore need to be asked regarding the opportunities and abilities to recycle and reuse the minerals. In the case of batteries, a lack of recycling infrastructure is not necessarily due to a lack of expertise in recycling but rather the issue of needing to scale for economic viability. For example, UWC has a lithium battery pilot programme, but to make the business case for this activity, recycling of larger amounts that are currently being collected is required.

Geographic and market-specific research

An important theme that came up during interviews included the need for more geographic and market-specific research. South Africa is not a single unit, and so it is important to consider spatial disaggregation in analyses, as well as the implications of building infrastructure in certain places. Commercial investment decisions cannot look at high level industry reports by the likes of International Renewable Energy Association (IRENA) and the International Energy Agency (IEA). Instead, geographic specific and applications specific research at the project level is needed. This would include granular information on RE, land use, and water at geographic specific locations. The H2 Atlas Africa initiative by SASSCAL (H2 Atlas, 2023) which explores the potentials of hydrogen production from the regions RE sources, is a good start. On the H2 Atlas website, there is an interactive mapping tool that allows the user to view production "hot spots".

An example of a more extensive tool that could be useful if developed for South Africa is the Australian Government's "AusH2 - Australia's Hydrogen Opportunities Tool" [14] which provides the user detailed information on energy storage, geological storage of CO_2, groundwater, hydrogen, infrastructure, natural hazard scenarios, renewable energy, and surface water.

Regional linkages

Research needs to consider the opportunities for regional linkages. For example, the opportunity potentially exists for South Africa to leverage its strengths in partnerships with Namibia, who has certain constraints on industrial capacities and export abilities.

Other topics mentioned during discussions:

- Hydrogen combustion engines

[14] *See: https://portal.ga.gov.au/persona/hydrogen*

- Hydrogen from methane[15]: Hydrogen produced from methane is easier to split than from water via electrolysis. Methane can be generated from biowaste (see the case of France and Australia). This is an important area of R&D to consider in the local context of water as a scarce resource. But would this hydrogen qualify as green?
- White hydrogen[16], or natural hydrogen, is attracting more attention and may be of interest going into the future, displacing the demand for GH_2.

[15] *See: https://www.sgh2energy.com/technology*

[16] *See: https://www.leap-re.eu/hyafrica/*

7. Conclusions and recommendations for future research

Based on the information presented in Section 6, the current GH_2 research activities of both the private and public sector were mapped onto the GH_2 value chain. Thereafter, the total number of entities actively involved in R&D in each of the value chain elements were calculated (see Appendix E) to give an indication of where current research is focused, and where there are few to no entities active. This information provided an initial indication of where research gaps remain - where potential opportunities lie for future GH_2 research in South Africa.

Using this information, together with the findings from the workshops held (see Appendix F), the team then compiled recommendations on future GH_2 research focal areas for SA which include, but are not limited to:

Table 4: Recommendations on future GH2 research focal areas for SA

Value chain element	Research areas
Upstream	
Manufacturing of equipment:	• Fuel cells (AFC, SOFC, MCFC, PAFC) • Manufacturing of original equipment • Membranes for much larger scale electrolysis • Commercial scale production of electrolysers • Large scale demonstrations and capabilities higher up the GH_2 equipment value chain (stacks and systems) including bipolar plates and BoP
RE and associated infrastructure: Electricity/ grid infrastructure	• Grid capacity • Integration with electricity system • Transmission and distribution
Hydrogen production: BoP– water requirements	• Shared infrastructure • Stability of larger production • Water requirements • Desalination and excess brine management in water stressed regions • Water purity requirements
Midstream	
Compression and conversion	• Compression and storage of GH_2
Additional feedstock	• Sustainable carbon - CCUS for feedstock
Storage/ infrastructure	• Compression and storage of GH_2 specifically • Refuelling of commercial vehicles (refuelling stations) • Pipeline infrastructure for GH_2 (pressure, material sciences etc.)
Downstream	
Handling/ distribution and transport	• Specifically at ports • Transportation and logistics of not only GH_2 but also that required to build the infrastructure across the value chain
Retail/ end-usage grid integration	• Energy storage and grid ancillary services • Use of methanol as bunker fuels
Cross-cutting	
Policy and overarching support	• Safety standards • Future GH_2 projections and market dynamics (local and global) • GH_2 integration into energy policy, specifically with regard to water usage and grid, transmission, and distribution requirements
Other topics	• Social acceptance • End of life waste and recycling • Market projections and access

8. References

African Petrochemicals and Energy. (2022). Thyssenkrupp Uhde's green technologies helping to drive Africa's green energy transformation . Retrieved from https://africanpetrochemicals.co.za/thyssenkrupp-uhdes-green-technologies-helping-to-drive-africas-green-energy-transformation/

Afrox. (2023). About us. Retrieved from https://www.afrox.co.za/en/about_afrox/index.html

Air Products. (2021). Air Products and ThyssenKrupp sign exclusive strategic cooperation agreement for world-scale electrolysis plants to generate green hydrogen. Retrieved from https://airproducts.co.za/air-products-and-thyssenkrupp-sign-exclusive-strategic-cooperation-agreement-for-world-scale-electrolysis-plants-to-generate-green-hydrogen/

Anglo American. (2022). Anglo American and EDF Renewables agree to renewable energy partnership in South Africa to form Envusa Energy – launching 600MW of wind and solar projects in first phase. Retrieved from https://www.angloamerican.com/media/press-releases/2022/04-10-2022

AOW. (2022). Energy Investment Village gives real opportunities to start-ups. Cape Town, South Africa: African Oil Week (AOW). Retrieved from https://africa-oilweek.com/Articles/atlanthia-showcasing-green-hydrogen-project-a

ArcelorMittal. (2023). Decarbonisation roadmap. South Africa. Retrieved from https://southafrica.arcelormittal.com/Portals/0/ArcelorMittal%20South%20Africa%20Decarbonisation%20Roadmap%20(January%202023)%20(2).pdf

Arnoldi, M. (2021). Creecy welcomes Northern Cape green hydrogen SEZ plans. Engineering News. Retrieved from https://www.engineeringnews.co.za/article/creecy-welcomes-northern-cape-green-hydrogen-sez-plans-2021-11-09

Arnoldi, M. (2023, January). *Omnia signs MoU with German energy group to explore green ammonia production.* Engineering News. Retrieved from https://www.engineeringnews.co.za/print-version/omnia-signs-mou-with-german-energy-group-to-explore-green-ammonia-production-2023-01-31#:~:text=Chemicals%20group%20Omnia%20has%20signed%20a%20memorandum%20of,a%20green%20ammonia%20production%20plant%20in%20

Ballard Power Systems. (2023). Ballard Power Systems. Retrieved from https://www.ballard.com/

Bulbulia, T. (2021). *Isondo project showcasing intent in green hydrogen in South Africa.* Engineering News. Retrieved from https://www.engineeringnews.co.za/article/isondo-project-showcasing-intent-in-green-hydrogen-in-sa-2021-08-02

Burger, S. (2022). Chieta launches skills and growth study to support hydrogen economy. South Africa: Engineering News. Retrieved from https://www.engineeringnews.co.za/article/chieta-launches-skills-and-growth-study-to-support-hydrogen-economy-2022-04-01

c*change. (2020). *Highlight # 9 – Research Outputs*. Retrieved from https://www.cchange.ac.za/wp-content/uploads/2020/11/cchange-highlights-9-Research-Outputs.pdf

c*change. (2023). *Welcome to c*change*. Retrieved from c*change: https://www.cchange.ac.za/

Cenec. (2022). The South African Ministerial Team visits Prieska Power Reserve. South Africa. Retrieved from https://cenec.com/news

CHEM Energy. (2023). CHEM Energy Solutions. Retrieved from https://www.chemenergysa.com/our-solutions/

Creamer Media. (2023). CHIETA and TETA forge a groundbreaking partnership to address hydrogen economy skills development. South Africa: Engineering News. Retrieved from https://www.engineeringnews.co.za/article/chieta-and-teta-forge-a-groundbreaking-partnership-to-address-hydrogen-economy-skills-development-2023-04-03

Creamer, T. (2021). Consortium unveils plans for zero-emission Eastern Cape e-methanol plant. Earth & Wire. Retrieved from https://earthandwire.com/blog/consortium-unveils-plans-for-zero-emission-eastern-cape-e-methanol-plant

Creamer, T. (2022). Green hydrogen pioneer seeks finance for commercial plant as Vredendal proof-of-concept facility enters production. Engineering News. Retrieved from https://www.engineeringnews.co.za/article/green-hydrogen-pioneer-seeks-finance-for-commercial-plant-as-vredendal-proof-of-concept-facility-enters-production-2022-04-14#:~:text=A%20small%20proof-of-concept%20green%20hydrogen%20facility%20in%20Vredendal%2C,

Crunchbase. (n.d.). Inala Technologies. Retrieved from https://www.crunchbase.com/organization/inala-technologies

CSIR. (2023). *Hydrogen Storage Facility: Equipped for innovative hydrogen storage technologies*. Retrieved from https://www.csir.co.za/hydrogen-storage-facility-equipped-innovative-hydrogen-storage-technologies

DBSA. (2020). IDC & DBSA invest in Mitochondria, an Energy Service Provider. Development Bank of Southern Africa (DBSA). Retrieved from https://www.dbsa.org/press-releases/idc-dbsa-invest-mitochondria-energy-service-provider

Department of Public Works and Infrastructure. (2022a). Speech by Minister of Public Works and Infrastructure, Patricia De Lille, MP at the South African Green Hydrogen Conference Summit. South Africa: Department of Public Works and Infrastructure. Retrieved from https://www.gov.za/speeches/minister-patricia-de-lille-south-african-green-hydrogen-conference-summit-29-nov-2022-0000

Department of Public Works and Infrastructure. (2022b). Public Works and Infrastructure on Prieska Power Reserve Project. Retrieved from https://www.gov.za/speeches/public-works-and-infrastructure-%E2%80%8B%E2%80%8B%E2%80%8B%E2%80%8B%E2%80%8B%E2%80%8B%E2%80%8Bprieska-power-reserve-project-26-aug-2022-0000

DFFE. (2015). EIA guidelines for renewable energy projects. Pretoria, South Africa: Department of Forestry, Fisheries and the Environment (DFFE). Retrieved from https://www.dffe.gov.za/sites/default/files/Pdf-Files/guidelines-and-policies/EIA_guidelineforrenewableenergyprojects_0.pdf

DFFE. (2021). South Africa’s First Nationally Determined Contribution under the Paris Agreement. Department of Forests, Fisheries and the Environment (DFFE). Retrieved from https://www.dffe.gov.za/sites/default/files/reports/draftnationalydeterminedcontributions_2021updated.pdf

DMRE. (2019). Integrated Resource Plan (IRP2019). South Africa. Retrieved from https://www.energy.gov.za/IRP/2019/IRP-2019.pdf

DMRE. (2021). DMRE Annual Report 2020/21. Retrieved from https://www.dmr.gov.za/resources

DMRE. (2023). SAREM 2023. South Africa. Retrieved from https://sapvia.co.za/wp-content/uploads/2023/07/South-African-Renewable-Energy-Masterplan-SAREM-Draft-III-002_compressed.pdf

DMRE, DBSA, National Treasury. (2023). *IPP Projects*. Retrieved from https://www.ipp-projects.co.za/

DSI. (2022). *South African Hydrogen Society Roadmap.* Pretoria: Department of Science and Innovation. Retrieved from https://www.greenbuildingafrica.co.za/wp-content/uploads/2022/02/South_African_Hydrogen_Society_RoadmapV1.pdf

DSI, Anglo American Platinum, Bambili Energy, Engie. (2021). Hydrogen Valley Feasibility Study Report. Soutb Africa: DSI. Retrieved from https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf

dtic. (2022). *Green Hydrogen Commercialisation Strategy.* Retrieved from http://www.thedtic.gov.za/wp-content/uploads/Full-Report-Green-Hydrogen-Commercialisation-Strategy.pdf

EDF Renewables. (2023). EDF Renewables. Retrieved from https://edf-re.co.za/

Eskom. (2023). *Just Energy Transition (JET)*. Retrieved from https://www.eskom.co.za/about-eskom/just-energy-transition-jet/

Freeport Saldanha. (2022). SBIDZ-LC Annual Report 2021/22. South Africa: Freeport Saldanha. Retrieved from https://freeportsaldanha.com/news-and-media/publications/

Genesis Anlaytics. (2022-2023). Making South Africa's Just Energy Programme a reality. South Africa. Retrieved from https://www.genesis-analytics.com/projects/making-south-africas-just-energy-programme-a-reality

GH2. (2023). South Africa. Green Hydrogen Organisation (GH2). Retrieved from https://gh2.org/countries/south-africa

Green Economy Media. (n.d.). SANEDI's SACCCS joins Global CCS Institute to promote climate change research. Retrieved from https://greeneconomy.media/sanedis-sacccs-joins-global-ccs-institute-to-promote-climate-change-research/

GreenCape. (2022a). *Large-scale Renewable Energy Market Intelligence Report.* Retrieved from https://www.westerncape.gov.za/110green/sites/green.westerncape.gov.za/files/atoms/files/RE_MIR_29_3_22_FINAL.pdf

GreenCape. (2022b). Supplier Database for Renewable Energy Stakeholders. Retrieved from https://green-cape.co.za/designated-local-content-market-intelligence-supplier-database/

GTAC. (2021). Export Promotion in the Industrial Development Zones. Government Technical Advisory Centre (GTAC). Retrieved from https://www.gtac.gov.za/pepa/wp-content/uploads/2021/11/IDZ-Summary.pdf

H2 Atlas. (2023). H2 Atlast Africa. Retrieved from https://www.h2atlas.de/en/

Heraeus Precious Metals . (2023). Sustainability & Climate Protection. Retrieved from https://www.heraeus.com/en/hpm/sustainability/sustainability.html

Heraeus Precious Metals. (2022). Sibanye-Stillwater and Heraeus enter into a Partnership to develop and commercialise Novel Electrolyser Catalysts for the Production of Green Hydrogen. Retrieved from https://www.heraeus.com/en/hpm/company/hpm_news/2022_hpm_news/sibanye_stillwater_and_heraeus_enter_into_a_partnership.html

Hermans, S. (n.d.). WSU makes efforts to lighten Eskom power burden. Retrieved from https://wsu.ac.za/index.php/component/content/article/286-wsu-newsletter/635-wsu-makes-efforts-to-lighten-eskom-power-burden?Itemid=437

Hive Energy. (2022). *Hive Hydrogen £5bn giga-scale projects leads the just energy transition in Nelson Mandela Bay, South Africa.* Retrieved from https://www.hiveenergy.co.uk/2022/11/21/hive-hydrogen-project-leads-the-just-energy-transition/

Hydrofuel Solutions. (n.d.). Our Projects. Retrieved from https://hydrofuels.co.za/our-projects/#richtersveld

Hydrox Holdings. (2023). About Us. Retrieved from https://hydroxholdings.co.za/

HyPlat. (2023). HyPlat. Cape Town, South Africa. Retrieved from https://www.hyplat.com/

HySA Infrastructure. (2023). *HySA Infrastructure*. Retrieved from https://hysainfrastructure.com/

HySA Infrastructure. (n.d.). Staff Details. Retrieved from https://hysainfrastructure.com/staff/dmitri-bessarabov/

HySA Systems. (n.d.). Staff. UWC. Retrieved from http://www.hysasystems.com/index.php/staff

Implats. (n.d.). Supporting growth in the hydrogen and fuel cell economy. Retrieved from https://www.implats.co.za/stories/Supporting-growth-in-the-hydrogen-and-fuel-cell-economy.php

Isa, M., & Yelland, C. (2022). Green hydrogen provides answer to many of South Africa's decarbonisation prayers, studies show. Daily Maverick. Retrieved from https://www.dailymaverick.co.za/article/2022-01-19-green-hydrogen-provides-answer-to-many-of-south-africas-decarbonisation-prayers-studies-show/

Kenned, L. (2022). A first in South Africa for Green Hydrogen. MyPressportal. Retrieved from https://pressportal.co.za/energy-and-environment/story/a-first-in-south-africa-for-green-hydrogen.html

Kilian, A. (2020). *Bambili Energy Supplies Hydrogen Fuel Cells to 1 Military Hospital in South Africa.* Bmbili Energy. Retrieved from https://www.bambilienergy.com/bambili-energy-supplies-hydrogen-fuel-cells-to-1-military-hospital-in-south-africa-the-countrys-flagship-military-medical-institution

Leo, T. (2023, March). https://www.fuelcellenergy.com/blog/fuel-cell-efficiency. Fuel Cell Energy. Retrieved from https://www.fuelcellenergy.com/blog/fuel-cell-efficiency

Mainstream Renewable Power. (2023). South Africa. Retrieved from https://www.mainstreamrp.com/markets-projects/africa/south-africa/

Metcalfe, J., Burger, L., & Mackay, J. (2020, October). Unlocking South Africa's hydrogen potential. PwC.

Mintek. (2022). *Annual Intergated Report 2021/2022.* Retrieved from https://mintek.co.za/media/annual-report/annual-report-2022.pdf

Mintek. (n.d.). Advanced Materials. South Africa: Mintek. Retrieved from https://mintek.co.za/clusters/miningmaterialsautomation/advanced-materials.html#:~:text=Through%20the%20Catalysis%20Group%2C%20Mintek%20has%20taken%20a,assemblies%2C%20fuel%20cell%20stacks%2C%20and%20fuel%20cell%20systems.

Mitochondria. (2022). Mitochondria Business Profile. South Africa. Retrieved from https://www.mitochondria.co.za/wp-content/uploads/2022/11/Mitochondria-Brochure-Updated.pdf

Mitochondria. (2023). About Us. Retrieved from https://www.mitochondria.co.za/about/#:~:text=In%202021%20the%20Gauteng%20Province%20through%20their%20Gauteng,of%20land%20has%20been%20allocated%20for%20this%20development.

Mulilo. (2023). Home. Retrieved from https://mulilo.com/

National Planning Comittee. (2012). National Development Plan 2030. South Africa: The Presidency. Retrieved from https://www.gov.za/sites/default/files/gcis_document/201409/ndp-2030-our-future-make-it-workr.pdf

Navitas Holdings. (2023). Navitas. Retrieved from http://navitasholdings.co.za/

NCP Chlorchem. (2023). NCP Chlorchem. Retrieved from https://ncp.co.za/

NMMU. (2023). *Centre for High Resolution Transmission Electron Microscopy*. Retrieved from https://chrtem.mandela.ac.za/access

NRF. (2022). Framework & Funding Guide for DSI/NRF-Sasol Research Chair in Green. Retrieved from https://www.nrf.ac.za/wp-content/uploads/2022/08/DSI-NRF-Sasol-Research-Chair-in-Green-Hydrogen-Framework-and-Funding-Guide.pdf

NRF. (2023). *Research*. Retrieved from https://www.nrf.ac.za/research/

NSTF. (2021). Prof Michael Claeys. National Science and Technology Forum (NSTF). Retrieved from https://nstf.org.za/2021/12/03/professor-michael-claeys/

Omnia. (2023). Another Omnia ESG Milestone: MoU signed with WKN Windcurrent to evaluate production of onsite green hydrogen and ammonia in South Africa. Retrieved from https://www.omnia.co.za/investors-and-media/press-releases/2023/261-another-omnia-esg-milestone-mou-signed-with-wkn-windcurrent-to-evaluate-production-of-onsite-green-hydrogen-and-ammonia-in-south-africa

Patel, M. (2020). Green hydrogen: A potential export commodity in a new global marketplace. TIPS. Retrieved from https://www.tips.org.za/research-archive/sustainable-growth/green-economy-2/item/4006-green-hydrogen-a-potential-export-commodity-in-a-new-global-marketplace

PetroSA. (2023). About Us. Retrieved from http://www.petrosa.co.za/discover_petroSA/Pages/Our-Company.aspx

Phelan Energy Group. (2022). Top SA governent official joins Phelan Energy Group. Retrieved from https://phelanenergygroup.com/top-sa-government-official-joins-phelan-energy-group/

Philco Green Energy. (2023). About. Retrieved from https://philcogreenenergy.wordpress.com/about/

Phillips, T. (2021, September 9). SA hydrogen energy development poised to unlock investment. Mail&Guardian. Retrieved from https://mg.co.za/environment/2021-09-09-sa-hydrogen-energy-development-poised-to-unlock-investment/#:~:text=Opportunities%20for%20Eskom%20were%20highlighted%20at%20the%20Joburg,transformed%20into%20chemical%20hubs%20for%20green%20hydrogen%20production.

Pollet, G. B., Pasupathi, S., Swart, G., Mouton, K., Lototskyy, M., Williams, M., . . . Linkov, V. (2014). Hydrogen South Africa (HySA) Systems Competence Centre: Mission, objectives, technological achievements and breakthroughs. *International Journal of Hydrogen Energy, 39*, 3577-3596.

PowerCell Group. (2023). About PowerCell. Retrieved from https://powercellgroup.com/about-powercell/

Prieska Power Reserve. (n.d.). A catalytic project that will start producing green hydrogen & ammonia in 2025. Retrieved from https://prieskapower.com/#

Rebel Group. (2023). Promoting the development of a hydrogen economy for South Africa. Retrieved from https://rebelgroup.com/en/projects/promoting-the-development-of-a-hydrogen-economy-for-south-africa/

Roos, T. (2021). The cost of production and storage of renewable hydrogen in South Africa and transport to Japan and EU up to 2050 under different scenarios. *International Journal of Hydrogen, 46*(36). doi:10.1016/j.ijhydene.2021.08.193

Roos, T., & Wright, J. G. (2021). Powerfuels and Green Hydrogen (public version). *Research Gate*. Retrieved from https://www.researchgate.net/publication/349140439_Powerfuels_and_Green_Hydrogen_public_version

SAASTA. (2023). SAASTA. South African Agency for Science and Technology Advancement (SAASTA).

SAIIA. (2023). *Research Themes*. Retrieved from https://saiia.org.za/research-themes/

SAIIA, DSI, DHET. (2022). *South African Green Hydrogen TVET Ecosystem Just Transition Strategic Framework.* Retrieved from https://saiia.org.za/research/the-south-african-green-hydrogen-tvet-ecosystem-just-transition-strategic-framework/

SAIMM. (2023). Southern African hydrogen andfuel cell conference 2023. *Conference Proceedings*. South Africa: Southern African Institute of Mining and Metallurgy (SAIMM). Retrieved from https://www.saimm.co.za/media/com_eventbooking/Hydrogen%20Fuel%20Cells%20Conference%20Final%20Programme-13042023.pdf

Salma, T., & Tsafos, N. (2022). South Africa's Hydrogen Strategy. Centre for Strategic and International Studies. Retrieved from https://www.csis.org/analysis/south-africas-hydrogen-strategy

SANEDI. (2022). Annual Report 2021/2022. South African National Energy Development Initiative (SANEDI). Retrieved from https://sanedi.org.za/publications/Annual%20reports/SANEDI%20AR2022%20WEB.pdf

SAPVIA. (2023). South African Photovoltaic Idustry Association. Retrieved from https://sapvia.co.za/

SARETEC. (2023). Retrieved from LinkedIn: https://www.linkedin.com/company/saretecsa/?originalSubdomain=za

Sasol. (2021). Sasol and Toyota South Africa Motors form green hydrogen mobility partnership. Johannesburg, South Africa. Retrieved from https://www.sasol.com/media-centre/media-releases/sasol-and-toyota-south-africa-motors-form-green-hydrogen-mobility

Sasol. (2022). Sasol, ArcelorMittal South Africa partner to decarbonise and reindustrialise Vaal, Saldanha through green hydrogen. Johannesburg, South Africa. Retrieved from https://www.sasol.com/media-centre/media-releases/sasol-arcelormittal-south-africa-partner-decarbonise-and-reindustrialise-vaal-saldanha-through

Sasol. (2022a). HyshiFT Consortium. Retrieved from https://sasol.com/hyshift-consortium

Sasol. (2023). Sasol and the ACED-IDEAS-REATILE Consortium sign Power Purchase Agreement (PPA) for long-term renewable power to Sasolburg. Johannesburg, South Africa. Retrieved from https://www.sasol.com/sasol-and-aced-ideas-reatile-consortium-sign-power-purchase-agreement-ppa-long-term-renewable-power

Sasol ecoFT. (2022). Sasol ecoFT and Deutsche Aircraft join forces to accelerate Power-To-Liquid (PTL) aiming for carbon-neutral flight. Retrieved from https://www.sasol.com/media-centre/media-releases/sasol-ecoft-and-deutsche-aircraft-join-forces-accelerate-power-liquid-ptl-aiming-carbon-neutral

SASSCAL. (2023). South African Service Centre for Climate Changea and Adaptive Land Managmenet. Retrieved from https://sasscal.org/

Savannah Environmental. (2020). Proposed development of the Upilanga Solar Park and associated infrastucture (Northern Cape Province). South African Heritage Resources Agency (SAHRA). Retrieved from https://sahris.sahra.org.za/sites/default/files/additionaldocs/BID_Eng.pdf

SAWEA. (2023). South African Wind Energy Association. Retrieved from https://sawea.org.za/

Slater, D. (2021). EWSETA planning to bolster domestic hydrogen development readiness, capabilities. Engineer News. Retrieved from https://www.engineeringnews.co.za/article/ewseta-planning-to-bolster-domestic-hydrogen-development-readiness-capabilities-2021-05-25

Slater, D. (2022). *Mitochondria Energy to build a fuel cell manufacturing facility in the Vaal SEZ in 2023.* Engineering News. Retrieved from https://m.engineeringnews.co.za/article/mitochondria-energy-to-build-a-fuel-cell-manufacturing-facility-in-the-vaal-sez-in-2023-2022-06-28

Steyn, L. (2023). Mantashe: Release of new-look electricity infrastructure plan is imminent. *News21*.

SU. (2023). Prof Prathieka Naidoo. South Africa: Stellenbosch University (SU). Retrieved from https://chemeng.sun.ac.za/staff/all-staff/?entry=1403

The Presidency. (2022). SA’s Just Energy transition Investment Plan (JET IP) 2023-2027. South Africa. Retrieved from https://www.thepresidency.gov.za/content/south-africa%27s-just-energy-transition-investment-plan-jet-ip-2023-2027

TIA. (2023). Call for Proposals: Natural Resources and Energy Technologies. South Africa: Technology Innovation Agency (TIA). Retrieved from https://www.tia.org.za/blog/2023/09/08/call-for-proposals-natural-resources-and-energy-technologies/

Tshisikhawe, P. (2023). TUT to lead hydrogen energy and 4IR curriculum development project. Tshwane University of Technology (TUT). Retrieved from https://www.tut.ac.za/news-and-press/article?NID=700

UCT. (2023a). *HySA Catalysis*. Retrieved from Research Activities: https://hysacatalysis.uct.ac.za/research-activities

UCT. (2023b). *Overview*. Retrieved from Mineral Law in Africa: http://www.mlia.uct.ac.za/overview-30/

UCT. (n.d.). Academic Staff. Department of Chemical Engineering, University of Cape Town (UCT). Retrieved from https://ebe.uct.ac.za/department-chemical-engineering/about-us-staff/academic-staff

UJ. (2023). National Research Foundation (NRF) awards two new SARChI chairs to the University of Johannesburg (UJ). Retrieved from https://news.uj.ac.za/news/national-research-foundation-nrf-awards-two-new-sarchi-chairs-to-the-university-of-johannesburg-uj-2/

UJ. (2023). Prof Tien-Chien Jen. University of Johannesburg (UJ). Retrieved from https://www.uj.ac.za/members/prof-tien-chien-jen/

UP. (n.d.). Prof Henrietta Langmi. University of Pretoria (UP). Retrieved from https://www.up.ac.za/chemistry/article/2857953/prof-henrietta-langmi

UWC. (2023a). *South African Institute for Advanced Materials Chemistry.* Retrieved from https://www.uwc.ac.za/study/all-areas-of-study/institutes/south-african-institute-for-advanced-materials-chemistry/overview

UWC. (2023b). *HySA Systems*. Retrieved from https://hysasystems.com/

UWC. (n.d.). *UWC Augments Green Hydrogen Production Development and Training.* Retrieved from https://www.uwc.ac.za/news-and-announcements/news/uwc-augments-green-hydrogen-production-development-and-training

Vaal University of Technology. (2023, February 15). VUT to play a key role in rejuvenating the declining economy of the Vaal region. Retrieved from https://www.vut.ac.za/vut-to-play-a-key-role-in-rejuvenating-the-declining-economy-of-the-vaal-region/

Viljoen, N. (2022). Driving the Hydrogen Economy in South Africa. South Africa: Anglo American Plantinum. Retrieved from https://www.angloamerican.com/our-stories/innovation-and-technology/driving-the-hydrogen-economy-in-south-africa

Wits. (n.d.). Sustainable Energy and Environment Research Unit (SEERU). University of the Witwatersrand (Wits). Retrieved from https://www.wits.ac.za/chemmet/research/sustainable-energy-and-environment-research-unit/

Appendix A: Documents reviewed

Author/Institution	Year	Name of document	Accessibility
AHK	2023	H2.SA Hydrogen Economy Stakeholder Database	*Not publicly available*
GIZ, Millenium Institute	2023	The Green Hydrogen Economy: Risks and Opportunities for national development	*Not publicly available*
SA-EU Dialogue Facility	2023	SA-EU Dialogue Facility Workshop on Green Hydrogen domestic utilisation through industrial growth, trade and investment – workshop agenda and attendee list	*Not publicly available*
World Bank Group	2022	South Africa & Southern Africa Battery Market & Value Chain Assessment Report	https://ces-ltd.com/wp-content/uploads/P17268201ebc89050b1960f40c8377523a2.pdf
GIZ	2022	Stakeholder Map	*Not publicly available*
SAIIA - co-developed by SAIIA and consortium partners, alongside the DSI and other government stakeholders	2022	The South African Green Hydrogen TVET Ecosystem Just Transition Strategic Framework	https://saiia.org.za/wp-content/uploads/2022/06/SAIIA_SR_GreenHydrogenTVet.pdf
dtic	2022	Green Hydrogen Commercialisation Strategy for South Africa	http://www.thedtic.gov.za/wp-content/uploads/Full-Report-Green-Hydrogen-Commercialisation-Strategy.pdf
Laurens Cloete: A project implemented by a Consortium led by Hulla & Co. Human Dynamics GmbH &Co. KG A DAI Global Company	2022	Dialogue project: Green Hydrogen domestic utilisation through industrial growth, trade and investment	*Not publicly available*
GFA	2022	Analysis and recommendations for improving the regulatory framework and strategic planning basis in South Africa in the context of a favourable policy for green hydrogen / PtX production, application, and export	*Not publicly available*
The Presidency, RSA	2022	South Africa's Just Energy Transition Investment Plan (JET IP) 2023-2027	https://www.thepresidency.gov.za/content/south-africa%27s-just-energy-transition-investment-plan-jet-ip-2023-2027
Africa Green Hydrogen Alliance	2022	Africa's Green Hydrogen Potential	https://gh2.org/sites/default/files/2022-11/Africa%27s%20Green%20Hydrogen%20Potential.pdf
CSIR		CSIR Hydrogen Study	*Not received*
GIZ, Infrastructure South Africa, Digital Council	2022	South Africa Green Hydrogen Summit (SAGHS) – event programme	https://infrastructuresa.org/wp-content/uploads/2022/11/SAGHS-Program_v21.pdf

	2021	Green Hydrogen Summit - attendee list	*Not publicly available*
DSI	2021	Hydrogen Society Roadmap For South Africa	https://www.dst.gov.za/images/South_African_Hydrogen_Society_RoadmapV1.pdf
IHS Markit	2021	A Super H2igh Road Scenario for South Africa	https://www.ee.co.za/wp-content/uploads/2021/06/IHS-Markit-Super-H2igh-Road-Scenario-for-South-Africa-Public-Report-6-21.pdf
DSI	2021	Hydrogen Valley Feasibility Study Report	https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf
PwC	2020	Unlocking South Africa’s Hydrogen Potential	https://www.pwc.co.za/en/assets/pdf/unlocking-south-africas-hydrogen-potential.pdf

Appendix B: Private sector stakeholders

Table 5: Private sector energy and climate sector partners across the GH2 value chain

Entity	GH_2 relevance	Position in the value chain	Segment
Afrox (part of the Linde group)	Hydrogen producer for the Hive Green Ammonia project (Hive Energy, 2022). Announced a collaboration between Sasol, Linde, Enertrag and Navitas to bid for the production of SAF for export to Germany (Sasol, 2022a)	Upstream	Hydrogen production
Air Liquide	Gas manufacturer. Working with Anglo American in GH_2 projects, including the Sasolburg GH_2 project.	Upstream	Hydrogen production
Air Products	Manufactures, supplies and distributes a wide variety of industrial and specialty gas products to the Southern African region (Air Products, 2021). Was involved in the now decommissioned Windsor Clinic fuel cell and Cofimvaba Rural Schools fuel cells, and	Upstream	Hydrogen production
Anglo American and Anglo American Platinum (Amplats)	Driving the nuGen™ Zero Emission Haulage Solution (ZEHS) - an agreement with Engie to develop and fuel the world's largest hydrogen-powered mine haul truck (Viljoen, 2022). Partner in the Hydrogen Valleys Feasibility Investigation and the Rhynbow H_2 freight corridor project.	Downstream	End-usage in heavy industry
ArcelorMittal	A large potential off-taker of GH_2 in SA includes ArcelorMittal SA's mothballed Saldanha steel works, which would require 104,000 tonnes of hydrogen per year to produce 1.5 million tonnes of hot briquetted iron per year (Isa & Yelland, 2022). Vaal carbon capture and utilisation (CCU) study (Sasol, 2022).	Downstream	End-usage in heavy industry – green steel
Atlanthia	Project Developer and operations and maintenance (O&M) operator in Saldanha Bay - focuses on technologies that convert hydrogen into electricity. Atlanthia is developing an economically viable GH_2 project at-scale in the Western Cape (AOW, 2022).	Upstream	Hydrogen production
Ballard Power Systems	A developer and manufacturer of PEM membrane fuel cell products (Ballard Power Systems, 2023). Equipment provider for the Telecoms towers stationary power demonstration.	Upstream	Manufacturing of equipment (fuel cells)
Bambili Energy	Partner in the Hydrogen Valleys Feasibility Investigation – provide fuel cell systems for transport and stationary uses (DSI, Anglo American Platinum, Bambili Energy, Engie, 2021)	Upstream	Manufacturing of equipment (fuel cell stacks and systems)
BuiltAfrica	Project funder for Hive green ammonia project (Hive Energy, 2022). Focused on RE and have been successful in the REIPPPP	Upstream	Renewable electricity and associated infrastructure

Cape Stack	Hydrogen fuel-cell component manufacturer (electrolysers and fuel cell stacks) Cape Stack and Namaqua Engineering partnered with Keren on the Vredendal GH_2 (proof of concept) plant's design and construction (Creamer, Green hydrogen pioneer seeks finance for commercial plant as Vredendal proof-of-concept facility enters production, 2022).	Upstream	Manufacturing of equipment (fuel cell stacks)
Cenec	Central Energy Corporation (Cenec) develops, builds, operates, and own RE plants. Partner in the Prieska Power Reserve project (Cenec, 2022).	Upstream	Renewable electricity and associated infrastructure
CHEM Energy	CHEM Energy has over 400 patents and 10-year track record. CHEM Energy produces fuel cells of up to 5 kW capacity (G5 fuel cell system), with a fuel cell manufacturing facility to be built at the Dube Trade Port, Durban (CHEM Energy, 2023).	Upstream	Manufacturing of equipment (fuel cells)
Earth and Wire	Develop and produce clean energy that is sold directly to private clients - partner in the e-methanol feasibility study (Indigen Project) (Creamer, 2021).	Upstream	Renewable electricity and associated infrastructure
EDF Renewables	A local, fully integrated independent power producer that develops, finances, builds, owns and operates commercial RE generation facilities (EDF Renewables, 2023).	Upstream	Renewable electricity and associated infrastructure
Egoli Gas	Partner of Mitochondria– natural gas provision for the 100-kW combined heat and power phosphoric acid fuel cell (dtic, 2022) at the Chamber of Mines offices in Johannesburg (launched in 2015 by the IDC and Mitochondria).	Upstream	
Emvelo Capital Projects	Independent power developer – partner in the Upilanga Solar and GH_2 Park (Savannah Environmental, 2020).	Upstream	Renewable electricity and associated infrastructure
Enertrag	Partner in the e-methanol feasibility study and the Enertrag Postmasburg Project (Ammonia) in the Northern Cape. Enertrag is also part of the HySHiFT consortium (SAF production).	Upstream	Hydrogen generation
Engie	A global energy and energy services company. Partner in the Hydrogen Valleys Feasibility Investigation, the Rhynbow H_2 freight corridor project, and nuGen™ ZEHS,	Upstream Midstream Downstream	Along the entire length of the hydrogen value chain – from production of RE to end uses
Envusa Energy	EDF Renewables partnered with Anglo American to form Envusa Energy (Anglo American, 2022) - nuGen™ ZEHS project partner.	Upstream	Renewable electricity and associated infrastructure
Eskom	The Eskom RT&D team is interested in a GH_2 pilot study due to the opportunities for Eskom in decommissioning coal-fired power infrastructure and transforming them into chemical hubs for GH_2 production (Phillips, 2021).	Upstream	
Gridline Construction	Construction contractor for the now decommissioned Windsor clinic fuel cell.	Upstream	
Grindrod	Global logistics and shipping company – partnered with Keren Energy on the Vredendal Project.	Downstream	Handling/ distribution and transport

Heraeus Precious Metals	Provider of precious metal services and products - R&D on novel electrocatalysts for the production of GH_2 - based on ruthenium and iridium (Heraeus Precious Metals, 2022).	Upstream	Manufacturing of equipment (electrolysers)
Hive Hydrogen	Project managers of Hive green ammonia project[17] (Hive Energy, 2022).	Project management	
Horizon Fuel Cell Technologies	Production of PEM fuel cell system – equipment provider for the fuel cell operational at 1 Military Hospital (dtic, 2022).	Upstream	Manufacturing of equipment (fuel cell)
Hydregen	Part of the HySHiFT consortium (SAF production). 80% black owned and controlled local company that develops and invests in GH_2 infrastructure and projects focused on the just energy transition (Sasol, 2022a).	Project developer and funder	
Hydrofuel Solutions	HydroFuel Solutions a SA based RE company which specializes in the development of commercially viable GH_2 production projects via plasma waste gasification and electrolysis (Hydrofuel Solutions). Projects include the Richtersveld 1GW hydrogen hub – green ammonia, Coega plasma waste gasification plant, and the Saldanha Bay IDZ plasma waste gasification plant.	Upstream	Manufacturing of equipment (electrolysers and balance of plant)
Hydrox Holdings	Producers of Divergent-Electrode-Flow Through (DEFT) and Advanced Alkaline Electrolyser (AAE) technology (alkaline-based water electrolysis system). Appear to still be at the development/pilot stage (Hydrox Holdings, 2023).	Upstream	Manufacturing of equipment (electrolysers)
Impala Platinum (Implats)	Installed 1.5kW stationary fuel cell for testing under realistic load conditions at Springs Refineries with piped grey hydrogen; as well as a fully operational mobile hydrogen fuel cell-powered forklift (DSI, 2022)	Upstream	Manufacturing of equipment (fuel cell)
Inala Technology	Supplier of telecommunications, power solutions, unified communications, broadcasting, audio visual and test and measurement solutions (Crunchbase). Partner in the operational Telecom towers stationary power demonstration.	Project support	
Isondo Precious Metals	Establishing an industrial scale, high-tech, fuel cell and electrolyser component manufacturing facility within the OR Tambo SEZ (Bulbulia, 2021).	Upstream	Manufacturing of equipment (fuel cells, electrolysers and balance of plants)

[17] *Operational production of GH_2 and ammonia for export at Coega. Access to deep water harbour with berths, liquid bulk storage/shipping capability, large-scale on-site power generation capacity, water availability, large capacity grid connections for power wheeling. Project feasibility completed, and in discussion with 5 technology partners (including Afrox and Linde). Secured commitment from a global battery and solar panel manufacturers to establish plants in Coega.*

Keren Energy	A successful bidder in the REIPPP and has established a proof-of-concept GH_2 project in Vredendal in the Western Cape (Creamer, Green hydrogen pioneer seeks finance for commercial plant as Vredendal proof-of-concept facility enters production, 2022).	Upstream	Renewable electricity and associated infrastructure
Linde	Global industrial gases and engineering company - part of the HySHiFT consortium (SAF production).	Upstream	Hydrogen production
Mahlako a Phahla investments	Project developer for Prieska Power Reserve. Women-owned social infrastructure group in advisory services, financial services, and alternative investment management (Cenec, 2022)	Project funders	
Mainstream Renewable Power	Global RE company, with wind and solar assets. In 2021, awarded preferred bidder status in Round 5 of the REIPPP with a total capacity of 1.27 GW across wind (824 MW) and solar (450 MW) technologies (Mainstream Renewable Power, 2023). Looking at opportunities, including in Saldanha Bay.	Upstream	Renewable electricity and associated infrastructure
Mitochondria	Partner in Project Phoenix in the Vaal SEZ in Gauteng where fuel cells are manufactured on-site. 700 hectares of land allocated by the GGDA/ Emfuleni Municipality (Mitochondria, 2023; Slater, 2022). Emerging OEM supplier of fuel cells.	Upstream	Manufacturing of equipment (fuel cells)
Msenge Emoyeni Wind Farm	Sasol South Africa Limited (Sasol) and Msenge have signed a long-term contract for the supply of 69MW of renewable energy to the company's Sasolburg site (Sasol, 2023)	Upstream	Renewable electricity and associated infrastructure
Mulilo	Mulilo is the largest South African owned renewable energy Independent Power Producer (IPP) and is targeting at least 20% of the country's renewable energy market (Mulilo, 2023).	Upstream	Renewable electricity and associated infrastructure
Navitas	Energy advisor offering a wide range of energy supply solutions (Navitas Holdings, 2023).	Project funders	
NCP Chlorchem	Manufacturer of chlorine, caustic soda, and other alkali derivatives (NCP Chlorchem, 2023). Involved in a waste hydrogen recovery project.	Downstream	End-usage in the chemicals industry light industry)
Omnia	Chemicals group - mainly for mining, agriculture and manufacturing (Arnoldi, 2023). Partner in the Ubuntu green energy hydrogen project, and a green ammonia production plant with WKN Windcurrent (feasibility study).	Midstream Downstream	Beneficiated products - ammonia End-usage - ammonia in the agricultural, mining and manufacturing industries
PetroSA	PetroSA is also a pioneer of gas-to-liquids (GTL) technology, which is recognised for producing clean fuels – reports to the DMRE. Some of the commodities produced by PetroSA include unleaded petrol, kerosene (paraffin), diesel, propane, liquid oxygen and nitrogen, distillates, eco-fuels and alcohols. Its world-class synthetic fuels and petrochemicals are marketed internationally (PetroSA, 2023).	Downstream	End-usage - Powerfuels

PowerCell Group	Develops and manufactures fuel cell stacks and fuel cell systems with a uniquely high-power density (PowerCell Group, 2023). Partner in the operational 1 Military hospital fuel cell field deployment (dtic, 2022).	Upstream	Manufacturing of equipment (fuel cell – systems and stacks)
Phelan Energy Group	Aiming to become a key international supplier of green ammonia to service the vast demand for GH_2 products (Phelan Energy Group, 2022). Phelan will leverage its experience in low cost solar, that represents up to 75% of the production cost of GH_2.	Midstream	Beneficiated products - ammonia
Philco Green Energy	Project funders for the Ubuntu green energy hydrogen project (Philco Green Energy, 2023).	Project funders	
Powertech System Integrators	A system engineering business which operates in the power and energy sectors – partner in the Telecom towers stationary power demonstration (dtic, 2022). Its engineering solutions include secondary plant for substation automation, network planning and control software, mobile workforce and asset management systems, and systems for advanced and smart metering infrastructure.	Upstream	
Renew e	Focus on RE and gas projects, as well as the hydrogen economy. Involved in the Renew e waste hydrogen power generation project (Department of Public Works and Infrastructure, 2022b).	Upstream	Renewable electricity and associated infrastructure
Sakhumnotho Power	Partner in the Vredendal GH_2 project.	Upstream	Renewable electricity and associated infrastructure
Sasol[18]	Broad experience in hydrogen and R&D capabilities, combined with Fischer-Tropsch and catalyst technologies to enable the production of sustainable synthetic fuels and chemicals. Sasol has an aspiration to play a leading role in the establishment of a GH_2 economy in SA. Projects include Sasolburg GH_2, part of the HySHiFT consortium (SAF production) (Sasol, 2022a), Vaal CCU study (Sasol, 2022), partnership with Toyota to assess feasibility of GH_2 mobility ecosystem (hydrogen mobility corridor along the N3) (Sasol, 2021).	Upstream	Hydrogen production
Sasol ecoFT	Sasol ecoFT and Deutsche Aircraft SAF memorandum of understanding (Sasol ecoFT, 2022)	Midstream	Beneficiated products – e-kerosene
Sibanye Stillwater	A multinational mining and metals group, global PGM autocatalytic recyclers, and has interests in mine tailings retreatment operations. R&D on novel electrocatalysts for the production of GH_2 - based on ruthenium and iridium (Heraeus Precious Metals, 2022).	Upstream	Manufacturing of equipment (electrolysers)

[18] *Directed to Dr Thembakazi Mali in the inception meeting*

Siemens	Partner in the Prieska energy project (Prieska Power Reserve) – RE equipment manager and O&M. Technology provider of electrolysers, wind turbines, and monitoring systems. Additionally, involved in Hive green ammonia project (Hive Energy, 2022), and partnered with Atlanthia in Saldanha.	Upstream	Renewable electricity and associated infrastructure Manufacturing of equipment (electrolysers)
SMEC	Partner in the Prieska energy project (Prieska Power Reserve) – project support as an engineering and infrastructure solutions company.	Upstream	
ThyssenKrupp	Supply technology, specific engineering, equipment, and technical services for water electrolysis plants to be built. Have partnered with Air Products (Air Products, 2021).	Upstream	Manufacturing of equipment (electrolyser systems and balance of plants)
Toyota	Hydrogen Mobility Corridor along N3 (Sasol, 2021). Experience when it comes to hydrogen fuel cell electric vehicles.	Downstream	End-usage in mobility
Tswina Solutions	Project developer – in the planning phase of the 250 TPD green ammonia production facility project located in Saldanha Bay.	Project developer	
Ubuntu Green Energy	Project developer – Ubuntu GH_2 project	Project developer	
Vodacom	Partner in the Telecoms towers stationary power demonstration.	Downstream	End-usage in stationary applications (telecommunications)
Windlab South Africa	RE project developer involved in the Sasolburg GH_2 project	Upstream	Renewable electricity and associated infrastructure
WKN Windcurrent	RE project developers for onshore and offshore wind energy - partner in the green ammonia production plant with Omnia (feasibility study) (Arnoldi, 2023).	Upstream	Renewable electricity and associated infrastructure
24Solutions	CHEM Energy appointed 24Solutions as a service provider and sales representative for the SADC region for stationary applications. Partner in the e-methanol feasibility study (Indigen Project) (Creamer, 2021).	Project support	

Appendix C:

Dr. Dmitri Bessarabov – HySA Infrastructure, NWU

Director of HySA Infrastructure at NWU. Research interests include: Fuel cells, PEM electrolysis, hydrogen energy, hydrogen storage, hydrogen infrastructure, membranes, separations, applied electrochemistry, applied polymer science, environmental technologies, water treatment, post-graduate training in applied chemistry (membrane and electrochemical technology), international co-operation in membrane and electrochemical research (HySA Infrastructure, n.d.).

Dr. Sharon Blair – Centre for Catalysis Research, UCT

Director of HySA Catalysis, and founder and currently CEO and Director of HyPlat (Pty) Ltd. Research focuses on development of the early part of the fuel cell and fuel processing value chain (i.e., materials, components and units). Some of these technologies have matured to commercial-readiness and HyPlat is tasked with commercialisation of technologies emanating from the Centre.

Dr. Stanford Chidziva – SAIAMC, UWC

Acting director of the GH_2 programme at SAIAMC, hydrogen safety expert at UWC, and the SAIAMC technical and safety manager. Initiated the prototype GH_2 production system for general hydrogen consumption at the SAIAMC Innovation Centre's RDI facility (Kenned, 2022). In collaboration with an international electrolyser company, designed a Polymer Electrolyte Membrane Water Electrolyser (PEMWE) with a hydrogen discharge pressure of 20 bars (paying special attention to the operational safety of the prototype system). The hydrogen production system was extensively tested and validated at the SAIAMC facility, and then was integrated at the Namaqua Engineering facility in Vredendal (with Cape Stack).

Prof. Michael Claeys – Centre for Catalysis Research, Department of Chemical Engineering in the Faculty Engineering and the Built Environment, UCT

Director of the DSI-NRF Centre of Excellence in Catalysis (c*change). Research has included the development and use of novel and unique characterisation tools, which include patented devices such as the in-situ magnetometer (developed with Sasol), and an in-situ XRD reaction cell, which has been successfully commercialised by Cape Catalytix, a spinout company at UCT (NSTF, 2021).

Assoc. Prof. Nico Fischer – Centre for Catalysis Research, Department of Chemical Engineering in the Faculty Engineering and the Built Environment, UCT

DSI/NRF SARChI Chair in Sustainable Catalysis, and Deputy Director of the Catalysis Institute. Research includes synthesis gas chemistry, CO_2 activation, nanoparticle synthesis, material characterisation, and in situ characterisation techniques (UCT, n.d.).

Prof. Jack Fletcher – Centre for Catalysis Research, UCT

Professor of Chemical Engineering and co-founder of HYENA, a hard-tech spinout company from UCT. Experience in alternative fuels and heterogeneous catalysis relating to the energy field. Specific research includes heterogeneous catalysis, hydrogen, PtX, CO_2 utilization, fuel processing and hydroprocessing (UCT, n.d.).

Prof. Tien-Chien Jen – Department of Mechanical Engineering Science in the Faculty of Engineering and the Built Environment, UJ.

Sasol SARChI Chair in GH_2. Research includes atomic layer deposition, cold gas dynamics spraying deposition, hydrogen generation/ filtration/ storage, solar cell, fuel cell, nano fabrication, nano structure and materials, RE, and bio-fuel. (UJ, 2023). Focus on applying to fuel cells and the control system for on-demand power generation.

Prof. Patricia Kooyman – Centre for Catalysis Research, Department of Chemical Engineering in the Faculty Engineering and the Built Environment, UCT

Professor of Chemical Engineering. Focus on synthesis and characterisation of nanoparticles and their application in catalysis; supported and unsupported metallic, oxidic and sulphidic catalysts; zeolites and porous materials; Fischer-Tropsch catalysis, reduction-oxidation catalysis, hydrocarbon processing, wax upgrading, hydrodesulphurisation, photocatalysis, electrocatalysis; and high-resolution transmission electron microscopy and in situ transmission electron microscopy (UCT, n.d.).

Prof. Cobus Kriek - School for Physical and Chemical Sciences, NWU

Deputy director of the School for Physical and Chemical Sciences. Research focus on photo-electrocatalysis and electrocatalysis for clean and RE conversion and storage.

Prof. Henrietta Langmi, Department of Chemistry, UP

DSI/NRF SARChI Chair in Advanced Materials and Sustainable Energy. Primary research interests are in the fields of materials science and sustainable energy technologies, with hydrogen storage research at the core. This includes the development of porous materials, chemical carriers, and high-pressure composite cylinders for hydrogen storage applications (UP, n.d.).

Prof. Vladimir Linkov – SAIAMC, UWC

Director of the SAISMA. Research focus is on electrolysis and hydrogen compression.

Dr. Mykhaylo Lototskyy, HySA Systems and SAICMC, UWC

Senior researcher at SAIAMC. Research in the fields of hydrogen energy and technology, hydrogen storage, material science and applications of metal hydrides (HySA Systems, n.d.). Current research activities focus on the analysis of trends in hydrogen technologies, the preparation and advanced characterisation of metallic hydride-forming materials and nanocomposites on their basis, the experimental studies and modelling of thermodynamic and the kinetic performances of metal – hydrogen systems, gas-phase applications of metal hydrides including storage, compression and separation/ purification of hydrogen.

Associate Prof. Craig McGregor - Department of Mechanical and Mechatronic Engineering, SU.

Director of the Solar Thermal Energy Research Group (STERG). Concentrated on developing and commercialising synthetic fuels, and renewable/ sustainable technologies and solar power. Led the development of solar collector technology (the Stellio heliostat) in collaboration with Schlaich Bergmann Partner.

Prof. Amir Mohammadi – Department of Chemical Engineering in the School of Engineering, University of KwaZulu-Natal (UKZN)

Professor of Chemical Engineering. Research focuses on thermodynamics, gas hydrates, and petroleum engineering, with a specific focus on gas hydrate-based storage.

Associate Prof. Jean Mulopo, SEERU, School of Chemical and Metallurgical Engineering, Wits

Coordinator and co-founder of SEERU. Research includes understanding the opportunities and constraints provided by the general and hazardous waste generation in SA towards growing a green economy, particularly in the context of water and energy challenges.

Prof. Prathieka Naidoo - Department of Chemical Engineering in the Faculty of Engineering, SU.

Sasol-NRF Research Chair (SARChI) in GH_2. Research focus is on chemical thermodynamics, and separation processes and technologies, with a specific focus on the integration of hydrogen in the energy transition. Other research interests include high-pressure and low-pressure phase equilibria – modelling and measurements; chemical separation technologies; hydrate-based separations; distillation, enhanced distillation techniques, crystallization and extraction experiments, pilot plant distillation and extraction operations; supercritical studies and solid waste management processes (SU, 2023). With regards to waste management, currently pursuing research with regard desalination waste options to consider how to use concentrated brine, or whether to treat it before discharging.

Dr. Sivakumar Pasupathi - HySA Systems, UWC
Programme manager for HySA Systems, managing both (i) combined heat and power (CHP) and (ii) fuel cell vehicles (FCV), programmes (HySA Systems, n.d.). Current focus is on developing components and systems, covering the whole value chain of PEM fuel cells, for CHP and fuel cell vehicle applications. Interests include PEM based fuel cells and electrolysers.

Doctor Coneth Richards - Department of Electrical Engineering, TUT
Senior lecturer at TUT. Specific research focus on power systems and transmission network expansion planning with the penetration of RE sources.

Dr Darija Susac - Centre for Catalysis Research, Department of Chemical Engineering in the Faculty Engineering and the Built Environment, UCT
Senior research scientist. Focuses on fuel cells, material science, microscopy, and spectroscopy.

Prof. Eric van Steen - Centre for Catalysis Research, Department of Chemical Engineering in the Faculty Engineering and the Built Environment, UCT
DSI/ NRF SARChI Chair of Reaction Engineering. Research focus on heterogeneous catalysis and Fischer-Tropsch synthesis.

Appendix D: Interview guide

Stakeholder Group	Focus Discussion Points
GROUP A: Research groups	Research activities you are directly involved in or are collaborating with? Future research in the in the next 2 years and 5 years? Where do find research is currently focused? What is driving this focus? Research gaps you feel need more funding/attention? Why are these gaps not receiving enough attention? Do you think it makes sense for this research to be done in SA or could we be technology takers from overseas? Suggested future GH2 research focal areas for South Africa? Be specific (e.g., not just "fuel cells" but what aspects, types, components etc.) Why do you suggest this research? Known academics doing research in the field?
GROUP B: Research support; Independent consultants and research advisories	Research activities you are directly supporting. Elaborate? Future research in the in the next 2 years and 5 years? Driven/ funded by research institutions, private sector, or public sector? Where do find research is currently focused? What is driving this focus? Research gaps you feel need more funding/attention? Why are these gaps not receiving enough attention? Suggested future GH2 research focal areas for South Africa? Be specific (e.g., not just "fuel cells" but what aspects, types, components etc.) Why do you suggest this research? Known academics doing research in the field?
GROUP C: Government department enablers	Confirm funding/ support of research in this space? If there anything we have not picked up on, please elaborate? Confirm GH2 policy objectives? E.g., jobs, economic growth? Confirm if there are any specific national frameworks/plans/policies they are following? E.g., NDP, JET-IP, NDCs, IRP, HYSA, HSRM. Do you feel that the current GH2 research activities align with the policy objectives being pursued by government? Research gaps you feel need more funding/attention? Why are these gaps not receiving enough attention? Suggested future GH2 research focal areas for South Africa? Be specific (e.g., not just "fuel cells" but what aspects, types, components etc.) Why do you suggest this research? Known academics doing research in the field?
GROUP D: Private sector	Internal research capacity? Outsource research or reliance on research institutions? Why? Circumstances? R&D needs? Discuss in detail and really probe this one! Commercialization plans? Alignment of GH2 research activities (internal and external) with your needs/priorities? Research gaps you feel need more funding/attention? Why are these gaps not receiving enough attention? Suggested future GH2 research focal areas for South Africa? Be specific (e.g., not just "fuel cells" but what aspects, types, components etc.) Why do you suggest this research? Known academics doing research in the field?

Appendix E: Overview of current research

Table 6: Overview of current research activities (research institutions)

Research topic	Count	Research institutions
Policy and support	6	HySA Infrastructure; Mintek; SAIIA; SAASTA; SASSCAL; DSI/NRF-Sasol SARChi Chairs at UJ and Stellenbosch; AND advisory and research services including TIPS, GreenCape, PwC, Rebel Group, Genesis Analytics, GFA Consulting and DNA Economics
GH_2 production - Equipment – Membranes	3	HySA Catalysis; HyPlat, Vaal University of Technology
Fuel and fuel cell usage – Equipment – Fuel cell catalysts	5	HySA Catalysis; HyPlat; Centre for High Resolution Transmission Electron Microscopy (HRTEM), SEERU, Mintek
Storage, transport and safety – Research	3	HySA Infrastructure, HySA Systems, CSIR hydrogen storage facility
GH_2 production - Equipment – Electrolysers	2	HySA Catalysis; Mintek
Storage, transport and safety – Pilots	2	HySA Systems; CSIR hydrogen storage facility
Commercialisation	2	HyPlat; HYENA
GH_2 Production – Equipment – Balance of Plant	1	Walter Sisulu University of Technology
Fuel and fuel cell usage – Equipment – Other	2	Tshwane University of Technology, HySA systems
Hydrogen beneficiation – processes and products	2	c*change, SEERU

Table 7: Private sector research activities

Research topic	Count	Private Sector Entity
Commercialisation	13	Anglo American; Amplats, EDF; Envusa Energy; Engie; ArcelorMittal South Africa; Sasol; Linde/ Afrox; Enertrag; Hydregen; Omnia; Sasol ecoFT, Mitochondria

Hydrogen beneficiation – processes and products	11	ArcelorMittal South Africa; Sasol; Enertrag; Earth & Wire; 24Solutions; Linde/ Afrox, Enertrag, Hydregen; Omnia; Sasol ecoFT; Toyota
Fuel and fuel cell usage – Equipment – Fuel cell catalysts	6	Implats; Mitochondria; PowerCell; Isondo Precious Metals; Sibanye-Stillwater; Heraeus Precious Metals
Fuel and fuel cell usage – Equipment – Other	4	Implats, Mitochondria, PowerCell, Isondo Precious Metals
GH2 production - Equipment – Electrolysers	3	Hydrox Holdings; Isondo Precious Metals, Thyssenkrupp
GH2 Production – Equipment – Balance of Plant	2	Isondo Precious Metals; Thyssenkrupp
GH2 production - Equipment – Membranes	0	
Storage, transport and safety – Research	0	
Storage, transport and safety – Pilots	0	
Policy and overarching support	0	

Appendix F: Workshop notes

Workshop 1: 19 September 2023

30 attendees

Measurements: Another possibility in measuring research by institutions is to count their outputs (publications, research spending, IP).

Magnitude: Here R&D spending is specifically noteworthy, as SA's is historically very low.

Research focus: South Africa can adopt and adapt research from other countries, but this should not limit the countries research scope. It is, however, still important that industry helps to define research direction so that it is relevant ("mission driven innovation").

Splitting into basic versus higher-level research: Insights from Mitochondria suggest that there are two focus areas for research:

1. Basic research – these topics can be broad, but the aim is to keep research momentum in the GH_2 space going. Gets people thinking – doesn't have to be anything groundbreaking
2. High impact research – this relies on basic research and funding. Many of the high impact topics will come from the private sector who fund research for their own commercial interest.

Commercialization: There needs to be more collaboration between commercial companies and research institutions. For example, HyPlat is the Commercialisation arm of HySA Catalysis.

- Research institutions need to ask where the gaps in the research are, so that they can provide the R&D component
- There may be technologies that are sitting idle without being deployed or being allowed to be deployed due to other issues that cause delay or lack of uptake – including financing (speak to IDC).

Other notes:

Look at UK Pact and UKFCDO, Energy Systems Catapult. hydrogen is to the best of my understanding a big component of the decarbonisation research being done

Prof David Walwyn from University of Pretoria is on a European Union project on "white hydrogen". It may be interesting to talk to him about this as well as on sustainable transition / multi-level perspective on the transition to a renewables and green hydrogen base future.

- Safety standards and certification as GH2 research topics? SABS has started a process to define GH_2 for South Africa, and develop a methodology for certification - maybe link up with them?

Workshop 2a and 2b: 27 October 2023 and 9 October 2023

36 attendees

Public policy: A representative from the East London IDZ brought up the topic of the chicken and egg problem, and government's role here in ensuring collaboration and communication between the various stakeholder groupings (notably project developers and offtakers). A question was also posed with regard to the overall enablement of private sector development in the context of the existing policy framework.

Policy alignment – GH_2 needs to be explicitly integrated into energy policy and plans, with these considering GH_2 projections and requirements: The IRP2019, and upcoming updated release, should be split to understand RE generation to be used on the grid versus the RE used for exporting GH_2. The hydrogen industry therefore needs growth plans and allocations looking into the future, so that RE and transmission plans know what is happening and can align. This is particularly important when it comes to infrastructure, which takes time to build. The main comment here is that policy documents, including the Integrated Energy Plan (IEP) and subplans (such as the IRP), as well as water allocation plans, need to account explicitly for GH_2 and its growth projections.

Water requirements: What is going to happen for inland projects? What kind of quantities will projects require and can these amounts be projected going into the future? Where will this water come from - natural sources, aquafirs, acid mine drainage, treated waste water?

Pipelines: Can we repurpose natural gas pipelines or will we need new pipelines altogether? There was mixed feedback on this discussion point and so it remains an open question. Insufficient specific research has been done when it comes to explicitly looking at what it will take it take on either side - comprehensive refurbishment or completely replaced?

Grid requirements: Where would power flows be if RE is not generated on-site? Wheeling? Quantities required? Direction of power flow? What years would projects come online and require the relevant grid support?

Inland projects: How will water requirements be addressed here? Will hydrogen be produced on-site, or offsite and then transferred to these areas? This is particularly relevant in the case of the Hydrogen Valley project.

Reliance on export demand versus import demand: Certain countries have signalled their demand and willingness to pay a premium for GH_2 - so does South Africa capitalise early and profit from this export demand, or rather channel the GH_2 to local development first (i.e., build up domestic capabilities then move to exporting).

Academic bridging: The challenge of scaling up within a university environment.

South Africa in the context of a global field: Instead of diluting limited resources by doing all the R&D, it is worthwhile to consider research where the country has some experience and combine this with global outputs to get the best results. For example, when considering methanol synthesis, there may be little to no strategic advantage in pursuing R&D in this space - international outputs can instead be used or adapted for the local context and local methanol production to support the bunker fuel industry. Continuing along this train of thought, it was suggested that the team should take their findings and group research topics into three themes:

4. Direct knowledge transfer from international R&D
5. Localisation of international technologies e.g., use international desalination R&D and fit it to the South African context (temperatures, pressures etc.)
6. Primary R&D required, e.g., research on the South African grid

Where do we have experience? Beneficiation - Sasol can pivot their Fischer Tropsch and Haber Bosch experience meaning there is a lower level of research required here, although commercialisation will require more time and effort.

Hydrogen from methane: Hydrogen from methane is easier to split than from water via electrolysis. Methane can be generated from biowaste – see the case of France and Australia. This is an important area of R&D to consider in the local context of water as a scarce resource. But would this hydrogen be qualified as green?

White hydrogen, or natural hydrogen, is attracting more attention and may be of interest going into the future, displacing the demand for green hydrogen.

CCUS: What is going to happen if/ when the use of CCUS means that the production of hydrogen derivatives can no longer be classified as fully green? As it stands, GH_2 derivatives can use industrial carbon, but EU regulations mean that after 2035 this carbon will not be "sustainable". So then how do we get the carbon needed for the production of GH_2 derivatives?

Hydrogen combustion engines

Social acceptance of hydrogen by the communities where production takes place, and by the population when it comes to adopting GH_2 hydrogen in not only industrial, but also for consumer usage.

Workshop 3 (final roundtable hybrid event): 27 October 2023 and 9 October 2023

14 in-person attendees; 14 online attendees

An introduction was made by Dr. Karen Surridge from SANEDI, who also mentioned some of the research that GIZ is already doing to answer the questions being posed in this work. This was followed by a presentation of the results by the project team. Some of the main points that came from attendees included:

- **Bunker fuels** - specifically considering the International Maritime Organisations (IMOs) regulations and the use of methanol.
- **Storage of GH_2 and derivatives** – the country has experience when it comes to the storage of ammonia, methanol, and liquid fuel etc., and research is being pursued at HySA, but there is a need to focus on GH_2 compression and storage
- **Spatial distribution –** questions will not only arise when it comes to transmission, but also distribution. Spatial distribution is important considering the fact that by 2050 the country will need a national grid capacity of around 300GW for RE alone.
- **More emphasis on safety.**
- **The importance of a market analysis –** this includes locally and globally, and the requirements of both.
- **Policy –** a caution when it comes to integrating GH_2 into the IRP. If it were to be, other criteria would come into play which may affect GH_2 ambitions negatively. Included into the transmission development plan, but not the IRP.
- **South Africa is not a single unit –** the need to understand geographics in more detail, as well as the implications of having infrastructure in certain places.
- **Water purity of desalination and costs involved –** does the drinking water from desalination fit the water purity required by GH_2 plants? What are the costs involved, as the technology is already there but the costs will be big.
- **Acid-mine drainage** - Is water from acid-mine drainage an option, and would this fit the water purity requirements? Noting that GH_2 production using acid-mine drainage will require primary R&D within South Africa.
- **Edits to the word cloud –** the importance of market access, transportation and logistics, access to green finance. Questions with regard to the importance of CCUS in the word cloud.

DNA Economics

Tel +27 (0)12 362 0024 | +27 (0)12 362 0210
Email contact@dnaeconomics.com | www.dnaeconomics.com