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Energiewende Switch to the Future

Hydrogen Research Activities in South Africa

A Review

October 2016

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List of acronyms

AFC	Alkaline Fuel Cell
APU	Auxiliary Power Units
Amplats	Anglo American Platinum
BOP	Balance of Plant
CBD	Central Business District
CoC	Centre of Competence
CO_2	Carbon Dioxide
CFD	Computation Fluid Dynamic
CHP	Combined Heat and Power
CSIR	Council for Scientific and Industrial Research
DEFT	Divergent Electrode-Flow-Through
DST	Department of Science and Technology
DoE	Department of Energy
dti	Department of Trade and Industry
DMR	Department of Mineral Resources
FCEV	Fuel Cell Electric Vehicles
FUCHSIA	Fuel Cells and Hydrogen Stores for Integration into Automobiles
HCD	Human Capacity Development
HEI	Higher Education Institutions
HySA	Hydrogen South Africa
HyS	Hybrid Sulphur
H_2	Hydrogen
IDC	Industrial Development Corporation
Implats	Impala Platinum
kW	Kilowatt
LOHC	Liquid Organic Hydrogen Carrier
MCFC	Molten Carbonate Fuel Cells
MEA	Membrane Electrode Assembly
MISTRA	Mapungubwe Institute for Strategic Reflection
MUT	Mangosuthu University of Technology
NWU	North-West University
PAFC	Phosphoric Acid Fuel Cells
PEM	Proton Exchange Membrane
PGM	Platinum Group Metals

P2G	Power to Gas
POP	Persistent Organic Pollutants
RETECZA	Resource Driven Technology Concept Centre
R&D	Research and Development
RDI	Research, Development and Innovation
SA	South Africa
SET	Science, Engineering and Technology
SEZ	Special Economic Zone
SMME	Small, Medium and Micro-sized Enterprise
SMR	Steam Methane Reforming
SOFC	Solid Oxide Fuel Cells
S&T	Science and Technology
SANEDI	South African Energy Development Institute
TIA	Technology Innovation Agency
TUT	Tshwane University of Technology
UCT	University of Cape Town
UHG	United Hydrogen Group
UK	United Kingdom
UP	University of Pretoria
USA	United States of America
UWC	University of the Western Cape
WITS	University of the Witwatersrand
WISA	Women in Science Awards

EXECUTIVE SUMMARY

Introduction:

The South African government initiated a long term (15-year) hydrogen (H_2) research programme in 2007. This initiative is spearheaded by the Department of Science and Technology (DST) and implemented through the Hydrogen South Africa (HySA) programme. HySA aims to execute the DST's research, development, and innovation (RDI) strategy, officially launched in September 2008. In addition to the collaborative HySA programme, other research entities have also been actively engaging in hydrogen related research in South Africa. HySA consists of three Centres of Competence (CoC):

- **HySA Catalysis CoC:**
    - Co-hosted by the University of Cape Town (UCT) and MINTEK.
    - R&D focus: Catalyst and membrane electrode assemblies development.

- **HySA Infrastructure CoC:**
    - Co-hosted by the North-West University (NWU) and the CSIR.
    - R&D focus: Hydrogen production, storage, distribution and codes and standards.

- **HySA Systems CoC:**
    - Hosted by the University of the Western Cape (UWC).
    - R&D focus: Hydrogen system(s) development and validation.

This study aims to provide a review of the current hydrogen R&D activities at South African universities, other research institutions and private industry.

The information generated during the course of this study will be used to discuss increased co-operation between South African and German research institutions focused on hydrogen R&D.

The aim is to identify common themes and priorities in this research field, to identify possible gaps that are not being covered by current research, to compile a profile of the hydrogen researchers actively working in the field and to make recommendations on future hydrogen research focal areas for South Africa.

Overview of the hydrogen research and development landscape:

The high level hydrogen R&D landscape consists of the following activities:

- Hydrogen production R&D.
- Hydrogen storage R&D.
- Hydrogen distribution R&D.
- Hydrogen safety, codes and standards R&D.
- Hydrogen fuel cell (and component) R&D.
- Hydrogen systems and applications R&D.
- Hydrogen related auxiliary and ancillary services and activities.
- Catalyst development for hydrogen electrolysers and/or fuel cells.

Current hydrogen R&D in South Africa:

An internet based survey and screening was performed to determine the state of current hydrogen R&D in South Africa. The aim of the initial screening was to identify potential contributors to hydrogen R&D in South Africa in government, academia and private industry. A detailed questionnaire was then circulated to the identified parties that consisted of the following:

- 24 public higher education institutions (HEI).
- 6 government departments or entities.
- 4 research councils.
- 9 private entities.

The high level hydrogen R&D landscape and the subsequent mapping of activities by South African researchers are shown in the table on the following page.

The feedback provided by the respondents on the questionnaire was analysed and was represented in terms of the following for all respondents:

- The current hydrogen R&D being performed as per the hydrogen R&D landscape.
- Existing co-operation.
- Demonstration or pilot projects that have been executed.
- Future plans for hydrogen R&D.

Table 1: High level mapping of hydrogen R&D and institutions involved.

	HySA INF	HySA SYS	HySA Cat	UP	NWU	Wits	MUT	TUT	Implats
H_2 Production R&D	■	■	■		■	■		■	
H_2 Storage R&D	■	■					■		■
H_2 Distribution R&D	■								
H_2 Safety, Codes and Standards R&D	■								
H_2 Fuel Cell (and Component) R&D		■	■					■	■
H_2 Systems and Applications R&D	■	■						■	
H_2 Related Auxiliary and Ancillary Services and Activities		■						■	
Catalyst R&D for H_2 Electrolysers and / or FC	■	■	■	■	■				■

Common hydrogen R&D themes and trends in South Africa:

The high level hydrogen R&D activities in South Africa ranked in order of preference as per the respondents' questionnaires are:

- Hydrogen production R&D (23%)
- Catalyst development for hydrogen electrolysers and/or fuel cells (19%)
- Hydrogen fuel cell (and component) R&D (16%)
- Hydrogen storage R&D (13%)
- Hydrogen systems and applications R&D (13%)
- Hydrogen related auxiliary and ancillary services and activities (10%)
- Hydrogen distribution R&D (3%)
- Hydrogen safety, codes and standards R&D (3%)

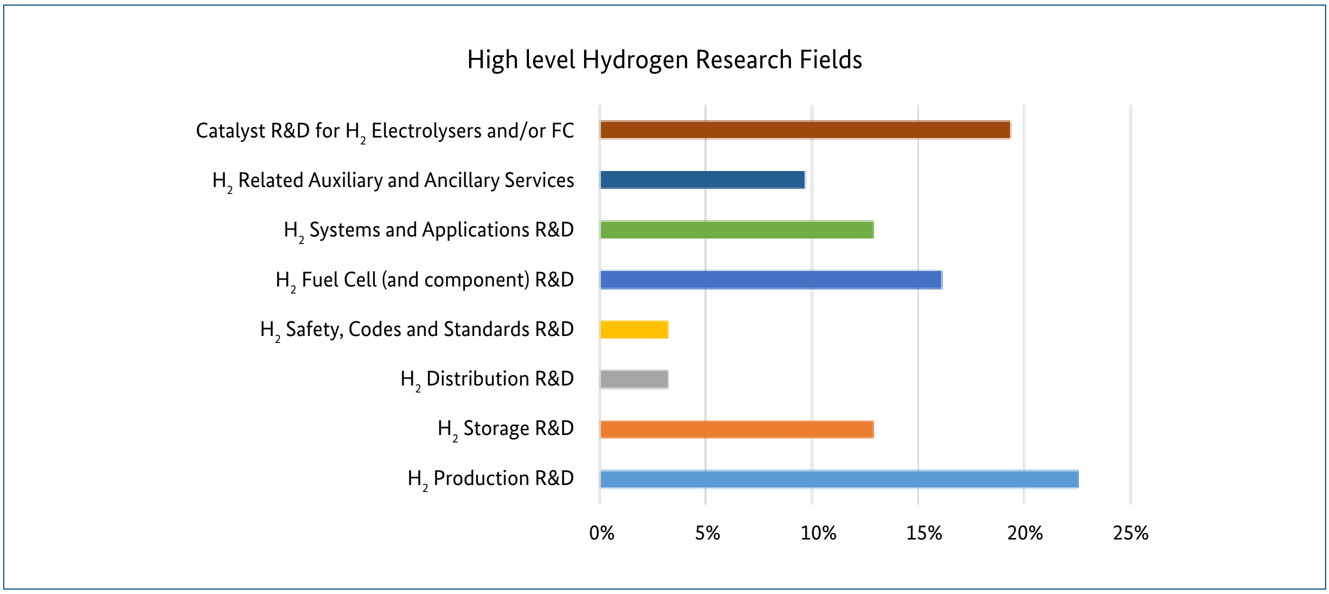


Figure 1: High level H_2 R&D overview

Hydrogen and fuel cell demonstration projects in South Africa:

There are a number of existing hydrogen and fuel cell demonstration projects in South Africa. Below is a list of these demonstration projects:

- **Mobility and transport applications:**
    - Hydrogen forklift and refuelling station (Gauteng: Springs)
    - 5kW fuel cell-battery hybrid powered golf cart (Western Cape: Cape Town)
    - TUT hydrogen bicycle (Gauteng: Pretoria)
    - Auxiliary power units in commercial airlines
    - Hydrogen drone (Western Cape: Cape Town)

- **Stationary applications:**
    - Hydrogen fuel cell for Cofimvaba School (Eastern Cape: Intsika Yethu)
    - 1kWe HT-PEMFC combined heat and power (Western Cape: Cape Town)
    - 15kW fuel cell mini-grid: Naledi Trust (Free State: Kroonstad)
    - 2.5kW hydrogen fuel cell power generator (Western Cape: Cape Town)
    - 100kW fuel cell at the Chamber of Mines (Gauteng: Johannesburg)
    - Renewable hydrogen production and storage (North West: Potchefstroom)

Existing South African-German collaboration:

Existing collaboration between South African and German entities on hydrogen R&D includes the following:

- HySA Catalysis Centre of Competence collaborating with Fraunhofer Institute on MEA electrode design and characterisation.
- HySA Infrastructure Centre of Competence collaborating with Areva (Germany) on hydrogen storage.
- HySA System Centre of Competence collaborating with the following entities:
    - Fumatech (Germany) on MEA development.
    - ZSW (Germany) on stack development.
    - Fraunhofer Institute on PEMFC development.
- University of Pretoria is collaborating with researchers from Germany on methanol electro-reforming to produce hydrogen on-board for mobile applications as well as syngas production from CO_2, possibly in collaboration with Sunfire in Dresden, Germany. This is done in association with Prof. Emil Roduner (visiting professor from Germany).
- Anglo American Platinum (as shareholder) collaborated with Hydrogenious, a high-tech spinoff of the University of Erlangen-Nuremberg, (Germany). Hydrogenious has achieved a breakthrough in liquid organic hydrogen carrier (LOHC) technology, which gives hydrogen diesel-like characteristics that allow it to be transported, distributed and stored in existing infrastructure for oil-based fuels.

Barriers experienced:

The following are some of the key observations made by the respondents of the study with regards to barriers experienced:

- Consistent funding of hydrogen R&D activities are required with less uncertainties in terms of size of allocation, timely disbursements, long term funding commitments and due process to follow to fund key projects in the research and project space.
- Funding cuts have forced a reduction in scope and have hampered plans to carry out long term planning.
- Funding is specifically required for human resources.
- Training and development of hydrogen and fuel cell resources should be investigated and addressed.

R&D gaps and focal areas:

The following are some of the key suggestions made for future focal areas and potential gaps identified by the respondents of the study:

- R&D on recycling of PGM-based fuel cell components.
- Development of novel materials for hydrogen storage.
- Gas hydrates represent an attractive means to safely store hydrogen.
- Solar hydrogen production R&D at large scale to enable application at commercial levels.
- Development of cost effective small scale hydrogen filling stations to assist with early adopters of FC vehicles, such as forklifts.
- Economically viable hydrogen production.
- Production of solar fuel (hydrogen and organic liquid) is essential for a transition to non-fossil fuel based electricity production and intermediate chemical energy storage should be further developed.

Findings:

- The hydrogen economy is a key future development for South Africa to develop safe, clean and reliable alternative energy sources to fossil fuels.
- PGMs are the key catalytic materials used in most fuel cells, and with more than 75% of the world's known platinum reserves found within South African borders,

there is great potential for socio-economic benefits to be obtained from these natural resources.

- Hydrogen and fuel cell technology not only contributes to the energy security grand challenge, but also has implications for global-change science with the potential to help mitigate the effects of climate change through reduced emissions and improved adaptation through use of cleaner energy technologies as well as partially addressing the grand challenge for human and social dynamics.
- Hydrogen R&D in South Africa is primarily driven by government and specifically by the DST in collaboration with academic institutions and industry.

Recommendations:

- Consistent, long term, sustainable funding is required for hydrogen R&D activities. This can include local and international funding.
- The funding should be balanced between basic R&D, applied R&D, piloting and demonstration and commercialisation. Different government departments should share information and have an integrated strategy.
- Government assistance for securing funding for a number of large scale demonstration projects should be considered.
- The South African and African market for hydrogen and fuel cell technologies should be quantified and used as guidance in defining strategies.
- Training and development of hydrogen and fuel cell resources should be investigated and addressed.
- Solar hydrogen production should be investigated given the fact that South Africa has abundant solar and PGM resources.

1 INTRODUCTION

The South African government initiated a long term (15-year) hydrogen research programme in 2007. This initiative is spearheaded by the DST and implemented through the Hydrogen South Africa (HySA) programme. HySA aims to execute DST's research, development, and innovation (RDI) strategy, officially launched in September 2008 [1]. In addition to the collaborative HySA programme, other research entities have also been actively engaging in hydrogen related research in South Africa.

This study aims to provide a review of the current hydrogen related research and development (R&D) activities at South African universities, other research institutions and private industry.

The aim is to identify common themes and priorities in this research field, to identify possible gaps that are not being covered by current research, to compile a profile of the hydrogen researchers actively working in the field and to make recommendations on future hydrogen research focal areas for South Africa.

The information generated during the course of this project will be used to highlight common research themes, identify potential areas of research collaboration and to foster increased co-operation between South African and German research institutions focused on hydrogen research.

Specifically the following was done:

- Information was collected from various identified hydrogen and fuel cell researchers at universities, government entities and private industry.
- Current hydrogen research information was analysed to formulate common research themes and current research gaps.
- Recommendations were formulated for future hydrogen research focal areas in South Africa.
- Prominent hydrogen energy researchers in South Africa were identified and a short profile on each researcher was compiled.

Questionnaires were circulated to all universities and to private companies that are involved in hydrogen and fuel cell related R&D.

The report consists of the following sections:

- Section 2: Overview of the hydrogen R&D landscape.
- Section 3: The South African hydrogen and fuel cell R&D initiative.
- Section 4: Current hydrogen R&D conducted in South Africa.
- Section 5: Common hydrogen R&D themes and trends in South Africa.
- Section 6: Hydrogen and fuel cell demonstration projects in South Africa.
- Section 7: Profiles of prominent hydrogen and fuel cell researchers.
- Section 8: Research barriers, gaps and future focal areas.
- Section 9: Conclusions.
- Section 10: References.
- Section 11: Appendices.

2 OVERVIEW OF THE HYDROGEN R&D LANDSCAPE

Hydrogen is the simplest, lightest and most abundant element in the universe. It is made up of just one electron and one proton. Hydrogen does not exist in a natural state on earth as a gas. It is always mixed with other elements, i.e. oxygen to produce water, or carbon to produce various compounds such as methane, coal and petroleum.

Hydrogen has a high energy content by weight (nearly three times that of gasoline). But by contrast, hydrogen has a low energy density by volume at a standard temperature and atmospheric pressure.

Due to the fact that it does not exist in a natural state, it must be manufactured in an energy intensive process. The energy required to produce hydrogen can be obtained from various sources such as traditional fossil fuels, nuclear energy as well as renewable energy sources. To produce and transport hydrogen in a cost effective and environmentally friendly way is one of the key challenges to the development of the hydrogen economy.

In accordance with various international research bodies' guidelines and research plans [2, 3, 4, 5 and 6], the hydrogen R&D landscape focuses on the aspects as portrayed graphically in Figure 2 below.

In the rest of this section, more detailed information is provided on the hydrogen R&D landscape.

2.1 Hydrogen production

At present the most common method for producing hydrogen is via steam methane reforming (SMR), where methane (and other hydrocarbons in natural gas) is converted into hydrogen and carbon monoxide by reaction with steam over a nickel catalyst. SMR accounts for approximately 95% of the world's hydrogen production. A major shortcoming of the SMR process is the resulting emissions of carbon dioxide and airborne pollutants.

Hydrogen is also produced via electrolysis – a process where electrical energy is used to split water into hydrogen and oxygen. The electricity use in the electrolysis process can be obtained from various sources. Other emerging technologies for hydrogen production include thermochemical and biochemical processes. Hydrogen is primarily used as a chemical feedstock in the petrochemical, food, electronics and metallurgical processing industries.

Other hydrogen production technologies that are in various stages of development are:

- Steam electrolysis (a variation on conventional electrolysis).
- Thermochemical water splitting.
- Photocatalytic systems.
- Photobiological systems.

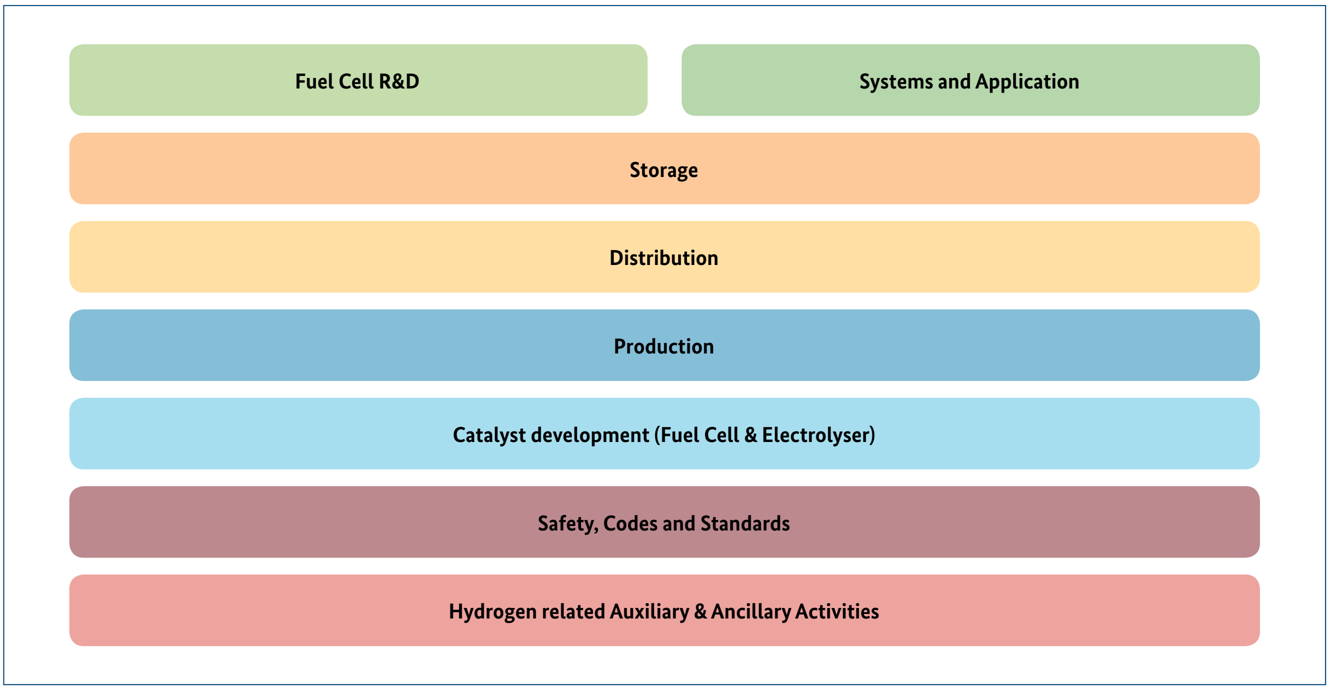


Figure 2: High level hydrogen R&D overview

- Biological systems.
- Thermal water splitting.
- Gasification.

2.2 Hydrogen storage

As highlighted, hydrogen has the highest energy content by weight (nearly three times that of gasoline) of any element but by contrast, a low energy density by volume. This is one of the major challenges for hydrogen storage R&D. Hydrogen storage R&D is a key enabler for hydrogen and fuel cell advancement in stationary power, portable power, and transportation applications.

At present hydrogen is stored in high pressure metal and composite storage tanks at pressures ranging from ~35 MPa to ~70 MPa. The energy consumed to compress the hydrogen, as well as the size and weight of these tanks compared with the driving ranges and running hours achieved, is still a challenge to be overcome. Hydrogen can also be liquefied by cooling it to its liquid state. Energy use for cooling the hydrogen, as well as associated hydrogen losses and insulation requirements, also pose challenges to be addressed in hydrogen storage R&D.

Other hydrogen storage technologies that are in various stages of development include:

- Metal hydride technology.
- Chemical hydride slurries or solutions.
- Carbon nanotubes.
- Adsorbent storage.
- Storage vessel development for stationary and transport applications.

2.3 Hydrogen distribution

Hydrogen is typically transported or distributed by road via cylinders, tube trailers, and cryogenic tankers, with a small amount shipped by railway or shipping barge. In areas where high volume hydrogen producers and users are located relatively close to each other, the hydrogen is piped to the client from the production site.

Typical hydrogen distribution and transport research and development includes:

- Development and enhancement of infrastructure (pipeline, depots, etc.)
- Hydrogen refuelling stations
- Development of novel hydrogen carriers such as liquid organic hydrogen carriers (LOHC)

2.4 Hydrogen safety codes and standards

A general challenge for the commercialisation of all hydrogen energy technologies and systems is the lack of safety information on hydrogen components and systems. The limited availability of uniform international codes and standards necessary to standardise the hydrogen technologies is also a challenge.

The development of uniform, internationally accepted codes and standards will be required to increase the confidence of various stakeholders in the use of hydrogen and fuel cell technology at various levels of government, end-users and the general public. At present safety codes and standards that exist have been developed mostly for the industrial use of hydrogen and were not designed for the volume and uses envisioned in the hydrogen economy.

Other aspects included under this topic are:

- Environmental protection
- Risk analysis
- Fire and explosion protection

2.5 Hydrogen fuel cells

Hydrogen fuel cells are one of the key enabling technologies for a hydrogen economy. A fuel cell is a device that uses hydrogen and oxygen to create electricity by an electrochemical process.

Fuel cells can be used for various applications such as replacing the internal combustion engine (ICE) in vehicles or to provide electrical power in stationary and portable power applications. At present the major challenges for fuel cell commercialisation are cost and durability.

There are various types of fuel cells. The most prominent fuel cells today are:

- **Proton exchange membrane** (PEM) fuel cells deliver high power density and have low weight and volume, compared with other fuel cells. PEM fuel cells operate at relatively low temperatures (around 80°C) and use PGM based catalysts. PEM fuel cells are primarily used for transportation and some stationary applications.
- **Alkaline fuel cells** (AFCs) use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst. High-temperature (100°C to 250°C) and lower temperature (~23°C to 70°C) AFCs have been developed. AFCs are typically used in remote locations and have demonstrated efficiencies near 60% in space applications.
- **Solid oxide fuel cells** (SOFCs) use a non-porous ceramic compound as the electrolyte. SOFCs are expected to be

around 50-60% efficient at converting fuel to electricity. In CHP applications, efficiencies of 80-85% is expected. SOFCs operate at very high temperatures (~1,000°C), removing the need for a precious-metal catalyst.

- **Phosphoric acid fuel cells** (PAFCs) use a PGM based catalyst and liquid phosphoric acid as an electrolyte. PAFCs are expected to be 37-42% efficient at converting fuel to electricity and 85% efficient when used in CHP applications. PAFCs are typically used for stationary power generation, but have also been used to power large vehicles such as city buses.

Other fuel cell technologies that are in various stages of development include:

- Molten carbonate fuel cells (MCFCs)
- Reversible fuel cells
- Direct methanol fuel cells

2.6 Hydrogen systems and applications

Hydrogen and fuel cell technologies offer a pathway to enable the use of clean energy systems to reduce emissions, enhance energy security, and stimulate the global economy. Typical applications of hydrogen fuel cells include:

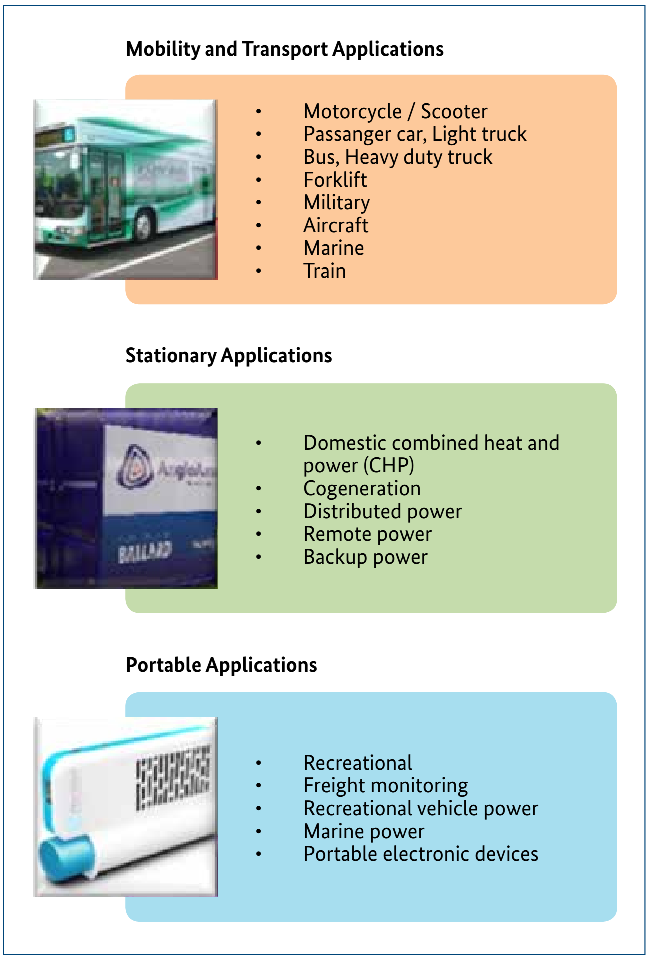


Figure 3: Hydrogen systems and applications

2.7 Hydrogen related auxiliary and ancillary services and activities

There are also a number of auxiliary and ancillary services that are associated with hydrogen research. This includes aspects of basic and applied research as well as technology development and commercialisation. Typical activities include the following:

- Theory development.
- Systems analyses and modelling.
- Manufacturing.
- Membrane technologies and development.
- Hydrogen purification.
- Concept studies.
- Control systems (electrical and non-electrical).
- Hydrogen sensors and detector development.
- Demonstration projects.
- Various consultancy services.

2.8 Catalyst development for hydrogen electrolysers and/or fuel cells

A key aspect for South Africa is the development of PGM based catalysts for hydrogen fuel cell and electrolyser applications. In order to reduce the cost impact of hydrogen equipment, non-PGM based catalysts are also considered.

A high level overview of the hydrogen R&D landscape is provided in Figure 4.

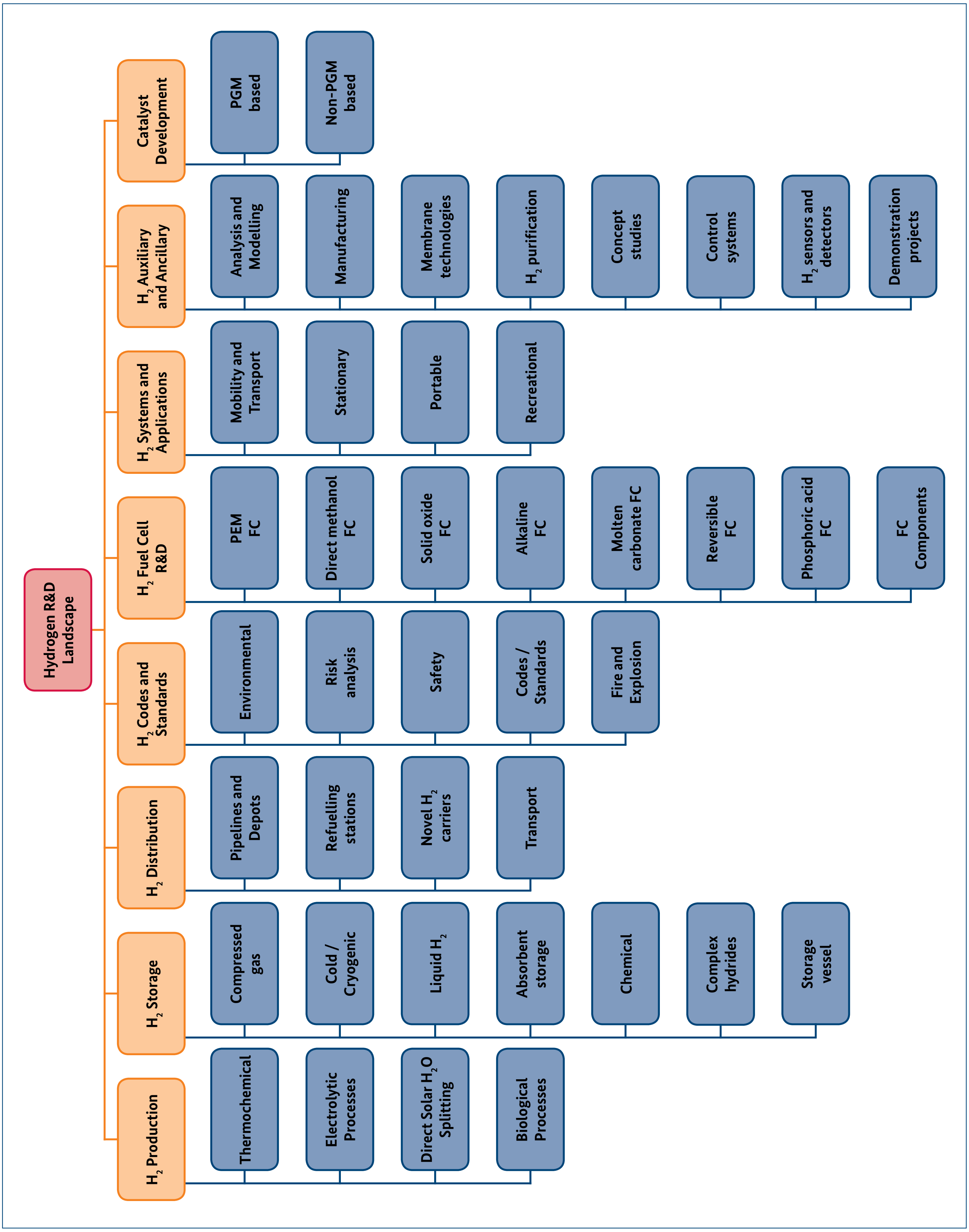


Figure 4: Overview of hydrogen R&D landscape

3 THE SOUTH AFRICAN HYDROGEN AND FUEL CELL R&D INITIATIVE

3.1 The South African government's strategy for hydrogen and fuel cells

The hydrogen economy is a key future development for South Africa to develop safe, clean and reliable alternative energy sources to fossil fuels. Hydrogen is an energy carrier and is used to store and distribute energy and can be combined with the use of fuel cell technologies to produce electricity.

A major driving force behind the hydrogen and fuel cell technology is South Africa's abundant reserves of platinum group metals (PGM) reserves. PGMs are the key catalytic materials used in most fuel cells, and with more than 75% of the world's known platinum reserves found within South African borders, there is great potential for socio-economic benefits to be obtained from these natural resources.

In the South African Department of Science and Technology's (DST) Ten-Year innovation plan ***"Innovation towards a knowledge-based economy: Ten-Year Plan for South Africa (2008 – 2018)"*** [1] a number of grand challenges are listed that include:

- The farmer to pharma value chain to strengthen the bio-economy.
- Space science and technology.
- Energy security.
- Global change science with a focus on climate change.
- Human and social dynamics.

In terms of the energy security grand challenge, the race is on for safe, clean, affordable and reliable energy supply, and South Africa must meet its medium-term energy supply requirements while innovating for the long term in clean coal technologies, nuclear energy, renewable energy and the promise of the hydrogen economy.

Hydrogen and fuel cell technology not only contributes to the energy security grand challenge, but also has implications for global-change science with the potential to help mitigate the effects of climate change through reduced emissions and improved adaptation, by using cleaner energy technologies and partially addressing the grand challenge for human and social dynamics.

Within the DST's grand challenge on energy security, this interest in hydrogen falls under the ***National Hydrogen and Fuel Cell Technologies Research, Development and Innovation strategy*** [1], branded as Hydrogen South Africa (HySA) in 2008. The strategy stimulates and guides innovation along the value chain of hydrogen and fuel cell technologies in South Africa. The aim is to position South Africa to drive and optimise local benefits from supplying high value-added products (i.e. PGMs) to the potentially increasing international markets. These local benefits should include economic benefits, through job, wealth and new industries creation; the development of appropriate skills and human resources capital; and an improved quality of life for all South Africans.

Hydrogen R&D in South Africa is primarily driven by government and specifically by the DST in collaboration with academic institutions and industry. A more detailed description of the HySA programme is provided in the next section.

3.2 DST's Hydrogen South Africa (HySA) Flagship Programme

Hydrogen South Africa or [1]HySA was initiated by the DST in May 2007 [1], and approved by the Cabinet. The aim of HySA is to be a long-term (15-year) programme to execute DST's research, development, and innovation (RDI) strategy, officially launched in September 2008.

This National Flagship Programme is aimed at developing South African intellectual property, knowledge, human resources, products, components and processes to support local participation in the nascent, but rapidly developing international platforms in hydrogen and fuel cell technologies.

HySA has been implemented in the context of the DST's various innovation strategies, the Department of Mineral Resources' (DMR) minerals beneficiation strategy, the Department of Energy's (DoE) Integrated Resource Plan (IRP) and the Department of Trade and Industry's (dti) industrial development strategies.

[1] Please refer to Section 4 for more detail with regards to the HySA CoC's activities.

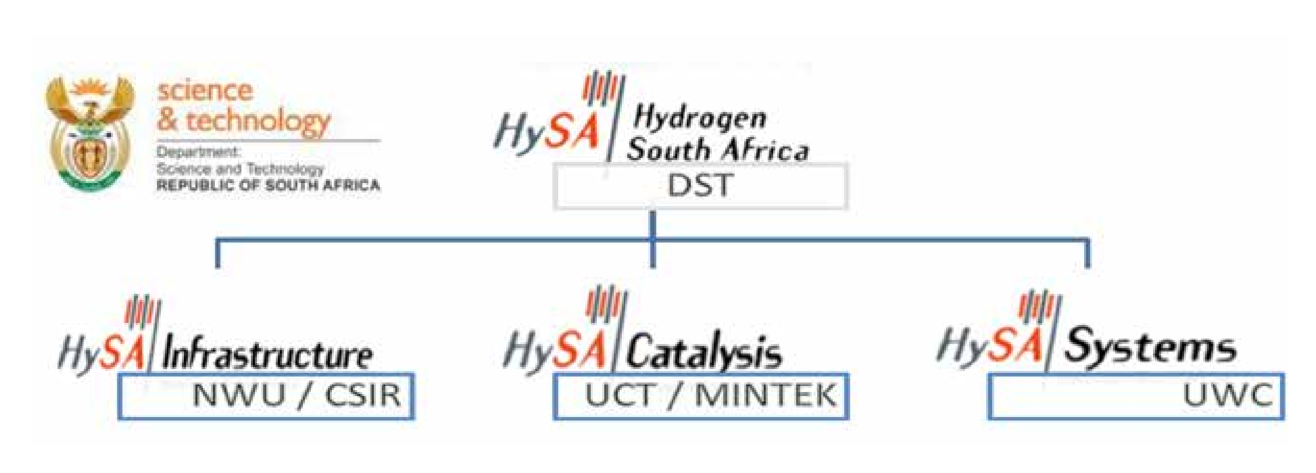


Figure 5: HySA structure

The principal strategy of HySA is to execute R&D work, with the main aim of achieving an ambitious 25% share of the global hydrogen and fuel cell market using novel PGM catalysts, components and systems.

In order to achieve this, the structure is aimed at the parallel development of knowledge and technology across all areas of the hydrogen and fuel cell value chain.

The HySA programme is comprised of three R&D Centres of Competence (CoC), as shown in the figure above.

- **HySA Catalysis CoC**
  - Director: Dr. Sharon Blair.
  - Co-hosted by the University of Cape Town (UCT) and MINTEK.
  - R&D focus: catalyst and membrane electrode assemblies development.

- **HySA Infrastructure CoC**
  - Director: Dr. Dmitri Bessarabov.
  - Co-hosted by the North-West University (NWU) and the CSIR.
  - R&D focus: hydrogen production, storage, distribution and codes and standards.

- **HySA Systems CoC**
  - Director: Dr. Cordelia Sita.
  - Hosted by the University of the Western Cape (UWC).
  - R&D focus: hydrogen system(s) development and validation.

Each of the three COCs has a unique responsibility, but all three are complementary within the common vision of fostering proactive innovation and developing the human resources required to undertake competitive R&D activities in the field of hydrogen and fuel cell technologies.

The first five years of funding focused on developing infrastructures at each centre with a major emphasis on human capacity development (HCD). Relevant international expertise was recruited by each CoC to access technical support and well-established implementation networks, and to ensure that the programme and its deliverables remain market related and world-class. Furthermore, to achieve the HySA strategy objectives, the three HySA CoCs form a national network of research 'hubs' and 'spokes' through collaboration with institutions and partners from the R&D sector, higher education, as well as industry.

The primary objectives of HySA include:

1. Wealth creation through value added manufacturing (this will be achieved by developing the PGM catalysis value chain in South Africa).
2. Development of a hydrogen infrastructure (this will be achieved by developing local cost competitive hydrogen production solutions based on renewable resources).

3. Equity and inclusion in sharing the economic benefit derived from South Africa's mineral endowment (this will be achieved through creating a viable industry for the finished products that will create jobs and boost economic growth, for the benefit of all South Africans).

4. Stimulation of PGM (in particular platinum) demand.

According to the ***DST's Annual Performance Plan (APP) for the 2016-2017 Fiscal Year*** [8] where hydrogen R&D resides under the *"Research and Development for Energy Security"* theme, the following activities are planned for hydrogen related R&D in the years to come:

- Focus will be on strengthening public-private partnerships.
- Communicating feedback on the work done by the DST, in the energy space, to other government departments,

and increasing public awareness.
- Influence long-term energy and mineral policy and decision making processes.
- Build strategic funding and commercialisation partnerships in 2016/17 to facilitate locally developed components and complete products, especially for fuel cell technologies.
- Pilot locally developed technologies in preparation for full commercialisation.
- Facilitate manufacturing partnerships as well opportunities for local deployment of fuel cell technologies.
- Ensure that the three HySA CoCs leverage each other's strengths to support the dti-led national fuel cell task team.
- Create an environment to enable world-class R&D, with outputs that support inclusive development aiming to integrate components developed via the HySA programme into fuel cell units to be positioned at selected schools and clinics for technology testing and validation.
- Facilitate technology commercialisation via partnerships between relevant stakeholders.
- Provide additional financial support to the order of ~R100 million per annum for the technology demonstration and validation phase such as membrane electrode assemblies stemming from the HySA CoCs.

The DST also aims to leverage foreign investment and increase the funding made available by international partners for co-operation with South Africa, with regards to national priority themes such as the bio-economy, hydrogen and fuel cell technology.

The DST has also adopted the approach to engage with the private sector on a project-by-project basis and assess how the private sector could support the scaling up and successful rollout of the technologies for inclusive development and to leverage demonstration of the use of hydrogen fuel cells in rural areas. These partnerships include companies like Anglo American Platinum and Impala Platinum.

In the past number of years, the DST has funded hydrogen and energy related R&D projects to the value of ~R130 to R150 million per year. The budget for the HySA programme is ~R75 million to R80 million per year, divided between the various COCs based on project specific requirements and applications.

Recently a special economic zone (SEZ) dedicated to mineral beneficiation has been proclamated for the platinum-rich Bojanala district of the North West Province [9]. The ***Platinum Valley SEZ*** was established in terms of the SEZ Act of 2014. The main hub of the Platinum Valley SEZ is to be housed in a 100 hectare site of the Bodirelo Industrial Park. The industrial park is located near the town of Mogwase in the Bojanala Platinum District of the North West Province. The site will be developed in three phases comprising of a logistics park, light manufacturing space and a heavy industries manufacturing space.

The Mapungubwe Institute for Strategic Reflection (MISTRA) is an independent research institute that takes a long-term view on the strategic challenges facing South Africa.

MISTRA published a research report in 2013 titled: ***"South Africa and the Global Hydrogen Economy: The Strategic Role of Platinum Group Metals."*** [11]

The scope of the research included, but was not limited to:

- An exploration of the trajectory of development of fuel cells globally and in South Africa.
- An assessment of the case for South Africa to establish downstream fuel cell capacity that included the necessary investments into developing key technology elements.
- An assessment of research capacity and activities within SA and further afield, and the availability of the technology locally and internationally to beneficiate PGM.
- An investigation of the comparative advantage South Africa and the region could have in engaging the PGM market.
- An interrogation of constraints to the evolution of a hydrogen-based energy economy, including methods to locate, develop, store and supply feedstock, and the challenges of energy storage.
- An interrogation of the scientific opportunities, economic impact, and geo-political implications of a migration to a hydrogen economy based on fuel cell technology on the South African and southern African economies and polities.
- Identifying some of the strategies the state could adopt in effecting a migration from fossil fuels to hydrogen, and the partnerships it should foster with the private sector to realise this.

The report concluded that the government's HySA initiatives are laudable both in the goals they seek to achieve and the execution thereof. Nevertheless, more needs to be done to enhance and further leverage the emergent capabilities as the opportunity space (for South Africa to carve a significant niche in the prospective global hydrogen economy) is quite large. Specifically, more aggressive development and acquisition of the know-how necessary to ensure successful local development of a hydrogen economy and penetration of global markets is therefore necessary.

Especially in view of the opportunity provided by rising costs of energy, and the need to enhance the capacity of the country's energy system, experimenting with the option of platinum-based fuel cells could lead to surprising outcomes on their potential to meet some of the country's energy policy objectives, in addition to supporting economic growth while reducing environmental emissions.

The report indicated that the window of opportunity for South Africa to influence the trajectory towards a platinum-based fuel cell option and to expanded markets for its PGMs remains open. However, investment (from both the private and public sectors) towards expanding and developing the capabilities associated with this technology, and further public awareness, is required to enhance market development. It also recommended that the implementation of visible demonstration projects will be helpful.

4 CURRENT HYDROGEN R&D CONDUCTED IN SOUTH AFRICA

An internet based survey and screening was performed to determine the state of current hydrogen R&D in South Africa. The aim of the initial screening was to identify potential contributors to hydrogen R&D in South Africa in government, academia and private industry. A more detailed questionnaire was then circulated to the identified parties that consisted of the following:

- 24 public higher education institutions (HEI)
- 6 government departments or entities
- 4 research councils
- 9 private entities

The feedback provided by the respondents on the questionnaire was analysed and was represented in terms of the following for all respondents:

- The current hydrogen R&D being performed as per the hydrogen R&D landscape.
- Existing co-operation.
- Demonstration or pilot projects that have been executed.
- Future plans for hydrogen R&D.

Table 2 shows a summary of the hydrogen R&D, as per the high level hydrogen R&D landscape defined in Section 2, being performed in South Africa, mapped to the organisations that responded to the questionnaire.

Table 2: High level mapping of hydrogen R&D fields and [2]institutions involved.

High level Hydrogen Research Fields	HySA INF	HySA SYS	HySA Cat	UP	NWU	Wits	MUT	TUT	Implats
H_2 Production R&D	■	■	■		■	■		■	
H_2 Storage R&D	■	■					■		■
H_2 Distribution R&D	■								
H_2 Safety, Codes and Standards R&D	■								
H_2 Fuel Cell (and Component) R&D		■	■					■	■
H_2 Systems and Applications R&D	■	■						■	
H_2 Related Auxiliary and Ancillary Services and Activities		■						■	
Catalyst R&D for H_2 Electrolysers and / or FC	■	■	■	■	■				■

[2] Please note that feedback from UCT and MINTEK as co-hosts of HySA Catalysis, NWU and CSIR as co-hosts of HySA Infrastructure and UWC as host of HySA Systems were included under the relevant HySA CoCs.

4.1 HySA Catalysis CoC

Contact:
Dr. Sharon Blair (CoC Director)

www.hysacatalysis.uct.ac.za/

4.1.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Thermochemical processes for hydrogen production using natural gas reforming (steam methane reforming) and liquid fuels
  - Electrolytic hydrogen production via PEM electrolysers
  - Direct solar water splitting via photo electrochemical water splitting

- **Fuel cell (and component) R&D**
  - PEM fuel cell R&D
  - Direct methanol fuel cell R&D
  - Fuel cell component development, i.e. fuel cell stack, processor and membrane electrode assembly (MEA)

- **Hydrogen systems and applications R&D**
  - Mobility and transport applications for aircraft and range extension
  - Stationary power applications for remote and backup power

- **Hydrogen related auxiliary and ancillary services and activities R&D include:**
  - Systems analyses and modelling
  - Manufacturing
  - Concept studies
  - Demonstration projects

- **PGM based catalyst development for hydrogen electrolysers and/or fuel cells**

4.1.2 Colleagues

- Prof. Jack Fletcher
- Dr. Gary Patrick
- Dr. Rein Weber
- Dr. Shiro Tanaka

4.1.3 Collaborators

- **Powertech Systems Integrators** (SA): Systems integration partner.
- **Powercell Sweden** (Sweden): Fuel cell company, telecom field trial (Vodacom), HyPlat customer development (MEA supply).
- **Senior Flexonics** (SA): FC supply chain development (heat exchanger development for foreign FC company).
- **FlyH$_2$** (SA): UAV fuel cell development.
- **Paul Scherer Institute** (Switzerland): HySA Catalysis: catalyst co-development and HyPlat MEA supply development.
- **Fraunhofer Institute** (Germany): MEA electrode design and characterisation.
- **SINTEF** (Norway): Electrode development.
- **Dalian Institute** (China): Catalyst development.
- **UCT Faculty of Engineering** (SA): Fuel cell modelling and prototype design for fast fuel cell impedance measurements.
- **Anglo Platinum** (SA): Fuel reforming catalyst development.
- **UKZN** (SA): Fuel reforming catalyst development.
- **Wits University** (SA): Catalyst support development.
- **North-West University** (SA): Sputter deposition of catalysts.
- **Stellenbosch Nanofiber Company** (SA): Nanofiber electrode development.

4.1.4 [3]Demonstration projects

- Fuel processors:
- H_2/reformate PEM devices.
- H_2/MeOH fuel cells.
- Portable power systems.
- [4]HyPlat (Pty.) Ltd.

[3] Refer to section 6 of this document or the HySA Catalysis website for more information
[4] HyPlat is a spin-out company from the University of Cape Town and MINTEK. HyPlat is expected to initiate its first commercial sales of the catalyst and possibly also membrane electrode assemblies towards the end of the 2016/17 financial year (www.hyplat.com).

4.1.5 Future plans for hydrogen R&D

- Continue to carry out research and development in low temperature PEM fuel cells (catalysts, MEA and subcomponents, stack and subcomponent design).
- Continue work on fuel processing (conversion of LPG, methane, diesel to hydrogen, microchannel reactors and fuel processing units).
- Apply developed skills to enter the electrolyser catalyst and MEA space.
- HySA Catalysis and HyPlat are promoting local electrification projects where local SMMEs are involved in delivering power to rural communities (e.g. schools, housing, clinics). This benefits HyPlat as it is driving local demand for its MEAs, either in a South African-designed stack or using HyPlat MEAs inside a foreign customer's stack. Both help HyPlat to gain market acceptance and market share.

4.2 HySA Infrastructure CoC

Contact:
Dr. Dmitri Bessarabov (CoC Director)

http://www.hysainfrastructure.org/

4.2.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Thermochemical processes
    - Solar (high temperature applications)
  - Electrolytic processes
    - PEM electrolysers
    - Alkaline electrolysers
    - SO_2 electrolysers

- **Hydrogen storage R&D**
  - Compressed hydrogen gas storage
  - Liquid hydrogen storage
  - Adsorbent storage
  - Chemical hydrogen storage
  - Storage vessel development (stationary and transportable)

- **Hydrogen distribution R&D**
  - Hydrogen distribution (pipelines and depots)
  - Hydrogen refuelling stations
  - Novel hydrogen carriers (i.e. LOHC)
  - Hydrogen transportation

- **Hydrogen safety, codes and standards R&D**
  - Environmental protection
  - Risk analysis
  - Codes and standards
  - Fire and explosion protection

- **Hydrogen fuel cell (and component) R&D**
  - Fuel cell components
    - Fuel processor
    - Membrane electrode assembly (MEA)

- **Hydrogen systems and applications R&D**
  - Mobility and transport applications
    - Bus and heavy duty truck
    - Train
  - Stationary applications
    - Remote power
    - Backup power

- **Hydrogen related auxiliary and ancillary services and activities R&D include:**
  - Membrane technologies and development
  - Hydrogen purification
  - Concept studies
  - Control systems (electrical and non-electrical)
  - Hydrogen sensors and detector development
  - Demonstration projects
  - Various consultancy services

- **PGM based and non-PGM based catalyst development for hydrogen electrolysers and/or fuel cells**

4.2.2 Colleagues

- Prof. Frikkie van Niekerk
- Dr. Martin Sanne
- Dr. Henrietta Langmi
- Dr. Gerhard Human

4.2.3 Collaborators

- **3M** (USA): Electrolysis
- **Areva** (Germany): Hydrogen storage
- **Proton OnSite** (USA): Electrochemical compression

4.2.4 [5]Demonstration projects

- 21kWp solar PV to hydrogen facility with battery storage and hydrogen booster to 200bar.
- Electrochemical hydrogen compression system.
- Laboratory-scale PV, wind turbine, electrolyser, and fuel-cell educational demonstration kits.
- Fuel cell testing system.
- PEM-based hydrogen production systems for remote operation.
- [6]New special purpose vehicle (SPV) to be incorporated for commercialisation purposes.

4.2.5 Future plans for hydrogen R&D

HySA Infrastructure has a focus on commercialisation of technologies and products developed in the CoC. Specific attention will be given to the following sectors:

- Telecom sector
  - The telecom industry provides a potential market for hundreds of thousands of fuel cell systems to be rolled out for stationary power supply.
- Rural electrification
- Mining sector
  - Using hydrogen commercially in underground mining applications is still a novel concept and further development needs to be done.
  - A major aspect of development is the reliable, cost effective production of hydrogen at the mining site.
- Power-to-gas in South Africa
  - Power-to-gas (P2G) is a technology that converts electrical power to a gas fuel.

[5] Refer Section 6 of this document or the HySA Infrastructure website (http://www.hysainfrastructure.org/) for more information
[6] HySA Infrastructure is busy establishing a SPV company for commercialisation activities. Please refer to the HySA Infrastructure website for more information

4.3 HySA Systems CoC

Contact:
Dr. Cordelia Sita (CoC Director)

http://www.hysasystems.com/

4.3.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Thermochemical processes
    - Natural gas reforming (steam methane reforming)
  - Electrolytic processes
    - PEM electrolysers

- **Hydrogen storage R&D**
  - Storage vessel development (stationary and transportable)
  - Metal hydride storage systems and compressors

- **Hydrogen fuel cell (and component) R&D**
  - PEM fuel cell
  - Fuel cell components
    - Fuel cell stack
    - Membrane electrode assembly (MEA)
    - Control systems
    - Balance of plant (BOP)

- **Hydrogen systems and applications R&D**
  - Mobility and transport applications
    - Motorcycle/scooter
    - Forklift
    - Aircraft
  - Stationary applications
    - Domestic combined heat and power (CHP)
    - Remote power
    - Backup power
  - Portable applications/recreational
    - Portable electronic devices
    - Educational kits

- **Hydrogen related auxiliary and ancillary services and activities R&D include:**
  - Manufacturing
  - Membrane technologies and development
  - Hydrogen purification

- **PGM based catalyst development for hydrogen electrolysers and/or fuel cells**

4.3.2 Colleagues

- Prof. Vladimir Linkov
- Prof. Berard Bladegroen
- Dr. Sivakumar Pasupathi
- Dr. Huaneng Su

4.3.3 Collaborators

- **NPL** (UK): MEA validation
- **Fumatech** (Germany): MEA development
- **ZSW** (Germany): Stack development
- **Fraunhofer ISE** (Germany): PEMFC development
- **Nedstack** (Netherlands): Stack development
- **Airbus** (France): FC stack testing
- **Graz University of Technology** (Austria): MEA development
- **Hot Platinum** (SA): UPS development
- **TF Design** (SA): CHP system development
- **Impala Platinum** (SA): Forklift development

4.3.4 Demonstration projects

- Hydrogen forklift and refuelling station.
- 1kWe HT-PEMFC combined heat & power system.
- 2.5kW FC generator.
- Fuel cell-battery hybrid powered golf cart.
- e-Bike with FC range extender.
- Hydrogen and fuel cell educational kits.
- MellowCab.

4.3.5 Future plans for hydrogen R&D

HySA Systems has commissioned prototypes on backup power and domestic CHP. Future research will be focused on reducing the costs and increasing the lifetime of these systems and facilitate their commercialisation, which will lead to job creation and overall improved socio-economic impact for the country.

[7] Refer to Section 6 of this document or the HySA Systems website for more information

4.4 SANEDI (RECORD Energy Centre)

Contact:
Dr. Karen Surridge-Talbot (RECORD Centre Manager)

www.record.org.za/www.sanedi.org.za

4.4.1 Overview of current hydrogen R&D

SANEDI is a state owned enterprise operating in the R&D environment under the guidance of the DoE and assists to stimulate R&D in the hydrogen area.

- **Hydrogen production R&D**
  - Interest in biological hydrogen production
- **Hydrogen storage R&D for end-user applications**
- **Hydrogen distribution as well as systems and applications R&D applicable to SANEDI's Green Transport Unit**

4.4.2 Collaborators

- **South African DST** (Dr. Rebecca Maserumule): R&D strategy

4.5 North-West University (NWU)

Contact:
Dr. Cobus Kriek (Group Leader: Electrochemistry for Energy & Environment Group)

http://www.nwu.ac.za/content/nwu-potchefstroom-campus-faculty-natural-sciences-crb-6

4.5.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Thermochemical processes i.e. hybrid sulphur (HyS) process
  - Electrolytic processes PEM electrolysers
    - o Alkaline electrolysers
    - o SO2 electrolysers
    - o Membraneless alkaline electrolysis
  - HyS electrocatalyst development
- **PGM based and non-PGM based catalyst development for hydrogen electrolysers and/or fuel cells**

4.5.2 Colleagues

- Prof. Schalk Vorster
- Prof. Vijay Ramani (Extra-ordinary Professor)

4.5.3 Collaborators

- University of Cape Town (SA): Electrocatalysts for alkaline water electrolysis

4.5.4 Future plans for hydrogen R&D

- The Electrochemistry for Energy & Environment Group, previously the PGM Group, has a unique laboratory, which is the only one of its kind in South Africa, geared towards the high-throughput synthesis and testing of combinatorial thin metal film electrocatalysts.
- This laboratory, together with regular electrochemistry equipment, is the focus of their continued research on electrocatalyst development.

4.6 University of Pretoria (UP)

Contact:
Prof. Egmont Rohwer (Chemistry Department)

http://www.up.ac.za/chemistry/

4.6.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Thermochemical processes
    - Liquid fuel
  - Electrolytic processes
    - PEM electrolysers
    - Co-electrolysis of water and CO_2

- **Hydrogen storage R&D**
  - Chemical hydrogen storage

- **Hydrogen fuel cell (and component) R&D**
  - Direct methanol fuel cell (reverse)

- **Hydrogen systems and applications R&D**
  - Stationary applications
    - Distributed power

- **PGM based catalyst development for hydrogen electrolysers and/or fuel cells**
    - Cathode catalyst development for direct liquid fuel production in PEM electrolyser

4.6.2 Colleagues

- **Prof. Emil Roduner (visiting professor)**

4.6.3 Collaborators

- **Empa (Switzerland): Solar fuel**

4.6.4 Future plans for hydrogen R&D

UP will continue the earlier work of researchers from Germany on methanol electro-reforming to produce hydrogen on-board for mobile applications as well as syngas production from CO_2, possibly in collaboration with Sunfire in Dresden, Germany.

4.7 University of the Witwatersrand (WITS)

Contact:
Dr. Shehzaad Kauchali (School of Chemical & Metallurgical Engineering)

www.wits.ac.za

4.7.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Thermochemical processes
    - Natural gas reforming (steam methane reforming)
    - Coal gasification
  - Membraneless electrolysis

- **Hydrogen systems and applications R&D**
  - Stationary applications
    - Backup power

- **Non-PGM based catalyst development for hydrogen electrolysers and/or fuel cells**

4.7.2 Colleagues

- **None**

4.7.3 Future plans for hydrogen R&D

WITS is working on hydrogen production via underground coal gasification using deep un-mineable coal.

4.8 Mangosuthu University of Technology (MUT)

Contact:
Dr. Kaniki Tumba

www.mut.ac.za

4.8.1 Overview of current hydrogen R&D

- **Gas hydrate-based hydrogen storage R&D**

4.8.2 Collaborators

- UKZN (SA) Prof. Amir Mohammadi: Gas hydrate-based storage

4.8.3 Future plans for hydrogen R&D

MUT aims to take hydrate-based hydrogen storage from laboratory scale to pilot and then industrial scales.

4.9 Tshwane University of Technology (TUT)

Contact:
Dr. Alufheli Nesamvuni (Acting DVC: Postgraduate Studies, Research and Innovation)

www.tut.ac.za

4.9.1 Overview of current hydrogen R&D

- **Hydrogen production R&D**
  - Direct solar water splitting processes
    - Photo electrochemical water splitting
- **Hydrogen fuel cell (and component) R&D**
  - PEM fuel cell
  - Fuel cell components
    - Control systems
- **Hydrogen systems and applications R&D**
  - Mobility and transport applications
    - Motorcycle/scooter
    - Passenger car/light truck
  - Stationary applications
    - Distributed power
- **Hydrogen related auxiliary and ancillary services and activities R&D include:**
  - Concept studies
  - Control systems (electrical and non-electrical)

4.9.2 Colleagues

- **Prof. Josiah Munda (Faculty of Engineering)**

4.9.3 Collaborators

- **CSIR (SA): Fuel cells**
- **CCMMM (Romania): Hydrogen energy for cooking**

4.9.4 Future plans for hydrogen R&D

TUT aims to develop systems for high capacity applications, starting with domestic energy use.

4.10 Impala Platinum Holdings

Contact:
Me. Fahmida Smith (Fuel Cell Co-ordinator)

www.implats.co.za

4.10.1 Overview of current hydrogen R&D

- **Hydrogen storage R&D**
  - Complex hydrides
- **Hydrogen distribution R&D**
  - Hydrogen refuelling stations
- **Hydrogen fuel cell (and component) R&D**
  - PEM fuel cells
  - Fuel cell components
    - Membrane electrode assembly (MEA)
- **Hydrogen systems and applications R&D**
  - Mobility and transport applications
    - Motorcycle/scooter
    - Forklift
    - Mining load haul dumpers
  - Stationary applications
    - Domestic combined heat and power (CHP)
- **Hydrogen related auxiliary and ancillary services and activities R&D include:**
  - Manufacturing
  - Membrane technologies and development
  - Demonstration projects
- **PGM based catalyst development for hydrogen electrolysers and/or fuel cells**

4.10.2 Collaborators

- HySA Systems and UWC (SA) – Dr. Cordelia Sita: hydrogen storage and refuelling
- HySA Catalysis, MINTEK and UCT (SA) – Dr. Sharon Blair: PGM catalyst development

4.10.3 [8]Demonstration project

- Hydrogen forklift and refuelling station (Section 6.1.1)

4.10.4 Future plans for hydrogen R&D

- Implats will continue work on catalyst development to a point of commercialisation.
- Implats will assist in the establishment of a special economic zone for fuel cell and sub-component manufacturing within South Africa.
- Implats will continue the development of a local power module for a fuel cell forklift and complete the large scale stationary fuel cell demonstration facilities.
- Implats is busy developing prototype underground mining vehicles and a safe refuelling infrastructure.

[8] Refer Section 6 of this document or the HySA Systems website for more information

4.11 Hydrox Holdings

Hydrox Holdings[9] is a South African company based in Gauteng that is developing a membraneless divergent electrode-flow-through (DEFT) alkaline electrolyser that reduces production costs by eliminating the need for membranes or expensive electrodes typically required to produce the gas.

Launched in December 2014, the Hydrox Electrolyser is a simplified, robust and effective unit capable of achieving high-current densities using inexpensive nickel electrodes.

Hydrox launched the new production method[10] at the CARISMA 2014 conference in Cape Town. The conference invites international scientists to discuss the challenges inherent in developing fuel cell materials and membrane electrode assemblies for transport and stationary applications.

Hydrox has been developing the technology used in the Hydrox Electrolyser for 15 years. Over the past two years, engineering project management company DemcoTECH Engineering and scientists from North-West University have conducted extensive testing on the electrolyser, confirming the enormous potential of this ground-breaking method [10].

4.12 Anglo American Platinum

Anglo American Platinum (Amplats) plays a significant R&D role in the hydrogen and fuel cell market in South Africa. Over the years, it has been involved in several R&D initiatives that included R&D in hydrogen production and hydrogen storage. Amplats has also invested in three global fuel cell companies: Ballard Power Systems, Altergy Systems and Johnson Matthey Fuel Cells. Recently, it invested in Hydrogenious Technologies, a PGM investment programme partner, on delivered hydrogen logistics and costs.

Hydrogenious is a high-tech spinoff of the University of Erlangen-Nuremberg, Germany, and has achieved a breakthrough in liquid organic hydrogen carrier (LOHC) technology, which gives hydrogen diesel-like characteristics that allow it to be transported, distributed and stored in existing infrastructure for oil-based fuels. The technology binds the hydrogen molecules to LOHCs, which facilitate safe, easy-to-handle, high-density energy storage at ambient conditions, addressing the existing challenges associated with storing gaseous hydrogen.

Amplats has recently also invested in the United Hydrogen Group (UHG) of the US, which is aiming to lower the delivered costs of hydrogen and is supporting the development of hydrogen refuelling stations, which would bolster the demand for platinum used in fuel cell electric vehicles (FCEVs). UHG will work with Hydrogenious Technologies on delivered hydrogen logistics and costs. [12, 13]

Hydrogenious Technologies has launched its first commercial hydrogen storage and logistics system using innovative LOHC technology in May 2016. The system includes a number of new technologies, including a PEM electrolyser that generates hydrogen using solar power and a Hydrogenious 'StorageBOX' that uses LOHC technology to enable storage without any losses for extended periods of time.

Hydrogenious Technologies recently signed a deal with United Hydrogen Group (UHG), a hydrogen distribution company based in the United States, to supply two LOHC systems, one StorageBOX and one ReleaseBOX. The technology will increase delivery ranges and decrease the operating costs of hydrogen logistics for UHG. Further, the agreement enables Hydrogenious Technologies to enter the U.S. market, which represents over 50% of the global hydrogen market, and will catalyse the rollout of hydrogen refuelling infrastructure for FCEVs.

Amplats has recently also announced that it has invested in a company that is developing a small-scale, gas-to-liquids technology to convert flare gas, natural gas, natural gas liquids and biogas into clean liquid transportation fuels [14, 15, 16]. Hydrogen is produced as a by-product. Greyrock Energy's systems use proprietary catalysts to convert methane-containing feedstocks into premium transportation fuels.

Greyrock has synergies with previous Amplats investments in Hydrogenious Technologies and United Hydrogen Group. Together, these companies have the potential to reduce the delivered costs of hydrogen, laying the foundation for widespread adoption of platinum-using fuel cell technology.

[9] http://www.hydrogensa.co.za/
[10] Engineering News: "Cost-effective hydrogen production introduced", 30 January 2015

5 COMMON HYDROGEN R&D THEMES AND TRENDS IN SOUTH AFRICA

The results from the questionnaires were analysed and are portrayed graphically in this section showing the interest reported in the various sub-sets of hydrogen R&D as per the defined hydrogen R&D landscape in Section 2.

Figure 6 shows the distribution of reported effort divided between the main hydrogen R&D areas. The top 5 activities being pursued, as reported by the respondents, are:

- Hydrogen production R&D.
- Hydrogen storage R&D.
- Hydrogen fuel cell (and component) R&D.
- Hydrogen systems and applications R&D.
- Catalyst development for hydrogen electrolysers and/or fuel cells.

With less effort being spent on the following:

- Hydrogen related auxiliary and ancillary services and activities.
- Hydrogen distribution R&D.
- Hydrogen safety, codes and standards R&D.

5.1 Hydrogen production R&D

Figure 7 shows a more detailed breakdown of the hydrogen production R&D activities. It is clear that more effort is being spent on electrolytic and thermochemical hydrogen production R&D than on the biological and direct solar water splitting hydrogen production R&D processes.

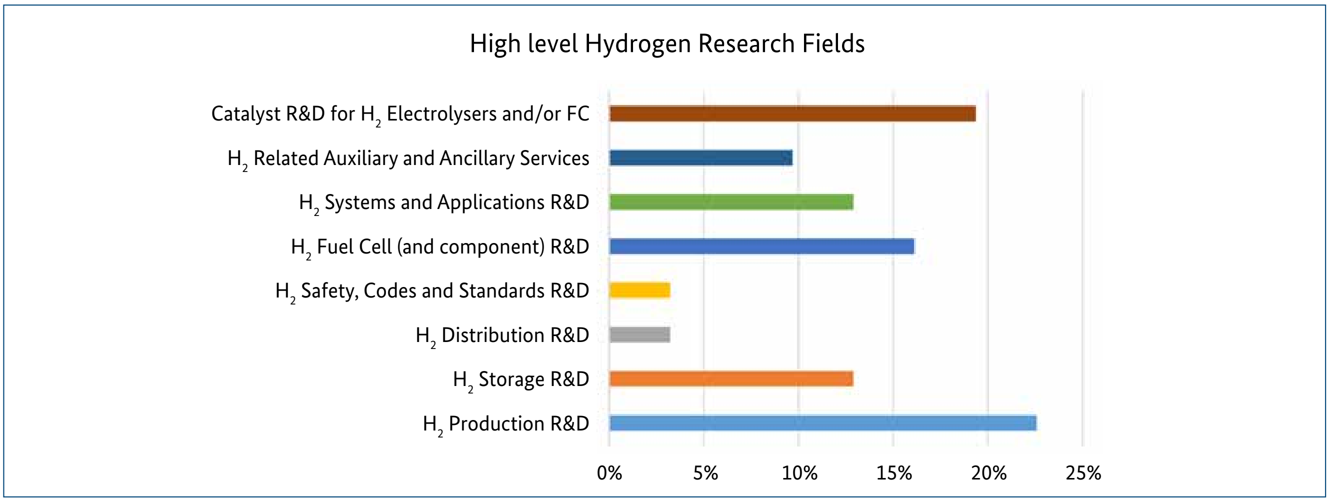


Figure 6: High level H_2 R&D overview

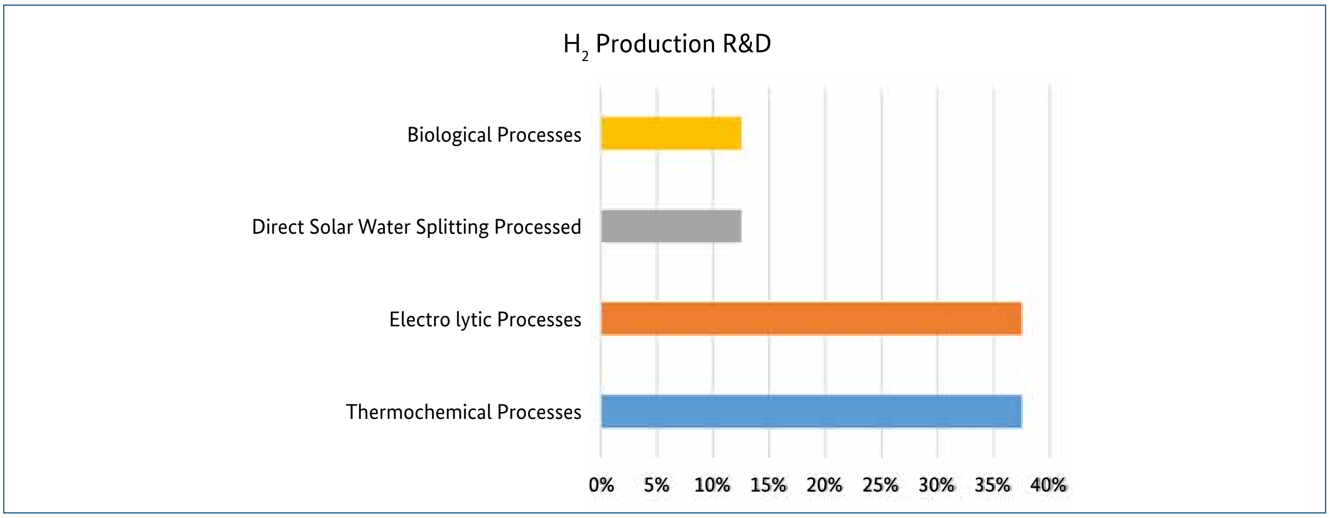


Figure 7: H_2 production R&D

Figure 8 shows that in terms of thermochemical hydrogen production R&D, liquid fuel and natural gas reforming are the most prominent. It appears that not much work is being done on biomass related hydrogen production.

PEM electrolysis appears to be a clear leader in the electrolytic hydrogen production sub-set as shown in Figure 9 below.

The feedback shows that for direct solar water splitting processes, only photo electrochemical water splitting is being researched in HySA Catalysis CoC.

In addition to the list of hydrogen production processes R&D above, the following two areas were also listed as fields of research at the NWU:

- HyS electrocatalyst development.
- Membraneless alkaline electrolysis.

5.2 Hydrogen storage R&D

As shown in Figure 11, the ongoing effort in hydrogen storage R&D is reasonably well balanced with storage vessel development leading the pack, and no effort being spent on cryogenic compressed hydrogen storage R&D.

5.3 Hydrogen distribution R&D

Figure 12 reveals that the R&D of novel hydrogen carriers (i.e. LOHCs), followed by hydrogen refuelling station R&D, leads the R&D effort in the hydrogen distribution R&D area.

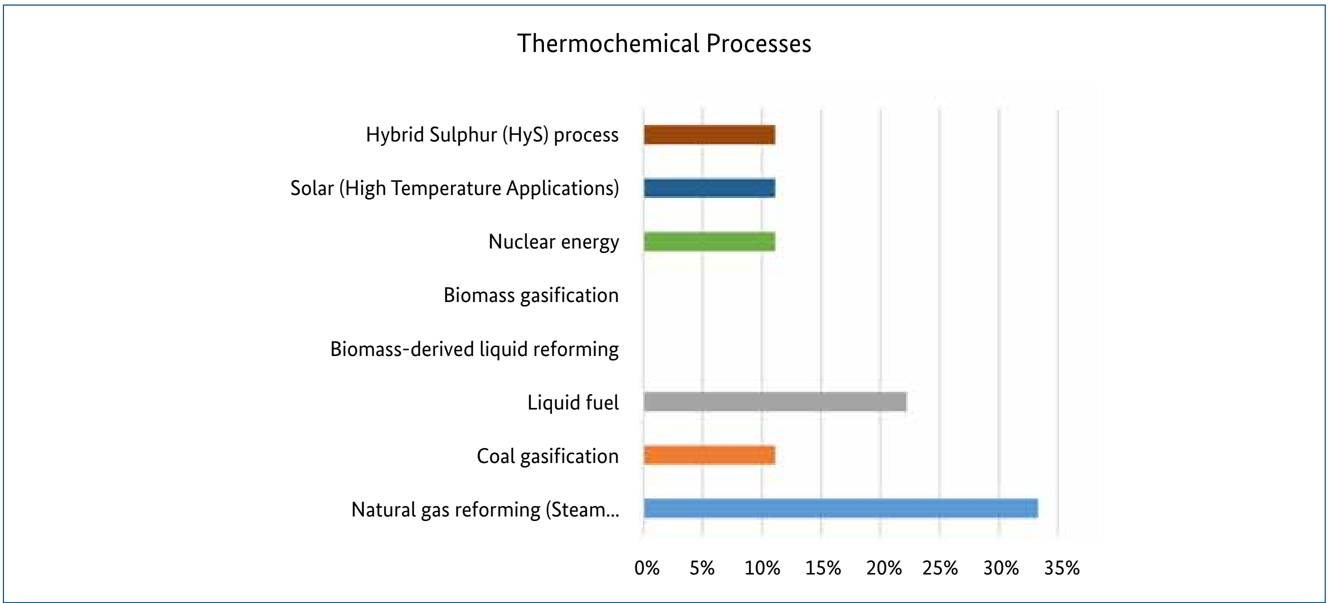


Figure 8: H_2 production (detail) – thermochemical processes

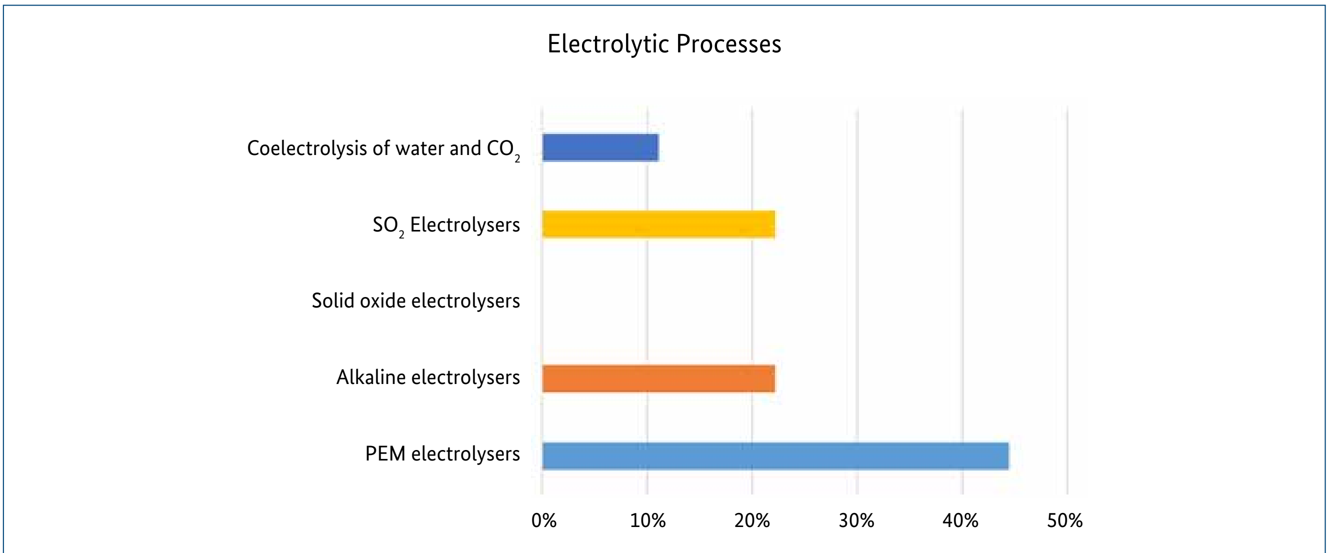


Figure 9: H_2 production (detail) – electrolytic processes

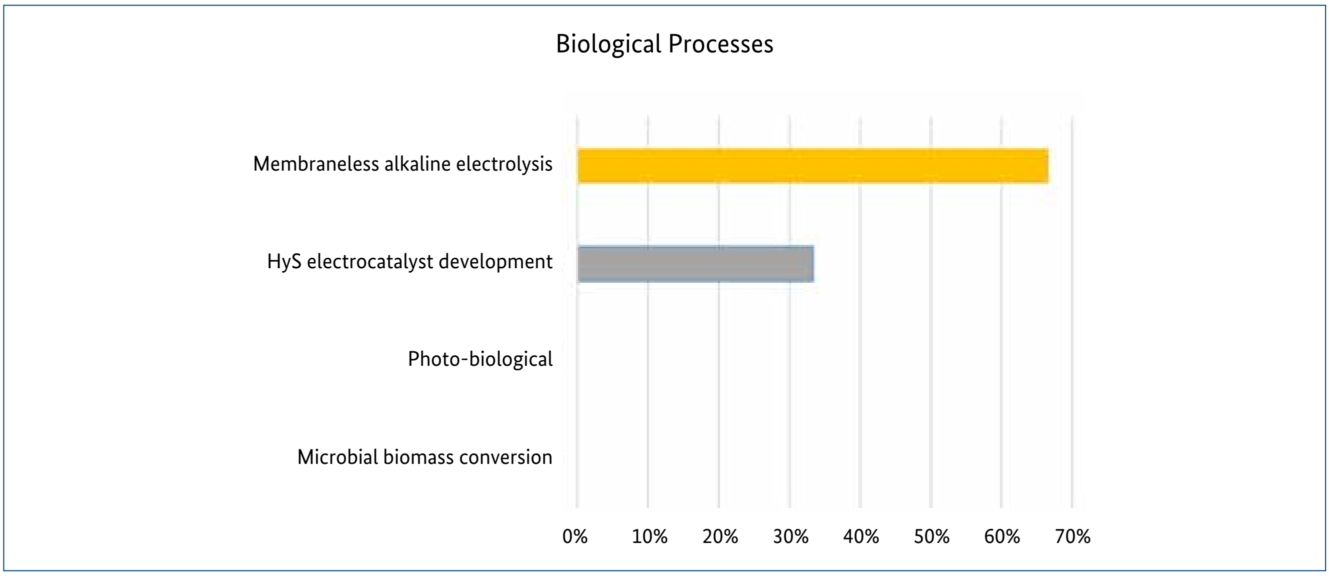


Figure 10: H_2 production (detail) – biological processes

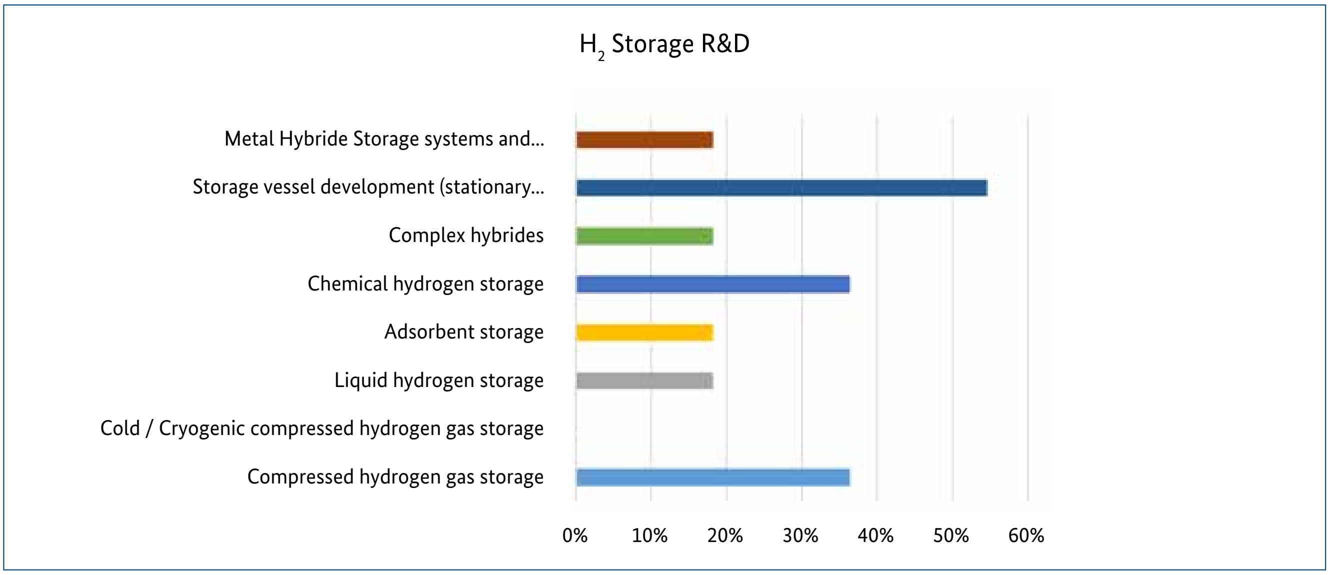


Figure 11: H_2 storage R&D

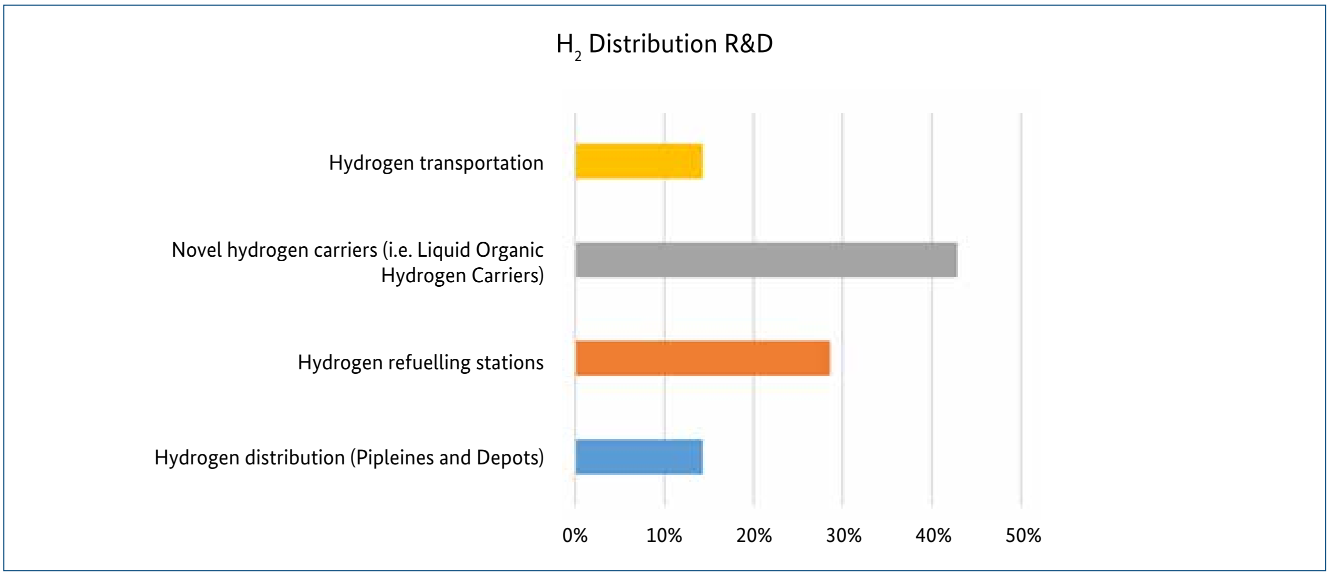


Figure 12: H_2 distribution R&D

5.4 Hydrogen safety codes and standards R&D

Hydrogen safety, codes and standards R&D is well balanced except for safety related computation fluid dynamic (CFD) modelling that is not being researched, as shown in Figure 13.

5.5 Hydrogen fuel cells R&D

It would appear that except for direct methanol and PEM fuel cells, most R&D effort is being spent on fuel cell components as shown in Figure 14. No R&D effort was reported on either of the following types of fuel cells:

- Solid oxide fuel cells.
- Alkaline fuel cells.
- Molten carbonate fuel cells.
- Reversible fuel cells.
- Phosphoric acid fuel cells.

Figure 15 shows the R&D activity at the fuel cell component level. 40% of R&D effort is being spent on membrane electrode assembly (MEA) R&D, while the remaining effort is equally divided between the following component R&D activities:

- Fuel cell stack.
- Fuel processor.
- Control systems.

No R&D is being done on balance of plant (BOP) FC components.

5.6 Hydrogen systems and applications R&D

It is clear from Figure 16 that in terms of hydrogen systems and application R&D, the least amount of R&D effort is being spent on portable hydrogen systems and applications, and the bulk of the effort is evenly split between stationary applications and mobility and transport applications. This is also aligned with previous and current demonstration projects as described in Section 6.

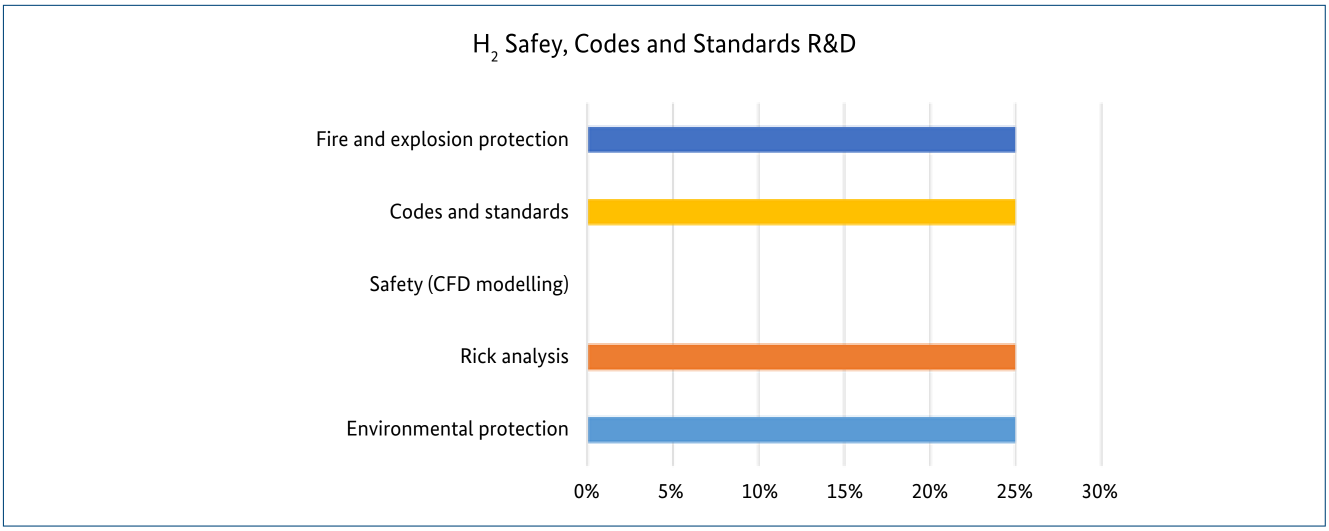


Figure 13: H_2 safety, codes and standards R&D

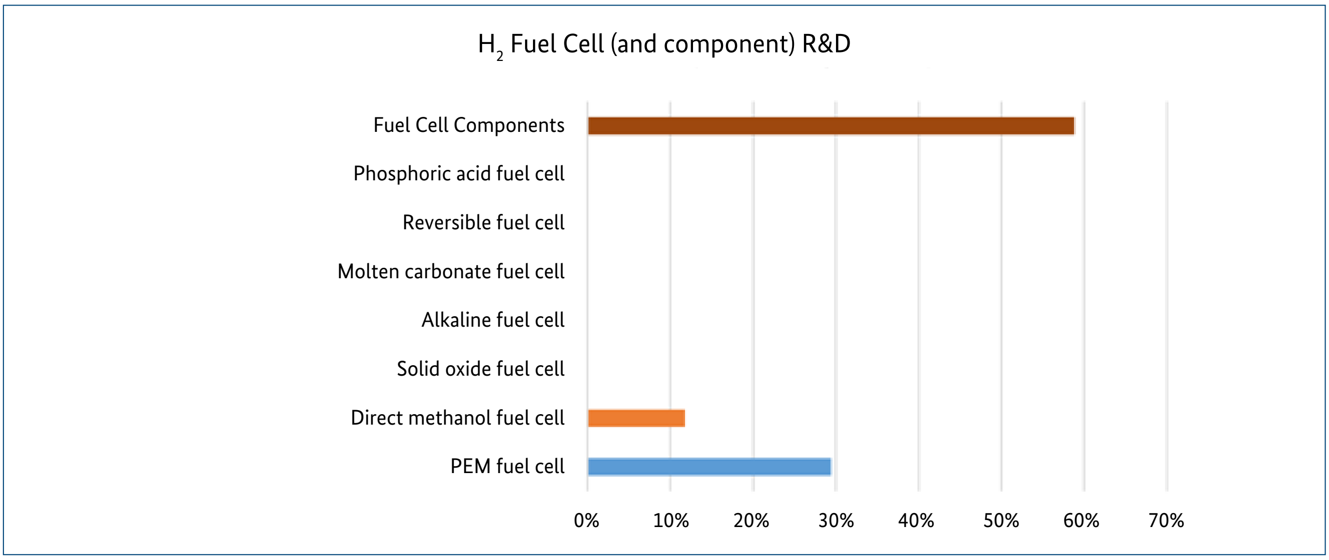


Figure 14: H_2 fuel cell (and component R&D)

The R&D efforts for mobility applications are well balanced with motorcycle/scooter and forklift applications leading the effort as shown in Figure 17.

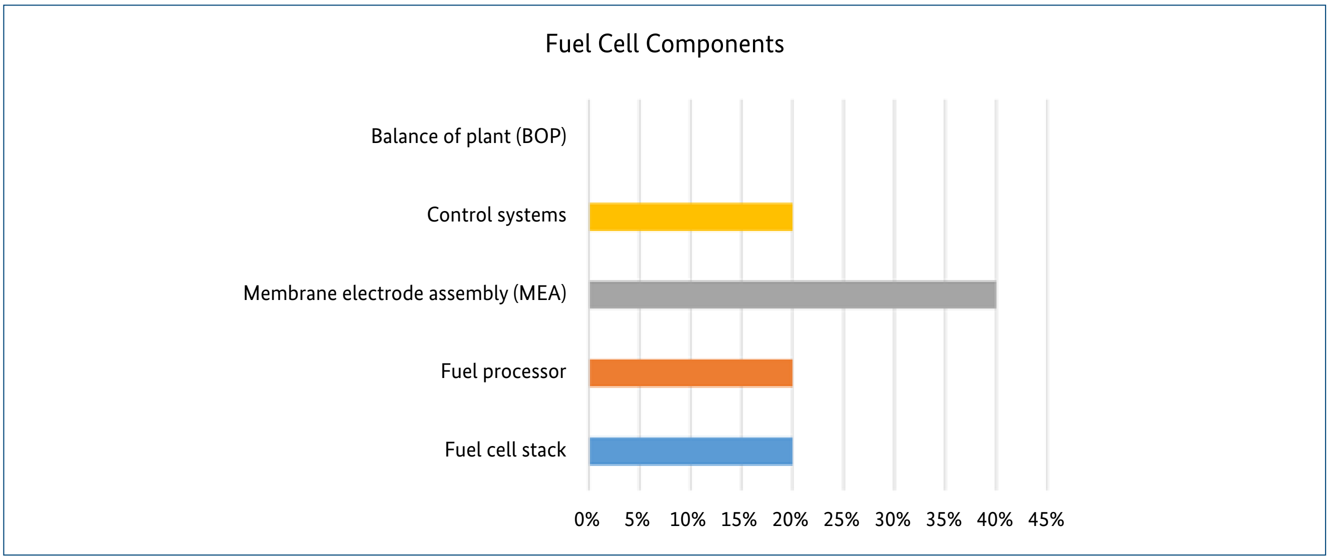


Figure 15: H_2 fuel cell component R&D (detail)

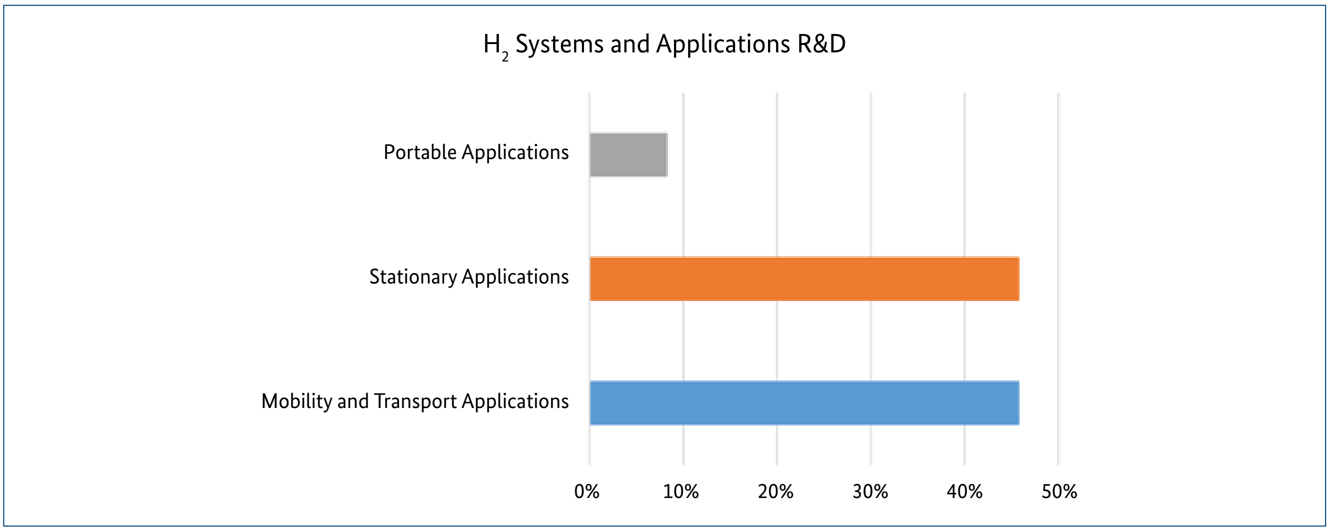


Figure 16: H_2 systems and applications

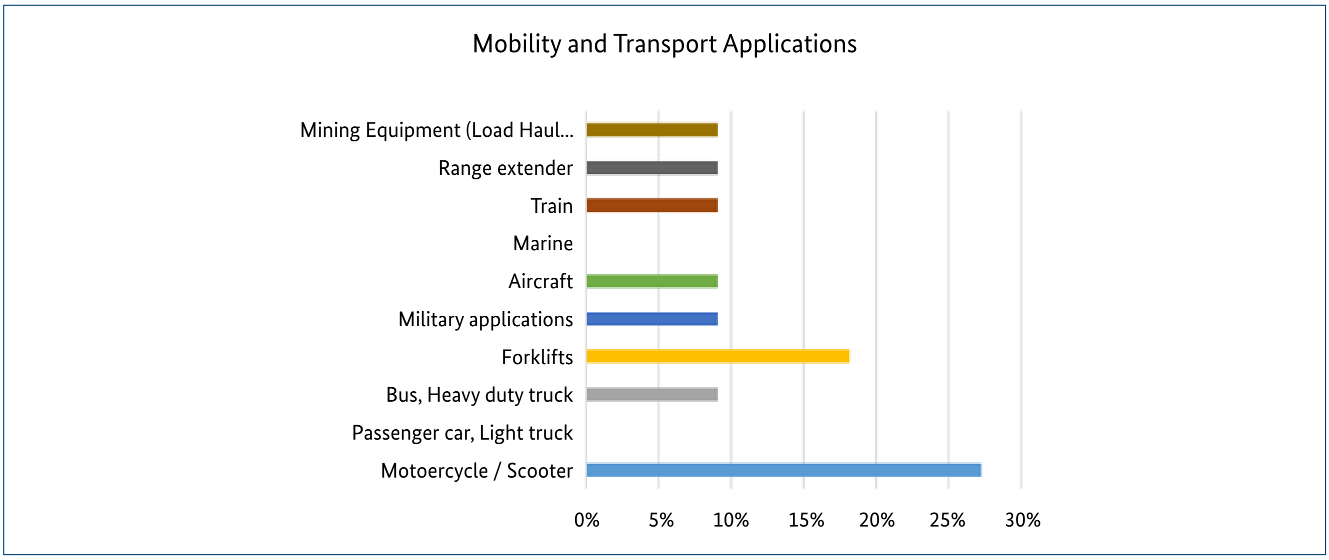


Figure 17: H_2 systems and applications (detail) – mobility and transport applications

For stationary hydrogen systems and applications, backup power application and distributed power R&D leads the effort, followed on an even basis by remote power and domestic CHP systems as shown in Figure 18.

The R&D focus for portable hydrogen systems is on educational kits and portable electronic devices as shown in Figure 19. This is aligned with specific needs in South Africa for education and awareness, as well as remote power supply opportunities.

5.7 Hydrogen related auxiliary and ancillary services and activities R&D

Figure 20 shows the distribution of R&D effort for the auxiliary and ancillary hydrogen R&D service and activities are spread across the range of activities with concept studies receiving the most effort.

5.8 Catalyst development for hydrogen electrolysers and/or fuel cells R&D

It is clear from Figure 21 that 60% of catalyst R&D is focused on PGM-based catalysts and 30% on non-PGM-based catalysts, with 10% of the effort being spent on catalysts for direct liquid fuel production in PEM fuel cells.

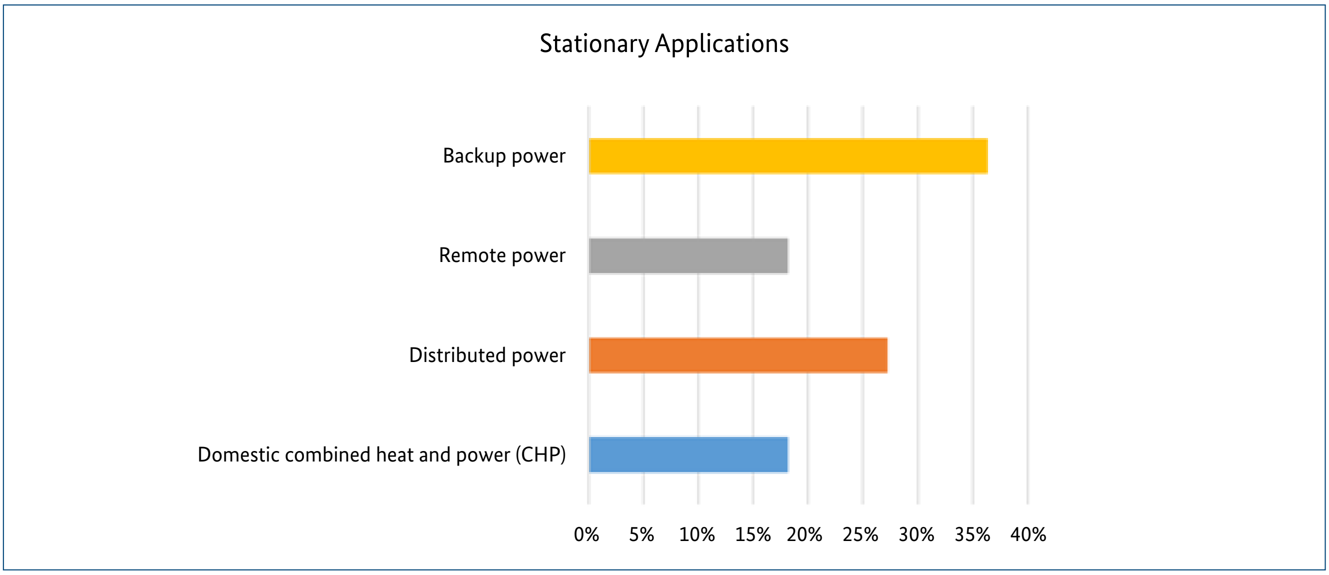


Figure 18: H_2 systems and applications (detail) – stationary applications

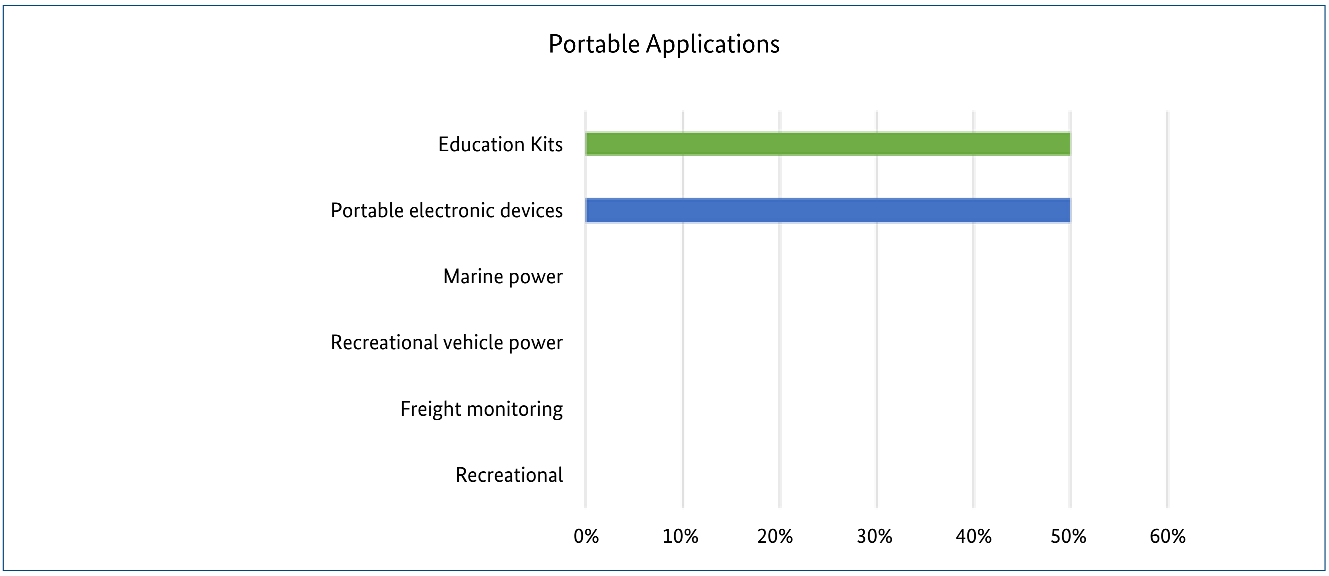


Figure 19: H_2 systems and applications (detail) – portable applications

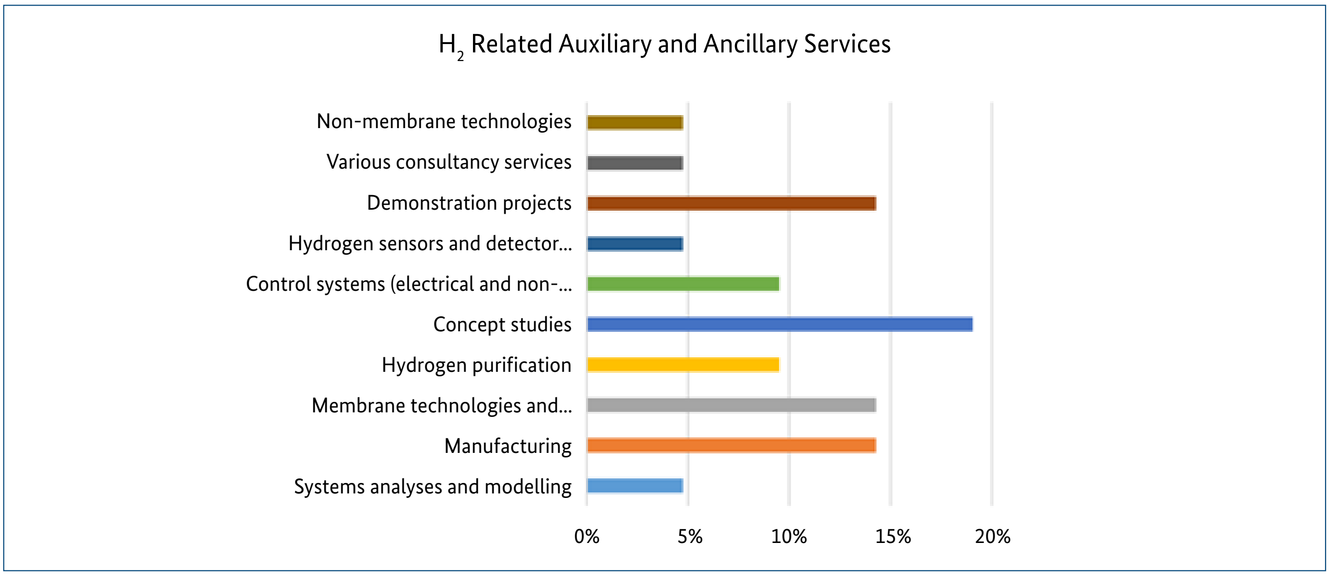


Figure 20: H_2 related auxiliary and ancillary services and activities

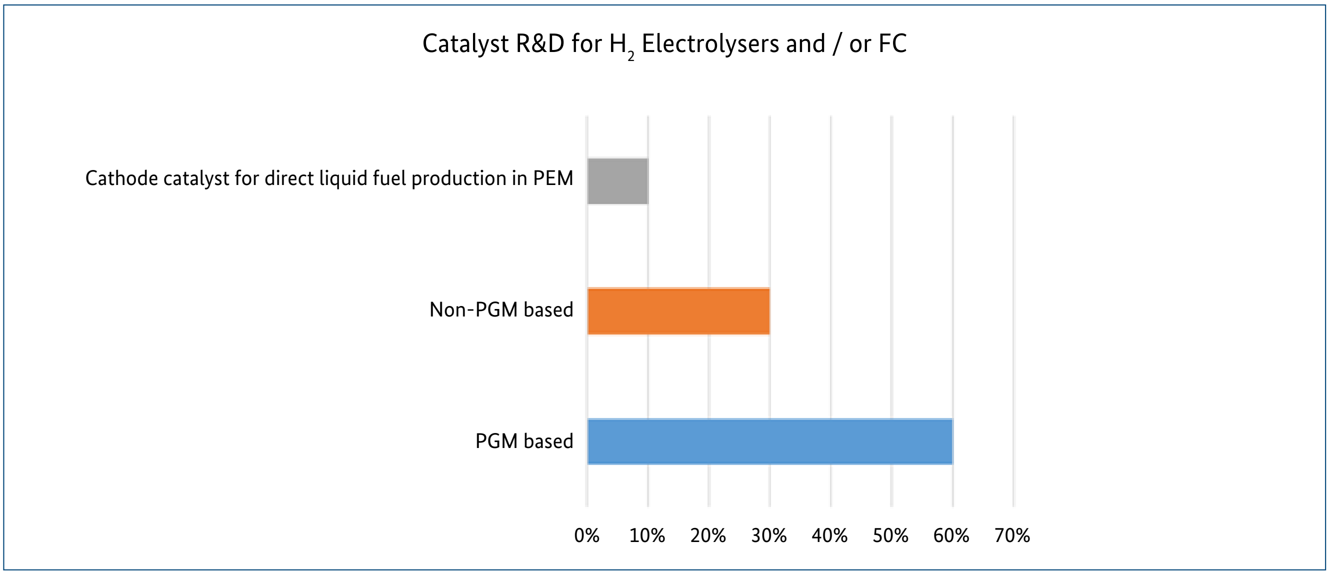


Figure 21: Catalyst R&D for H_2 electrolysers and/or fuel cells

6 HYDROGEN AND FUEL CELL DEMONSTRATION PROJECTS IN SOUTH AFRICA

Each of these is briefly described below to show the potential that exists for hydrogen and fuel cell applications.

6.1 Mobility and transport applications

6.1.1 Hydrogen forklift and refuelling station (Gauteng: Springs)

The hydrogen forklift and refuelling station in the East Rand is a collaborative project between the DST, Impala Platinum, Hydrogen South Africa and the University of the Western Cape. According to an Engineering News article published in April 2016, the South African government is intent on creating incentives for mines to derive greater benefit from investing in platinum fuel-cell technology. The picture below shows the Science and Technology Minister Naledi Pandor at the launch of the refuelling station.

She urged PGM mines to invest in local fuel-cell technology development through the Mining Charter's assessment of a minimum technology development spend of 3% of value added. She added that South Africa has an advantage in terms of access to PGMs, providing an edge over the competition. She expressed the hope that the collaboration between the DST, industry and other government departments would give South Africa the boost it needed to become a world leader in PGM based fuel cell and hydrogen technologies. The abundance of platinum in South Africa, together with capable researchers at Centres of Competence, placed the country in a strong position to seize the opportunities offered by a future hydrogen-based economy.

Implats fuel cell co-ordinator Fahmida Smith said that detailed design had been completed on an 8MW Doosan fuel cell power plant that used natural gas as a fuel source, as well as a 1.2MW Fuji fuel cell power plant that uses hydrogen.

Implats has the ultimate aim to take the entire site off grid and use only fuel cell technologies to power the company's platinum and base metals refineries complex in Springs. Both plants have been completed.

Minister Pandor expressed the wish that she wanted to see fuel cell golf carts, cars, air conditioners, houses and manufacturing plants, along with investment by venture capitalists in an SEZ established with proper incentives for a fuel cell industry.

© DST

© HySA PADEP

6.1.2 5kW fuel cell-battery hybrid powered golf cart (Western Cape: Cape Town)

HySA Systems designed, manufactured and integrated a 5kWe fuel cell-battery hybrid powered golf cart . This was done as an output of the project realised in the frame of hydrogen fuelled vehicles that proves the concept and possibility of PEMFC technology application and metal hydride hydrogen storage in the automotive industry.

HySA Systems designed, manufactured and integrated a 5kWe fuel cell-battery hybrid powered golf cart[11]. This was done as an output of the project realised in the frame of hydrogen fuelled vehicles that proves the concept and possibility of PEMFC technology application and metal hydride hydrogen storage in the automotive industry.

© UWC HySA Systems

6.1.3 TUT hydrogen bicycle (Gauteng: Pretoria)

Tshwane University of Technology (TUT) students in partnership with the DST and hydrogen South Africa developed a hydrogen powered bicycle in 2010, known as "A hi fambeni". The bicycle, translated as "Let's go", was unveiled by Science and Technology Minister Naledi Pandor at the 2nd annual Resource Driven Technology Concept Centre (RETECZA) Conference.

© TUT

6.1.4 Auxiliary power units in commercial airlines

During the final quarter of 2014, an agreement was made by Airbus and South Africa's National Aerospace Centre[12] to jointly fund a three-year research project conducted by Hydrogen South Africa that looks into the application of fuel cells on airliners.

This follows on from the Air Transport Action Group's policy for manufacturers to half 2005 net aviation carbon emissions by 2050, as there is urgency to search for alternative solutions to fossil-fuel based propulsion and energy sources.

Hydrogen fuel cells will be considered to replace the auxiliary power units (APUs), not the jet engines. Replacing the fossil-fuel-powered APUs with hydrogen fuel cells would help achieve the goals of emission-free and low-noise aircraft operation.

6.1.5 Hydrogen drone (Western Cape: Cape Town)

A Cape-Town based company FlyH2[13] Aerospace is developing a large, fixed-wing unmanned aircraft for survey and environmental research purposes. The aircraft will be powered by novel miniaturised hydrogen fuel cells designed, prototyped and trialled by TIA Seed Fund recipients at the University of Cape Town, HySA Catalysis.

[11] Please refer to the HySA Systems website for more information: http://www.hysasystems.com/
[12] Please refer to the following link https://www.uwc.ac.za/News/Pages/HySA,-NAC-and-Airbus-project-takes-flight.aspx
[13] Please refer to http://www.flyh2.com/ for more details.

FlyH2 Aerospace is a licensee for the patented fuel cell technology. The hydrogen fuel cells would provide an electric propulsion alternative which is carbon-neutral, has zero-emissions and is environmentally-friendly.

Among other uses, South African researchers will potentially be enabled to gather comprehensive and important earth observation data with the intention of improving land-use, planning and environmental management which, in turn, will add to improved sustainability management.

6.2 Stationary applications

6.2.1 Hydrogen fuel cell for Cofimvaba School (Eastern Cape: Intsika Yethu)

The DST has partnered with the private sector in a pilot project to use hydrogen fuel cell technology in three schools in Cofimvaba in the Eastern Cape. The schools include Arthur Mfebe Senior Secondary School, St Marks Junior Secondary School and Mvuzo Junior Secondary School.

© Anglo American Platinum

Hydrogen fuel cell technology is being used successfully to provide standby power in some schools in the Eastern Cape. The power generated by the fuel cells is used to support basic energy requirements, for example, charging stations for tablets, fax machines and computers.

Anglo American Platinum sponsored three platinum-based fuel cell systems, including installation and ongoing maintenance and operations. Air Products is supplying the hydrogen fuel requirements, while Clean Energy Investments (a South African company co-owned by the DST and Anglo American Platinum) commissioned the fuel cells to bring standby power to the schools.

Air Products conducted feasibility assessments and erected hydrogen storage facilities according to international standards to supply the fuel cells at the three schools. All the fuel cell power systems have been operating since September 2014.

6.2.2 1kWe HT-PEMFC combined heat and power (Western Cape: Cape Town)

HySA Systems developed a 1kWe high temperature PEM fuel cell[14]. The 1kWe HT-PEMFC unit was designed, manufactured and integrated at the HySA Systems CoC hosted at the UWC.

The aim of the HT-PEMFC CHP system was to demonstrate and test a system that delivers electrical power and thermal energy for households.

6.2.3 15kW fuel cell mini-grid: Naledi Trust (Free State: Kroonstad)

Anglo American Platinum, in partnership with Ballard Power Systems, is developing a next generation fuel cell product which forms the core of a power system that is capable of supplying 230V AC electricity through a mini-grid to households. The system is suitable for charging electronic devices, TV, radio, lighting, refrigeration and cooking appliances. The fuel cell mini-grid technology is an economically competitive alternative to extending grid transmission lines for rural communities located far away from the existing grid. The system is powered by liquid methanol fuel.

The fuel cell mini-grid technology provides an opportunity to electrify rural communities at a faster pace than through the extending grid, and is expected to be cost competitive, when compared to diesel generators and PV mini grid systems for rural communities.

The Naledi Trust Community is a perfect example of how fuel cell technology can benefit rural communities. The access to fuel cell electricity can provide a number of benefits to an indigent rural community, namely a scalable solution that can be right-sized, a clean, fuel efficient solution, no reliance on sun or wind for power and reduced safety hazards

[14] Please refer to the HySA Systems website for more information: http://www.hysasystems.com/

associated with using wood/paraffin for cooking. For other communities, the power can be available to pump water for irrigation of agricultural land, to refrigerate vaccines and provide essential health services at local clinics, and to enable improved teaching methods at schools.

The trial utilises Ballard's commercially proven 5 kW ElectraGen™-ME fuel cell system, integrated by Anglo American Platinum into a complete prototype off-grid solution, including a battery bank and inverter operating within a micro-grid. The system is designed to provide a total of 15 kW of fuel cell-generated electric power and can generate peak power of 70 kW with the support of batteries. This configuration will power the 34 rural homes in the Naledi Trust community. Monthly delivery of liquid methanol fuel to an external storage tank will enable uninterrupted primary power to these homes.

6.2.4 2.5kW hydrogen fuel cell power generator (Western Cape: Cape Town)

The HySA Systems COC (HySA Systems) and Hot Platinum Pty Ltd, a local company involved in power management and control electronics, have developed a 2.5kW hydrogen fuel powered generator prototype[15], with funds from the Department of Science and Technology at the University of the Western Cape in November 2014.

The unit is being tested at the Cape Flats Nature Reserve, on the UWC's Bellville campus, with remarkable results, according to a statement from the DST.

The hydrogen fuel cell power generator unit uses hydrogen to generate electrical power, with water vapour the only by-product, which means that electricity can be produced in an environmentally friendly way without pollution or noise.

Furthermore, hydrogen can be used to produce electricity in remote areas that do not have access to the national grid.

6.2.5 100kW fuel cell at the Chamber of Mines (Gauteng: Johannesburg)

A joint venture between the dti, Mitochondria Energy Company, the Industrial Development Corporation (IDC) and Egoli Gas has installed its first building baseload fuel cell: a 100kW installation[16] at the Chamber of Mines Building in the Johannesburg Central Business District (CBD).

It is the fuel cell's reliability and security of supply that make it particularly attractive in the South African context. There are many more advantages: apart from ticking the green energy box, its ability to provide distributed, off grid generation together with low operating and maintenance costs make it an appropriate technology of choice.

One of the key reasons the Chamber has selected fuel cell technology is to showcase its use of platinum. Containing over 1kg of the precious metal, the use of this technology is of strategic importance to South Africa's beneficiation agenda; by increasing the use of platinum through growing markets for the metal, we will further grow the mining industry, contributing to job creation and economic growth.

This project demonstrates the potential of the market to large production companies, drives beneficiation through one of our core commodities, platinum, and encourages the localisation of fuel cell technology production in South Africa and Africa.

6.2.6 Renewable hydrogen production and storage (North West: Potchefstroom)

In 2012 to 2013, HySA Infrastructure Competence Centre led by Dr Dmitri Bessarabov, developed a solar-to-hydrogen demonstration plant. The first generation commercial scale system consisted of PV modules (26 x 230W) with maximum power point tracker (MPPT) (6kW), tubular gel lead-acid battery storage (640Ah (C10) @ 48V) with charge controller (2x5 W), PEM water electrolyser (282sL/h), high pressure hydrogen storage cylinders (8x50L), de-ionised water supply equipment, ventilation equipment and a PLC and PC for control and monitoring purposes [17, 18, 19].

The commercial scale system capability has recently been upgraded from 6kW PV to 15kW PV, 30kWh to 90kWh battery storage and 0.56kg to 2.5kg production of high purity hydrogen per day. Additionally, an air-driven hydrogen booster provides filling pressures up to 200barg with upgrade capability to 400barg. HySA Infrastructure has also completed the first phase of the compressed renewable hydrogen storage project. It is the first of its kind pilot plant in South Africa at a university campus.

[15] Please refer to the HySA Systems website for more information: http://www.hysasystems.com/

[16] Please refer to the Chamber of Mines website for more information: https://www.google.com/url?q=http://www.chamberofmines.org.za/industry-news/publications/fact-sheets/send/3-fact-sheets/248-chamber-of-mines-fuel-cell-fact-sheet&sa=U&ved=0ahUKEwjRtOirxODPAhXFPRoKHYXFDY8QFggHMAE&client=internal-uds-cse&usg=AFQjCNE22uZg2rgyNQSYNciefHnIyqpwlw

7 PROFILES OF PROMINENT HYDROGEN AND FUEL CELL RESEARCHERS

The study identified some of the prominent researchers active in the hydrogen R&D landscape. This is a challenging exercise as there are numerous highly competent researchers active in the hydrogen R&D landscape, all making valuable contributions to hydrogen and fuel cell R&D.

The table below lists all the [17]researchers active in hydrogen R&D in South Africa that directly via their research entity responded to the circulated questionnaire grouped by the research institution.

Title	Name & Surname	Designation	Institution
Dr.	Sharon Blair	CoC Director	HySA Catalysis
Dr.	Rein Weber	Business Support Manager	HySA Catalysis
Dr.	Shiro Tanaka	Key Technology Specialist	HySA Catalysis
Prof.	Jack Fletcher	Contract Director and Director: Centre for Catalysis Research (UCT)	HySA Catalysis
Dr.	Gary Patrick	Contract Director and Head Catalysis, Advanced Materials Division (MINTEK)	HySA Catalysis
Mr.	Matthew Stevenson	Research Engineer	HySA Catalysis
Mr.	Nabeel Hussain	Research Engineer	HySA Catalysis
Mr.	Francois van Schalkwyk	Research Engineer	HySA Catalysis
Me.	Ellen Kwenda	Research Scientist	HySA Catalysis
Me.	Tenda Mudzimu Ramulifho	Research Scientist	HySA Catalysis
Dr.	Bernhard W. Schwanitz	Postdoctoral Research Fellow	HySA Catalysis
Dr.	Walter Böhringer	Honorary Senior Lecturer	HySA Catalysis
Dr.	Dmitri Bessarabov	CoC Director	HySA Infrastructure
Dr.	Martin Sanne	Contract Director and CSIR Executive Director: Materials Science and Manufacturing (MSM)	HySA Infrastructure
Prof.	Prof. Frik van Niekerk	Contract Director and NWU: DVC: Research, Innovation and Technology	HySA Infrastructure
Dr.	Henrietta Langmi	Key Programme Manager: KP4	HySA Infrastructure
Dr.	Gerhard Human	Key Programme Manager: KP5	HySA Infrastructure
Dr.	Jianwei Ren	Senior Researcher	HySA Infrastructure
Mr.	Ashton Swartbooi	Researcher	HySA Infrastructure
Mr.	Andries Kruger	Research Scientist	HySA Infrastructure
Mr.	Phillimon Modisha	Research Engineer	HySA Infrastructure
Dr.	Nicholas Musyoka	Senior Researcher	HySA Infrastructure
Dr.	Steven Chiuta	Research Engineer	HySA Infrastructure

[17] More details of the listed researchers are available on the websites of their universities or institutes.

Title	Name & Surname	Designation	Institution
Mr.	Faan Oelofse	Senior Engineer	HySA Infrastructure
Me.	Tembelihle Mehlo	Candidate Researcher	HySA Infrastructure
Mr.	Pieter Van Niekerk	Engineer	HySA Infrastructure
Dr.	Immanuel Vincent	Postdoctoral Research Fellow	HySA Infrastructure
Me.	Mushavhanamadi Lindelani	Research Assistant	HySA Infrastructure
Dr.	Cordelia Sita	CoC Director	HySA Systems
Prof.	Professor Vladimir Linkov	Contract Director and Director of South African Institute for Advanced Materials Chemistry (SAIAMC)	HySA Systems
Dr.	Sivakumar Pasupathi	Programme Manager	HySA Systems
Mr.	Adrian Parsons	Programme Manager	HySA Systems
Dr.	Piotr Bujlo	Key Technology Specialist	HySA Systems
Dr.	Mykhaylo Lototskyy	Key Technology Specialist	HySA Systems
Prof.	Ben Bladergroen	Deputy Director & Associate Professor: SAIAMC Innovation Centre and Key Technology Specialist	HySA Systems
Dr.	Huaneng Su	MEA Development for High Temperature PEMFC Head of R & D Group	HySA Systems
Dr.	Cobus Kriek	Group Leader: Electrochemistry for Energy & Environment Group	NWU
Prof.	Schalk Vorster	Researcher	NWU
Prof.	Egmont Rohwer	HOD: Chemistry	UP
Prof.	Emil Roduner	Visiting Professor	UP
Dr.	Shehzaad Kauchali	Researcher	Wits
Dr.	Kaniki Tumba	Researcher	MUT
Prof.	Amir Mohammadi	Researcher: Gas hydrate-based storage	UKZN
Dr.	Alufheli Nesamvuni	Acting DVC: Postgraduate studies, Research and Innovation (TUT)	TUT
Prof.	Josiah Munda	Faculty of Engineering	TUT

The aim was to provide a non-exclusive selection of researchers based on a consistent and unbiased selection criteria that included prominence with regards to position in research institutions; existing collaboration with German research partners; NRF rating and up-and-coming researchers. The profiles of the identified researchers are provided below.

7.1 Dr. Sharon Blair (HySA Catalysis)

Position:

- **CoC Director: HySA Catalysis**
- **CEO: HyPlat (Pty.) Ltd.**

Areas of expertise:

Fuel cells, electro catalysis, MEA and cell design.

Contact:

E-mail: sharon.blair@uct.ac.za
Tel: +27 21 650-5559

Condensed CV:

Dr. Blair joined the HySA Catalysis team in April 2012 and provides overall technical leadership and co-ordination of the HySA/Catalysis Centre's key programme: Portable Power Systems. This role encompasses responsibility to initiate development activities required across the three HySA Centres of Competence (Catalysis, Systems, Infrastructure) and with external partners. She drives the vision and technical horizon for the programme to develop commercially viable and ready prototypes in the 50W to 5kW power sector.

She obtained her Ph.D. in Materials Chemistry from Simon Fraser University (BC, Canada) in 1997. After graduate school, she became Director of Research for an SFU spin-off company with technology based on nanomaterials. Her team developed applications for these nanomaterials in NiMH batteries, hydrogen storage materials, water purification and petroleum upgrading catalysts and scaled up production from 3 grams per week to commercial scale quantities.

In 2003, she co-founded a formic acid fuel cell company called Tekion, where she and her team took technology from a university laboratory and developed the direct formic acid fuel cell to the pre-commercial prototype stage. She was responsible for catalyst, MEA, unit cell, alternative system designs and fuel production. Through this experience, she was invited to write book and encyclopaedia chapters in her field of expertise.

Prior to joining HySA Catalysis, Dr. Blair was Principal of Marble TMC, a technology management consulting company that assisted start-up companies with strategic planning and funding. In addition, she performed technical due diligence on start-ups for venture capital firms.

7.2 Dr. Dmitri Bessarabov

Position:

- **CoC Director: HySA Infrastructure**

Areas of expertise:

NRF rating for established researcher with specialisation in hydrogen technologies, fuel cells, membrane separations.

Contact:

E-mail: Dmitri.bessarabov@nwu.ac.za
Tel: +27 18 285 2460

Condensed CV:

Dr. Dmitri Bessarabov joined DST HySA Infrastructure Centre of Competence at NWU and CSIR in 2010. He was recruited for the position from Canada. He is an internationally-recognised scientist with academic and industrial decision-making experience in the area of hydrogen and electro-catalytic membrane systems for energy applications and fuel cells. Dmitri has over 15 years of progressively increasing responsibility in academic and industrial R&D environments and leadership roles in the hydrogen energy sector in Canada and South Africa. He is a strategic and creative thinker with a proven ability to identify problems, propose and implement solutions.

Dmitri is passionate about PEM fuel cells, electrolysers and membranes. His current responsibilities include leadership in the National Hydrogen and Fuel Cell Programme, HySA Infrastructure business plan development and implementation, and providing excellence in research, development and management. He is currently also leading PEM electrolyser development projects at HySA Infrastructure, which include establishment of technology platforms for electrolyser development, related characterisation tools, electrochemical hydrogen compression and hydrogen production using renewables.

7.3 Dr. Henrietta Langmi

Position:

- **Key Programme Manager: HySA Infrastructure**

Areas of expertise:

C2 NRF rating with specialisation in hydrogen storage, materials science, porous materials, fluid/solid processes, hydrogen energy, metal hydrides, metal-organic frameworks, porous carbon.

Contact:

E-mail: hlangmi@csir.co.za
Tel: +27 12 841 2604

Condensed CV:

Dr. Henrietta Langmi is an experienced R&D scientist with a highly multidisciplinary background. She obtained a BSc (Hons) in Chemistry from the University of Buea, Cameroon before moving to the UK where she completed an M.Sc. with distinction in Environmental Technology at Imperial College London. She later joined the University of Birmingham where she obtained a PhD in Materials and Metallurgy under the supervision of Prof. Rex Harris and Dr. Paul Anderson.

Her PhD research examined hydrogen storage in zeolites and carbon materials, and constituted part of the EU Framework Programme 5 – Fuel Cells and Hydrogen Stores for Integration into Automobiles (FUCHSIA). She subsequently worked at the same institution for 10 months as a Research Fellow under the EPSRC SUPERGEN UK–Sustainable Hydrogen Energy Consortium in the research group of Dr. David Book. In 2006, Dr. Langmi moved to Canada and joined the University of New Brunswick as a Postdoctoral Fellow in Dr. Sean McGrady's Group. She later became a Stipendiary Lecturer and Research Scientist at the same institution and worked on collaborative hydrogen storage projects, most notably lithium aluminium hydride as part of the US DOE Hydrogen Program. Dr. Langmi moved to South Africa in September 2012 to assume a new role as Key Programme Manager for HySA Infrastructure. In the 2016 Women in Science Awards (WISA), Dr Henrietta Langmi was awarded second runner-up in the category of Distinguished Young Women Scientists: Physical and Engineering Sciences.

7.4 Dr. Steven Chiuta

Position:

- **Research Engineer: HySA Infrastructure**

Areas of expertise:

Hydrogen production, power-to-gas technology, nuclear process heat applications for hydrogen production, renewable hydrogen production.

Contact:

E-mail: **steven.chiuta@nwu.ac.za**
Tel: **+27 18 285 2466**

Condensed CV:

Steven joined HySA Infrastructure in 2011 as a PhD student. He is currently involved in technology development as a postdoctoral research engineer in the area of hydrogen production and renewable hydrogen applications. Steven has a combined 8 years' of industry, research and product development experience attained in fertilizer manufacturing, sulphuric and phosphoric acid manufacturing plants, as well as the hydrogen production and storage industry.

His industry and research skills include; technology development; proof of concept validations; process de-bottlenecking and re-engineering; process inspection and analysis; process unit optimisation; continuous improvement; product and technology development; conceptual design; project proposal development; chemical micro-process technology; CFD modelling and multi-physics simulations; heterogeneous catalysis; reaction engineering; nuclear process heat applications; power-to-gas technology; smart grids; chemical hydrogen production technologies; and computer-aided process engineering (NLP and MINLP process optimisation techniques: Primary Level). Steven has authored 7 peer-reviewed journal publications in international journals and 8 conference publications.

7.5 Dr. Nicholas Musyoka

Position:

- **Senior Researcher: HySA Infrastructure**

Areas of expertise:

NRF rating for promising young researcher with specialisation in applied chemistry, chemistry of clay minerals, chemical synthesis and environmental chemistry.

Contact:

E-mail: nmusyoka@csir.co.za

Condensed CV:

Nicholas Musyoka's research background is in materials synthesis, characterisation and testing for various applications. His previous research interests were based on beneficiation of coal fly ash by converting it into different high-value zeolites. In that case, he was able to come up with new and efficient synthesis processes as well as study the crystallisation mechanism of fly ash zeolitization process. His current research interests are in the field of sustainable clean energy technologies with hydrogen research being at the core.

NRF rating for promising young researcher with specialisation in applied chemistry, chemistry of clay minerals, chemical synthesis, environmental chemistry, extraction (chemistry), green chemistry, inorganic chemistry – synthesis, materials chemistry, analytical chemistry, sonochemistry.

7.6 Dr. Cordelia Sita

Position:

- **CoC Director: HySA Systems**

Areas of expertise:

Chemical engineering, hydrogen systems.

Contact:

E-mail: **csita@uwc.ac.za**
Tel: **+27 21 959 9319**

Condensed CV:

Cordellia Sita was appointed Director: HySA Systems on 1 May 2015, responsible for the day to day running of the HySA Systems Competence Centre. Cordellia holds a PhD in Chemical Engineering from the University of Pretoria. During her 17 year career, Cordellia has had the privilege to work in academia, private and public sectors and she is confident that her experience will be useful in taking HySA Systems to the next level.

7.7 Dr. Sivakumar Pasupathi

Position:

- **Programme Manager: HySA Systems**

Areas of expertise:

Combined heat and power systems, PEM based fuel cells and electrolysers.

Contact:

E-mail: **spasupathi@uwc.ac.za**
Tel: **+27 21 959 9318**

Condensed CV:

He obtained his PhD from the University of Pisa, Italy and has been working in the field of hydrogen and fuel cells since the late 1990s. He is a NRF rated scientist. He is a PI/Co-PI in several bilateral projects with international partners. He has recently successfully organised a National South African Hydrogen and Fuel Cell Supply Chain Workshop with the participation of over 30 companies and SMMEs. He is chairing and organising the first international conference on hydrogen and fuel cells in South Africa, with participation from leading researchers and businesses globally.

As programme manager for HySA Systems, he manages both combined heat and power (CHP) and fuel cell vehicles (FCV) programmes. His current focus is on developing components and systems, covering the whole value chain of PEM fuel cells, for CHP and FCV applications. His interests include PEM based fuel cells and electrolysers.

He has published several peer-reviewed international journals and conference proceedings, and is an inventor of 9 patents to date. He has served as speaker at the Zing Hydrogen and Fuel Cells Conference (July 2013) and plenary speaker at the 2nd International Symposium on Electrochemistry (July 2012).

7.8 Prof. Ben Bladergroen

Position:

- **Key Technology Specialist: HySA Systems CoC**
- **Deputy Director & Associate Professor: SAIAMC Innovation Centre**

Areas of expertise:

Clean and renewable energy, membrane technology, gas separation, fuel cell technology, catalysis, energy storage.

Contact:

E-mail: **bbladergroen@uwc.ac.za**
Tel: **+27 21 959 9309**

Condensed CV:

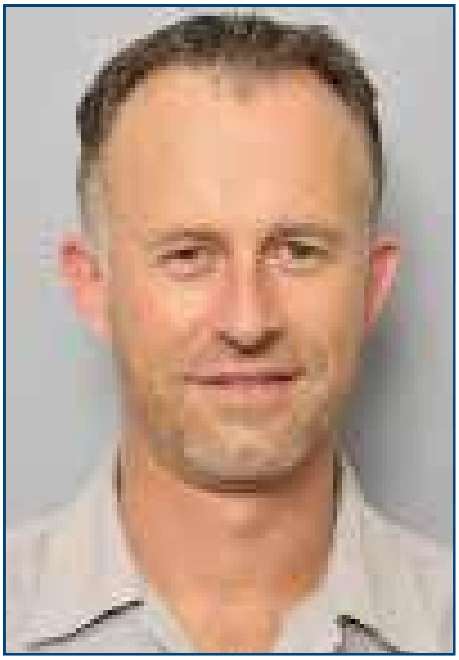
Prof. Bladergroen, a former student at the University of Twente in the Netherlands, joined UWC in 1998 as a PhD student and continued as a postdoctoral fellow in hydrogen separation (2003), hydrogen production (2004) and was appointed as research manager for industrial contract research in 2005, followed by a senior lecturer appointment in 2006. In 2011 he was promoted to the level of Associate Professor at SAIAMC, where his main role is managing applied research and development activities. Since 2007, Prof. Bladergroen has been Deputy Director Operations, establishing the operational procedures at SAIAMC.

In 2011, his portfolio included innovation activities at SAIAMC and two HySA projects. Prof. Bladergroen is the Vice-Chair of the International Association for Hydrogen Energy Youth Division. He has NRF rating for established researcher in the following specialisation areas: clean and renewable energy, membrane technology, gas separation, fuel cell technology, catalysis (heterogeneous), energy storage.

7.9 Dr. Cobus Kriek

Position:

- **Senior Lecturer and Researcher, Electrochemistry for Energy & Environment Group**



Areas of expertise:

Clean and renewable energy, membrane technology, gas separation, fuel cell technology, catalysis, energy storage.

Contact:

E-mail: **cobus.kriek@nwu.ac.za**
Tel: **+27 18 299 2345**

Condensed CV:

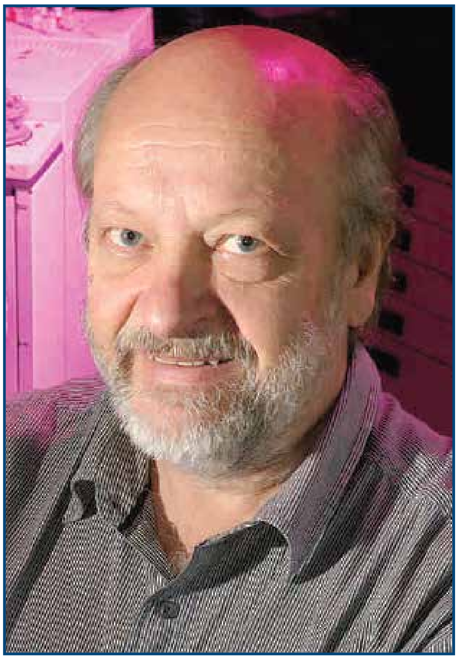
His research focus can be summarised as focusing on "electron transfer to and from metals and metal species as well as the facilitation of electron transfer by metals". To that regard we are interested in (i) the research and development of metal based electrocatalysts for electrolytic water splitting (hydrogen production) and fuel cells towards clean and sustainable energy production, (ii) the photocatalytic reduction of aqueous metal species as a means of recovery, and (iii) the oxidative leaching of metallic or mineral based metal species as a means of recovery/recycling. His R&D is focused on:

- Electrocatalysis
- Photocatalysis
- Electrochemistry/leaching

7.10 Prof. Egmont Rohwer

Position:

- **Head of Department of Chemistry (UP)**



Areas of expertise:

B3-rated NRF researcher. Analytical chemistry.

Contact:

E-mail: egmont.rohwer@up.ac.za
Tel: +27 12 420 5218

Condensed CV:

Prof. Rohwer is the Head of the Department of Chemistry in the Faculty of Natural and Agricultural Sciences at the University of Pretoria, and leads the Mass Spectrometry and Chromatography Laboratory. His research focus is the application of chromatography, mass spectrometry and laser spectroscopy in order to establish the chemical composition of complex mixtures and to identify isolated compounds. This is done to address research problems in fields ranging from engineering, biology, geology and archaeology, to forensic, environmental and food sciences.

Prof. Rohwer finds the greatest challenge in designing new instrumentation and developing customised chemical analytical methods. His research group's latest inventions include versatile silicone rubber-based concentration techniques with published applications in the fields of air pollution, aroma and natural gas composition, with the latter recently contributing to a new hypothesis on the origin of the so-called fairy circles in Namibia.

Because of its expertise and research activities, the Mass Spectrometry and Chromatography Laboratory has been identified by Sasol as a strategic national asset that requires its long-term support. Prof. Rohwer publishes in high-impact journals including Analytical Chemistry, and is a member of several professional bodies. He served on the South African team that negotiated the detailed terms of the International Stockholm Convention on Persistent Organic Pollutants (POPs). He received the Von Humboldt Stipend for two years, and was selected as the Shimadzu Chromatographer of the Year in 2002. He has had a B3-rating from the NRF since 2003.

8 RESEARCH BARRIERS, GAPS AND FUTURE FOCAL AREAS

8.1 Barriers experienced

As part of the survey, the researchers were requested to provide details of barriers experienced in terms of their hydrogen research. Below is a summary of the key feedback.

8.1.1 Funding

Consistent funding of hydrogen R&D seems to be a major concern for researchers. Government funding in particular is a challenge and uncertainties exists in terms of size of allocation, timely disbursements, long term funding commitments and due process to follow to fund key projects in the research and project space. Private sector funding is available but tends to focus on funding demonstration and pilot projects instead of applied or basic R&D.

It was observed that South Africa invests a tiny fraction of GDP into hydrogen R&D compared to other countries.

Specific items that were highlighted under funding barriers included:

- Funding cuts have forced a reduction in scope and have hampered plans to carry out long term planning
- Funding is specifically required for human resources including the following:
    - Postdoctoral positions
    - Student bursaries (in particular for non-South African citizens)
    - Competitive salaries for qualified and skilled engineers and researchers

8.1.2 Infrastructure

Feedback in terms of infrastructure as a barrier to perform hydrogen R&D varied from feedback that indicated that infrastructure is in place and/or easily obtainable if required (if funding is available), to feedback that supporting infrastructure for R&D and demonstration projects are limited or non-existent. Infrastructure availability is considered a barrier for hydrogen R&D.

8.1.3 Equipment

It was observed that researchers feel that required equipment in South Africa is either not known or doesn't exist. It was also identified that there is currently a lack in ability of SMMEs to make fuel cell components such as gold-plated metal bipolar plates and other components, which are currently manufactured elsewhere in the world and subsequently need to be imported. There could be opportunities for SMMEs if localisation is addressed.

8.1.4 Human resources

Researchers felt that the availability of human resources is also a challenge (but not insurmountable). There are already a number of highly qualified engineers in South Africa and a number of these talented individuals are being trained in the hydrogen and fuel cell fields.

South Africa has not been on par with global hydrogen and fuel cell activities for many years. Therefore, when critical and specific experience is required, it must be obtained from abroad.

When talent is required from abroad, there are ways to acquire it in such a way that South Africa benefits from industry-experienced professionals. This must be carefully managed and is being successfully implemented at some research entities as present.

Sometimes graduates want to be exposed to foreign institutions and industry. This should be facilitated to enable these individuals to gain this type of exposure through international partnerships. In this way, South Africa is not losing talent but instead engineers are gaining foreign experience and building a global network while staying in South Africa.

8.2 Potential hydrogen research gaps and future focal areas

The researchers provided inputs and feedback on what they see as research gaps and potential future hydrogen R&D focal areas.

The following suggestions were made for future focal areas and potential gaps:

- R&D on recycling of PGM-based fuel cell components. This will improve the security of South Africa's position in the fuel cell sector as foreign countries are recycling their PGM, therefore reducing demand for raw platinum.

- Development of novel materials for hydrogen storage.
- Gas hydrates represent an attractive means to safely store hydrogen.
- Solar hydrogen production R&D at large scale to enable application at commercial levels.
- The safety aspects and codes for hydrogen application in the mining environment need further development and validation.
- The behaviour of hydrogen (release, turbulence) in enclosed spaces i.e. mining, should be modelled and better understood.
- Currently, mine regulations for hydrogen codes and standards are not available for using hydrogen PEM fuel cell power and storage.
- It is of paramount importance that site hydrogen storage and distribution infrastructure needs to be established to initiate the deployment of mining fuel cell vehicles.
- Development of cost effective small scale hydrogen filling stations to assist with early adopters of FC vehicles, such as forklifts.
- R&D in high impact areas, including catalyst design, MEA manufacturing, stack optimisation and simplified BOP components in order to improve the durability and reliability of the systems, reduce costs and facilitate their commercialisation.
- Economically viable hydrogen production.
- Production of solar fuel (hydrogen and organic liquid) is essential for a transition to non-fossil fuel based electricity production, and intermediate chemical energy storage should be further developed.
    - This will require the development of new catalysts for CO_2 conversion.

9 CONCLUSION

9.1 Key findings

9.1.1 Background

- The hydrogen economy is a key future development for South Africa to develop safe, clean and reliable alternative energy sources to fossil fuels.
- PGMs are the key catalytic materials used in most fuel cells, and with more than 75% of the world's known platinum reserves found within South African borders, there is great potential for socio-economic benefits to be obtained from these natural resources.
- Hydrogen and fuel cell technology not only contributes to the energy security grand challenge, as defined in the DST Ten-Year Innovation Plan [1], but also has implications for global-change science with the potential to help mitigate the effects of climate change through reduced emissions and improved adaptation through use of cleaner energy technologies, as well as partially addressing the DST grand challenge for human and social dynamics.
- Hydrogen R&D in South Africa is primarily driven by government and specifically by the DST in collaboration with academic institutions and industry.
- This National Flagship Programme Hydrogen South Africa (HySA) is aimed at developing South African intellectual property, knowledge, human resources, products, components and processes to support the South African participation in the nascent, but rapidly developing international platforms in hydrogen and fuel cell technologies.
- HySA comprises of three CoCs:
    - HySA Catalysis CoC
    - HySA Infrastructure CoC
    - HySA Systems CoC
- Each of the three CoCs has a unique responsibility, but all three are complementary within the common vision of fostering proactive innovation and developing the human resources required to undertake competitive R&D activities in the field of hydrogen and fuel cell technologies.
- The DST also aims to leverage foreign investment and increase the funding made available by international partners for co-operation with South Africa, related to national priority themes such as the bio-economy, hydrogen and fuel cell technology.
- The budget for the HySA programme is ~R75 million to R80 million per year, divided between the various CoCs based on project specific requirements and applications.
- Recently a Special Economic Zone (SEZ) dedicated to mineral beneficiation has been proclamated for the platinum-rich Bojanala district of the North West Province.

9.1.2 Current hydrogen R&D

- There are a number of government institutions, universities, and private companies working on fuel cell and hydrogen R&D in South Africa.
- The leading hydrogen R&D institutions are:
    - HySA Catalysis
    - HySA Infrastructure
    - HySA Systems
- A number of universities are active in hydrogen R&D
- Anglo American Platinum and Impala Platinum are the most prominent private companies in the hydrogen R&D space

9.1.3 Common R&D

- Hydrogen R&D activities being researched are:
    - Hydrogen production R&D (23%)
    - Catalyst development for hydrogen electrolysers and/or fuel cells (19%)
    - Hydrogen fuel cell (and component) R&D (16%)
    - Hydrogen storage R&D (13%)
    - Hydrogen systems and applications R&D (13%)
    - Hydrogen related auxiliary and ancillary services and activities (10%)
    - Hydrogen distribution R&D (3%)
    - Hydrogen safety, codes and standards R&D (3%)
- Hydrogen production: More effort is being spent on electrolytic and thermochemical hydrogen production R&D than on the biological and direct solar water splitting hydrogen production R&D processes.
- Hydrogen storage: Is reasonably well balanced with storage vessel development leading the pack, while no effort is being spent on cryogenic compressed hydrogen storage R&D.
- Hydrogen distribution R&D: The R&D of novel hydrogen carriers (LOHCs), followed by hydrogen refuelling station R&D, leads the R&D effort in the hydrogen distribution R&D area.
- Hydrogen safety, codes and standards R&D: Is well balanced except for safety related computation fluid

dynamic (CFD) modelling not being researched.
- Hydrogen fuel cell: Most R&D effort is being spent on fuel cell components and the remaining effort is divided between direct methanol and PEM fuel cells R&D.
- Hydrogen systems and application: The least amount of R&D effort is being spent on portable hydrogen systems and application, and the bulk of the effort is split evenly between stationary application and mobility and transport application.
- Auxiliary and ancillary hydrogen R&D service and activities: R&D is spread across the range of activities with concept studies receiving the most effort.
- Catalyst R&D: Mostly focused on PGM-based catalysts (60%) and 30% on non-PGM based catalysts, with 10% of the effort being spent on catalysts for direct liquid fuel production in PEM fuel cells.

9.1.4 Hydrogen and fuel cell demonstration projects in South Africa:

- Mobility and transport applications:
  - Hydrogen forklift and refuelling station (Gauteng: Springs)
  - 5kW fuel cell-battery hybrid powered golf cart (Western Cape: Cape Town)
  - TUT hydrogen bicycle (Gauteng: Pretoria)
  - Auxiliary power units in commercial airlines
  - Hydrogen drone (Western Cape: Cape Town)
- Stationary applications:
  - Hydrogen fuel cell for Cofimvaba School (Eastern Cape: Intsika Yethu)
  - 1kWe HT-PEMFC combined heat and power (Western Cape: Cape Town)
  - 15kW fuel cell mini-grid: Naledi Trust (Free State: Kroonstad)
  - 2.5kW hydrogen fuel cell power generator (Western Cape: Cape Town)
  - 100kW fuel cell at the Chamber of Mines (Gauteng: Johannesburg)
  - Renewable hydrogen production and storage (North West: Potchefstroom)

9.1.5 Existing collaboration

- HySA Catalysis CoC with Fraunhofer Institute (Germany) on MEA electrode design and characterisation.
- HySA Infrastructure CoC with Areva (Germany) on hydrogen storage.
- HySA Systems CoC with:
  - Fumatech (Germany) on MEA development
  - ZSW (Germany) on stack development
  - Fraunhofer ISE (Germany): PEMFC development
- The University of Pretoria is collaborating with researchers from Germany on methanol electro-reforming to produce hydrogen on-board for mobile applications as well as syngas production from CO_2, possibly in collaboration with Sunfire in Dresden, Germany. This is done in association with Prof. Emil Roduner (visiting professor from Germany).
- Anglo American Platinum (as shareholder) collaborated with Hydrogenious, a high-tech spinoff of the University of Erlangen-Nuremberg, (Germany). Hydrogenious has achieved a breakthrough in liquid organic hydrogen carrier (LOHC) technology, which gives hydrogen diesel-like characteristics that allow it to be transported, distributed and stored in existing infrastructure for oil-based fuels.

9.1.6 Barriers experienced

The following are some of the key observations made with regards to barriers experienced:

- Consistent funding of hydrogen R&D activities are required with less uncertainties in terms of size of allocation, timely disbursements, long term funding commitments and due process to follow to fund key projects in the research and project space.
- Funding cuts have forced a reduction in scope and have hampered plans to carry out long term planning.
- Funding is specifically required for human resources.
- Training and development of hydrogen and fuel cell resources should be investigated and addressed.

9.1.7 R&D gaps and future focal areas:

The following are some of the key suggestions made for future focal area and potential gaps:

- R&D on recycling of PGM-based fuel cell components.
- Development of novel materials for hydrogen storage.
- Gas hydrates represent an attractive means to safely store hydrogen.
- Solar hydrogen production R&D at large scale to enable

application at commercial levels.

- Development of cost effective small scale hydrogen filling stations to assist with early adopters of FC vehicles, such as forklifts.
- Economically viable hydrogen production.
- Production of solar fuel (hydrogen and organic liquid) is essential for a transition to non-fossil fuel based electricity production, and intermediate chemical energy storage should be further developed.

9.2 Recommendations

Fuel cells and associated hydrogen infrastructure represent an exciting new market which could drive growth for platinum as well as spark significant new opportunities internationally and locally in South Africa, and Africa.

Hydrogen and fuel cell technologies for the mining and telecom sectors as well as for rural electrification could potentially create a new large market opportunity for fuel cell technology deployment in South Africa and internationally.

Benefits of developing hydrogen infrastructure and fuel cell market in South Africa include:

- Means of meeting increasing demand for energy.
- Reduction of carbon footprint.
- Platform for mineral beneficiation.
- Opportunity for job creation.
- Wealth creation.
- Export opportunities to the rest of Africa.
- Increase demand for Platinum Group Metals.

In order to achieve the above-mentioned, the following key recommendations are made:

- Consistent, long term, sustainable funding is required for hydrogen R&D activities. This can include local and international funding.
- The funding should be balanced between basic R&D, applied R&D, piloting and demonstration and commercialisation. Different government departments should share information and have an integrated strategy.
- Government assistance for securing funding for a number of large scale demonstration projects should be considered.
- The South African and African market for hydrogen and fuel cell technologies should be quantified and used as guidance in defining strategies.
- Training and development of hydrogen and fuel cell resources should be investigated and addressed.
- Solar hydrogen production should be investigated given the fact that South Africa has abundant solar and PGM resources.

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11 APPENDICES

11.1 Letter of Introduction

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

GIZ Office Pretoria, P.O. Box 13732, Hatfield 0028, Pretoria, South Africa

Office Pretoria,

Hatfield Gardens
Block C, 2nd Floor
333 Grosvenor Street
Hatfield 0028, Pretoria, Pretoria
South Africa

T +27 (12) 423 5900
F +27 (12) 342 0185

Your reference
Our reference WINDAC1

01/07/2016

To Whom it May Concern

RE: Data collection by Raventech Consulting to review the state of hydrogen research in South Africa.

Dear Madam/Sir

The Governments of Germany and South Africa are cooperating on a number of energy initiatives under the auspices of the Enery Partnership Programme, funded by the German Federal Ministry for Economic Affairs and Energy (BMWI). The Energy Partnership receives administerial support from the South African German Energy Programme (SAGEN) implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Under the Energy Partnership, Raventech Consulting, represented by Jan van Ravenswaay has been appointed to carry out a review hydrogen energy research in South Africa. The project aims to identify current research activities, research themes as well as eminent researchers in the field. Ultimately, the project hopes to foster new collaborations, strengthen existing ones and advance mutually agreed research topics between South African and German research institutions. The success of the project and future follow-up activities will depend entirely on the information shared by active actors in the research field and we therefore kindly request your cooperation and support for the Raventech team.

Should you need further information, please do not hesitate to contact Marlett Balmer on marlett.balmer@giz.de.

Kind regards

Mr Tobias Zeller
International Advisor
South African German
Energy Partnership

Marlett Balmer
Senior Energy Advisor
South African German
Energy Programme (SAGEN)

11.2 Questionnaire Used for Data collection

Questionnaire: Review of Hydrogen Research Activities in RSA (GIZ)

A. Researcher and Research Organization information:

1. Please complete list your personal and organization details below:

A.1 Researcher details				
Title				
Name				
Surname				
Position in Organisation				
Highest Qualification				
Are you a NRF Rated researcher?	Yes		No	
Email Address				
Contact Number				

A.2 Organization details		
Organization Name		
Please indicate your organization type		Mark (x)
	Academic / Research Institution	
	Public Company	
	Private Company	
Name of Business Unit		
Website		

A.3 Hydrogen Collaborators (Please list collaborator who you are working with in hydrogen research)			
Collaborator Name	Organization Name	Country	Field of Hydrogen Collaboration

B. Details of Hydrogen Research:

Please mark the appropriate block(s) to identify the areas of hydrogen research you are involved in.

High level Hydrogen Research Fields	Mark (x)
B.1 Hydrogen Production Research and Development (General)	
B.2 Hydrogen Storage Research and Development	
B.3 Hydrogen Distribution Research and Development	
B.4 Hydrogen Safety, Codes and Standards Research and Development	
B.5 Hydrogen Fuel Cell (and component) Research and Development	
B.6 Hydrogen Systems and Applications Research and Development	
B.7 Hydrogen Related Auxiliary and Ancillary Services and Activities	
B.8 Catalyst Development for Hydrogen Electrolysers and/or Fuel Cells	
Other (Please Expand)	

Note: Please add additional brochures and documentation as required to the response.

B.1 Hydrogen Production Research and Development		Mark (x)
Thermochemical Processes	Natural gas reforming (Steam methane reforming)	
	Coal gasification	
	Liquid fuel	
	Biomass-derived liquid reforming	
	Biomass gasification	
	Nuclear energy	
	Solar (High Temperature Applications)	
	Other (Please Add)	
Electrolytic Processes	PEM electrolysers	
	Alkaline electrolysers	
	Solid oxide electrolysers	
	SO_2 Electrolysers	
	Other (Please Add)	
Direct Solar Water Splitting Processed	Photo electrochemical water splitting	
	Photo-biological	
	Other (Please Add)	
Biological Processes	Microbial biomass conversion	
	Photo-biological	
	Other (Please Add)	

B.2 Hydrogen Storage Research and Development	Mark (x)
Compresses hydrogen gas storage	
Cold/Cryogenic compressed hydrogen storage	
Liquid hydrogen storage	
Adsorbent storage	
Chemical hydrogen storage	
Complex hydrides	
Storage vessel development (stationary and transportable)	
Other (Please Add)	

B.3 Hydrogen Distribution Research and Development	Mark (x)
Hydrogen distribution (Pipelines and Depots)	
Hydrogen refuelling stations	
Novel hydrogen carriers (i.e. Liquid Organic Hydrogen Carriers)	
Hydrogen transportation	
Other (Please Add)	

B.4 Hydrogen Safety, Codes and Standards Research and Development	Mark (x)
Environmental protection	
Risk analysis	
Safety (CFD modelling)	
Codes and standards	
Fire and explosion protection	
Other (Please Add)	

B.5 Hydrogen Fuel Cell (and component) Research and Development	Mark (x)
PEM fuel cell	
Direct methanol fuel cell	
Solid oxide fuel cell	
Alkaline fuel cell	
Molten carbonate fuel cell	
Reversible fuel cell	
Phosphoric acid fuel cell	
Fuel Cell Components	
Fuel cell stack	
Fuel processor	
Membrane electrode assembly (MEA)	
Control systems	
Balance of plant (BOP)	
Other (Please Add)	

B.6 Hydrogen Systems and Applications Research and Development		Mark (x)
Mobility and Transport Applications	Motorcycle / scooter	
	Passenger car, Light Truck	
	Bus, Heavy duty truck	
	Forklift	
	Military applications	
	Aircraft	
	Marine	
	Train	
	Other (Please add)	
Stationary Applications	Domestic combined heat and power (CHP)	
	Cogeneration	
	Distributed power	
	Remote power	
	Backup power	
	Other (Please add)	
Portable Applications	Recreational	
	Freight monitoring	
	Recreational vehicle power	
	Marine power	
	Portable electronic devices	
	Other (Please add)	

B.7 Hydrogen related Auxiliary and Ancillary Services and Activities	Mark (x)
Theory development	
Systems analyses and modelling	
Manufacturing	
Membrane technologies and development	
Hydrogen purification	
Concept studies	
Control systems (electrical and non-electrical)	
Hydrogen sensors and detector development	
Demonstration projects	
Various consultancy services	
Other (Please add)	

B.8 Catalyst Development for Hydrogen Electrolysers and/or Fuel Cells	Mark (x)
PGM Based	
Non-PGM based	
Other (Please add)	

C. Barriers, Future Hydrogen Research activities and Potential Gaps:

C.1 What barriers have you experienced in terms of your Hydrogen Research? I.e. • **Funding** • **Infrastructure** • **Equipment** • **Human Resources**
Please elaborate:

C.2 What future plans do you have regarding Hydrogen research?
Please elaborate:

C.3 Do you have any recommendations on future hydrogen research focal areas? I.e. • **Novel materials for hydrogen storage** • **Membranes for separation, purification, and ion transport** • **Design of catalysts at the nanoscale** • **Solar hydrogen production** • **Bio-inspired materials and processes**
Please elaborate: