CENTRE FOR RENEWABLE & SUSTAINABLE ENERGY STUDIES

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H_2GEN

Hydrogen Generation and Energy Network

Building South Africa's Hydrogen Future

CONTENTS

EXECUTIVE SUMMARY

The Hydrogen Generation and Energy Network (H_2GEN) at Stellenbosch University (SU) presents a platform for extending South Africa's reach in the global hydrogen economy.

By leveraging the country's abundant renewable energy resources in alignment with the national green hydrogen roadmap, H_2GEN addresses critical knowledge gaps in hydrogen engineering through research across chemical, electrical, industrial, and mechanical engineering disciplines.

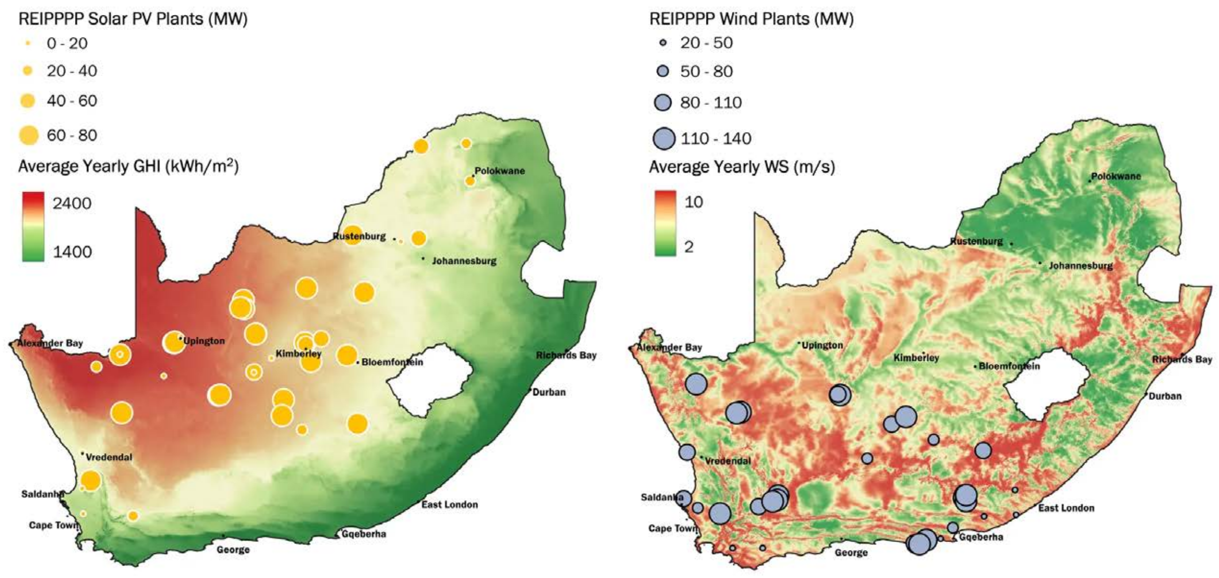
RENEWABLE ENERGY AND HYDROGEN: SOUTH AFRICA'S OPPORTUNITY

Green hydrogen presents a strategic solution for South Africa's renewable energy transition. Produced through electrolysis powered by renewable energy, hydrogen enables long-duration energy storage and transport, addressing the temporal and spatial mismatch between renewable energy generation and demand. This positions hydrogen as a critical enabler for decarbonizing hard-to-abate sectors while maximizing the value of South Africa's exceptional renewable resources.

South Africa possesses world-class renewable energy resources, with exceptional solar irradiation levels and significant wind potential. Through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), utility-scale wind and solar photovoltaic (PV) projects have been strategically located in areas with optimal resource availability. The geospatial distribution of wind and PV plants aligns with regions having the highest wind speeds and solar irradiation, as illustrated in the map. However, the high variability of renewable energy generation, combined with geographic concentration of production sites and time-dependent local variations between supply and demand, creates a need for effective energy storage and transport solutions.

Hydrogen, along with derivative carriers such as ammonia, provides the solution to these challenges. By producing green hydrogen through renewable-powered electrolysis or other sustainable methods, South Africa can store excess renewable energy, transport it to demand centers, and utilize it in fuel cells, combustion engines, or prepare it for export—bridging the gap between abundant renewable generation and diverse energy needs.

South African REIPPPP Solar PV and Wind Plants



The Centre for Renewable and Sustainable Energy Studies (CRSES) | Stellenbosch University
Source: Eskom 2025a. **Notes:** REIPPPP: Renewable Energy Independent Power Producer Procurement Programme; GHI: Global Horizontal Irradiance.

VISION AND MISSION

Vision

To position SU as the premier partner for international research projects and leader in clean hydrogen systems engineering in South Africa.

Mission

To establish a state-of-the-art, multi-disciplinary hydrogen laboratory that drives innovation, fosters collaboration, and develops highly skilled professionals in the green hydrogen sector.

STELLENBOSCH UNIVERSITY'S STRATEGIC RESPONSE

While South Africa stands at the threshold of this hydrogen opportunity, realizing its full potential requires addressing critical knowledge gaps and building specialized engineering capacity. Many aspects of hydrogen technology - from electrolyser design and manufacturing to system integration and infrastructure planning - demand expertise that is currently scarce in the South African context.

H_2GEN at Stellenbosch University was established to bridge this gap. Operating within the Centre for Renewable and Sustainable Energy Studies (CRSES), H_2GEN brings together researchers from chemical, mechanical, electrical, industrial, and civil engineering disciplines to tackle the engineering challenges that are essential for South Africa's participation in the global hydrogen economy.

Our transdisciplinary approach is distinct: rather than focusing solely on fundamental science, H_2GEN emphasizes engineering systems development, addressing the practical challenges of designing, manufacturing, and integrating hydrogen technologies at scale. This focus on engineering implementation positions H_2GEN to make unique contributions to South Africa's hydrogen ambitions.

Through strategic partnerships with industry, government, and international research institutions, H_2GEN is building the knowledge base and developing the skilled professionals needed to translate South Africa's renewable energy advantage into tangible hydrogen economy outcomes. Our research programme spans the entire hydrogen value chain, from production technologies to end-use applications and system integration, ensuring a comprehensive approach to this complex transition.

STRATEGIC POSITION

H_2GEN operates within the Stellenbosch University Centre for Renewable and Sustainable Energy Studies (CRSES), building on its strong foundation in energy systems modelling.

H_2GEN leverages expertise across the following engineering disciplines:

Chemical:
Process and materials optimization

Mechanical:
Component design and manufacturing

Electrical:
Power management and control

Industrial:
Manufacturing and system integration

Civil:
Safety and infrastructure

H_2GEN has secured funding from the following sources

- **NRF-Sasol SARChi** (South African Research Chairs Initiative) Chair in Green Hydrogen
- **SU Strategic Funding Secretariat** (2023–2027) for staffing, administration, and operational support.
- **Private five-year grant** (2025–2029) for equipment, consumables, and postgraduate student funding.

RESEARCH AND DEVELOPMENT PROGRAMMES

The research activities are split into the following three major themes:

I. **Hydrogen production**

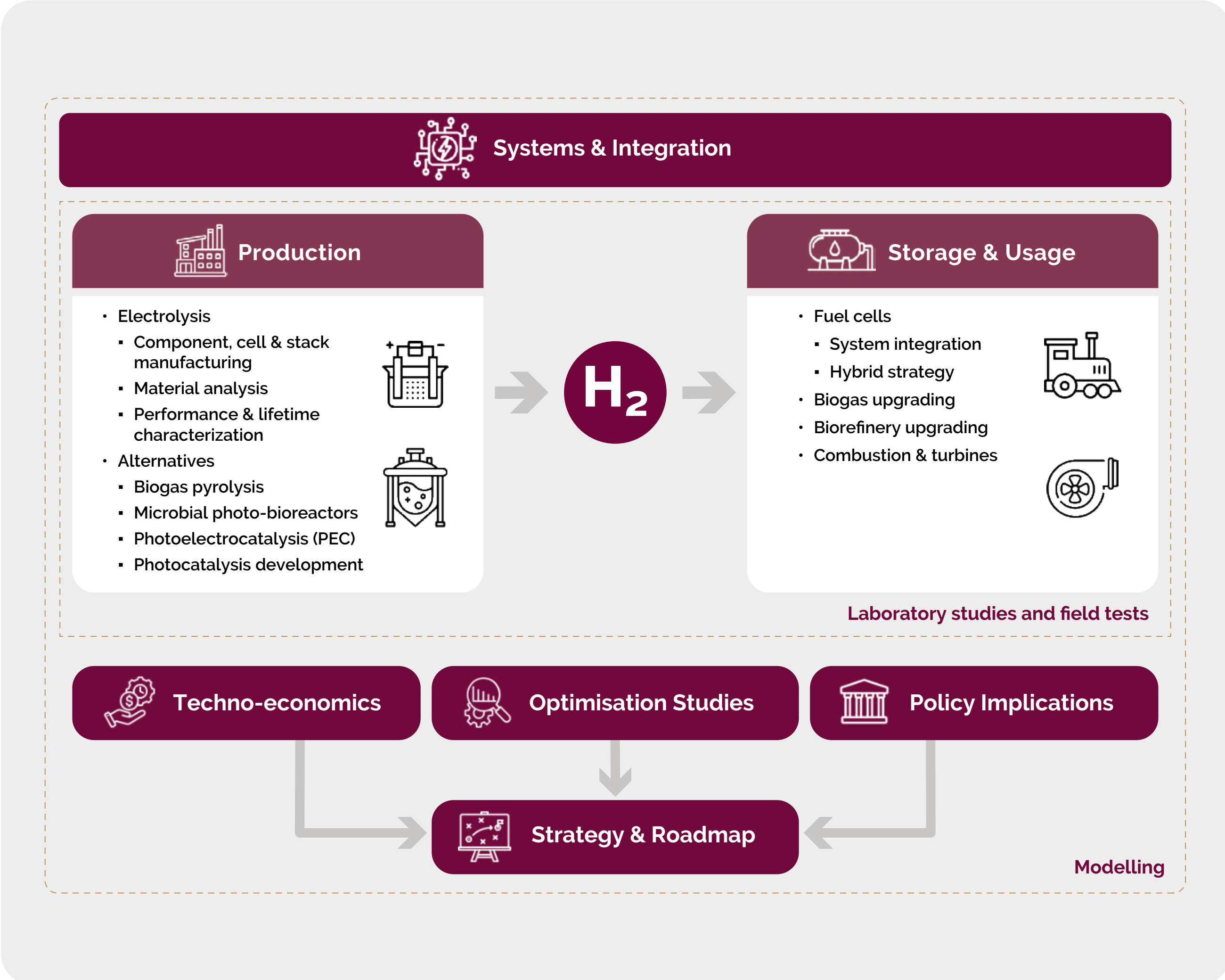
II. **Hydrogen storage and usage**

III. **Systems and integration**

Research on hydrogen production includes electrolysis with a special focus on material development to reduce the use of precious metals and alternative manufacturing methods. On the other hand, alternative production methods such as biogas pyrolysis, microbial photobioreactors, and photoelectrocatalysis are investigated.

Hydrogen is used in various application technologies such as fuel cells and combustion engines, either in its pure form or as a subsequent fluid such as ammonia, the production of which in biogas plants is also investigated. Storage research currently focuses on metal hydride materials but may be extended to, for example, pressurized tanks in the future.

It is crucial to investigate not only the production and usage of hydrogen but also its integration into the energy system. Thus, techno-economic and optimization studies, including policy implications, are conducted to develop a strategy and roadmap for optimal implementation in the overall energy system.



I. PRODUCTION

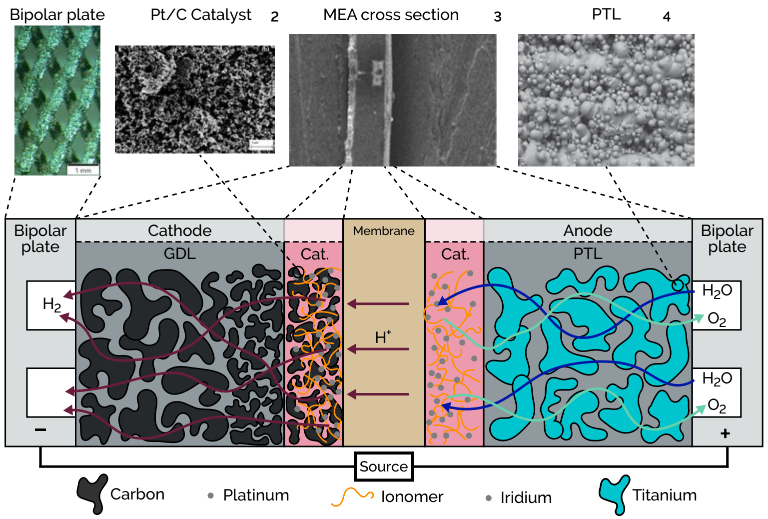
ELECTROLYSER TECHNOLOGY PROGRAMME

This programme focuses on developing comprehensive research and development capabilities for electrolyser technology, covering research activities in both electrocatalytic and photocatalytic water electrolysis.

ELECTROCHEMICAL WATER ELECTROLYSIS

Electrochemical water splitting has long been considered an effective energy conversion technology for converting intermittent renewable electricity into hydrogen fuel. Proton exchange membrane water electrolysis (PEMWE) is considered one of the most efficient and practical methods for green hydrogen, with the advantages of zero carbon emissions, compact structure, small footprint, high current density, and high purity of hydrogen production. The research is divided into the development of non-noble metal catalysts and the design and additive manufacturing of porous components. While current activities are focused on PEMWE, future work will expand to include alkaline and solid oxide electrolysis as well.

Schematic overview and working principle of a PEMWE[1]



- ***Cat.:*** *Catalyst*
- ***GDL:*** *Gas diffusion layer*
- ***MEA:*** *Membrane electrode assembly*
- ***PTL:*** *Porous transport layer*

1. *Adopted from Paul Thiele, Dissertation, RWTH Aachen University, publication pending, "Realistic Accelerated Stress Tests for PEM Fuel Cells in mobile applications"*
2. *A. Villamayor, A. Alba, L. V. Barrio, S. Rojas, and E. Gutierrez-Berasategui, "Magnetron Sputtered Low-Platinum Loading Electrode as HER Catalyst for PEM Electrolysis," Coatings, vol. 14, no. 7, p. 868, Jul. 2024*
3. *S. Siracusano, N. Van Dijk, R. Backhouse, L. Merlo, V. Baglio, and A. S. Aricò, "Degradation issues of PEM electrolysis MEAs," Renew. Energy, vol. 123, pp. 52–57, Aug. 2018.*
4. *G. Ter Haar and C. McGregor, "Additive manufacturing of titanium porous transport layers for efficient PEM water electrolysis," Mater. Today Sustain., vol. 32, p. 101219, Dec. 2025*

CATALYST DEVELOPMENT

Background

The anode and cathode electrocatalysts are crucial components of the membrane electrode assembly (MEA) of the PEMWE, as they promote the half-reactions, namely oxygen and hydrogen evolution reaction (OER and HER). Currently, noble metals are used in PEMWE catalysts, such as platinum (Pt)-based materials and iridium/ruthenium (Ir/Ru)-based compounds. However, these metals pose challenges for the large-scale commercialization of PEMWE, because their availability is affected by their low natural abundance, leading to high costs. These two factors directly impact the sustainability of the technology in the long term.

Research into non-platinum group metal (non-PGM) materials for catalyst development in PEMWE systems is currently being pursued by H_2GEN. This work is built upon the significant advances made in the design and synthesis of high-performance transition metal(TM)-based catalysts, including TM-based alloys and TM-based compounds (TMXs, where X = Ni, Co, Mo, etc.), which are investigated to enable commercial large-scale water electrolysis without dependency on scarce precious metals. Ex-situ characterization is conducted using a potentiostat and three-electrode-cell setup to simulate the HER or OER half-cell reactions.

In this manner, key performance parameters such as activity, stability, and reaction kinetics are measured. Materials that show promise in these tests are then advanced to in-situ characterization in a single-cell PEMWE, where their performance under real-world conditions is evaluated, allowing an assessment of how these catalysts function when integrated with other components in the electrolysis cell.

Groups Involved

Department of Chemical Engineering,

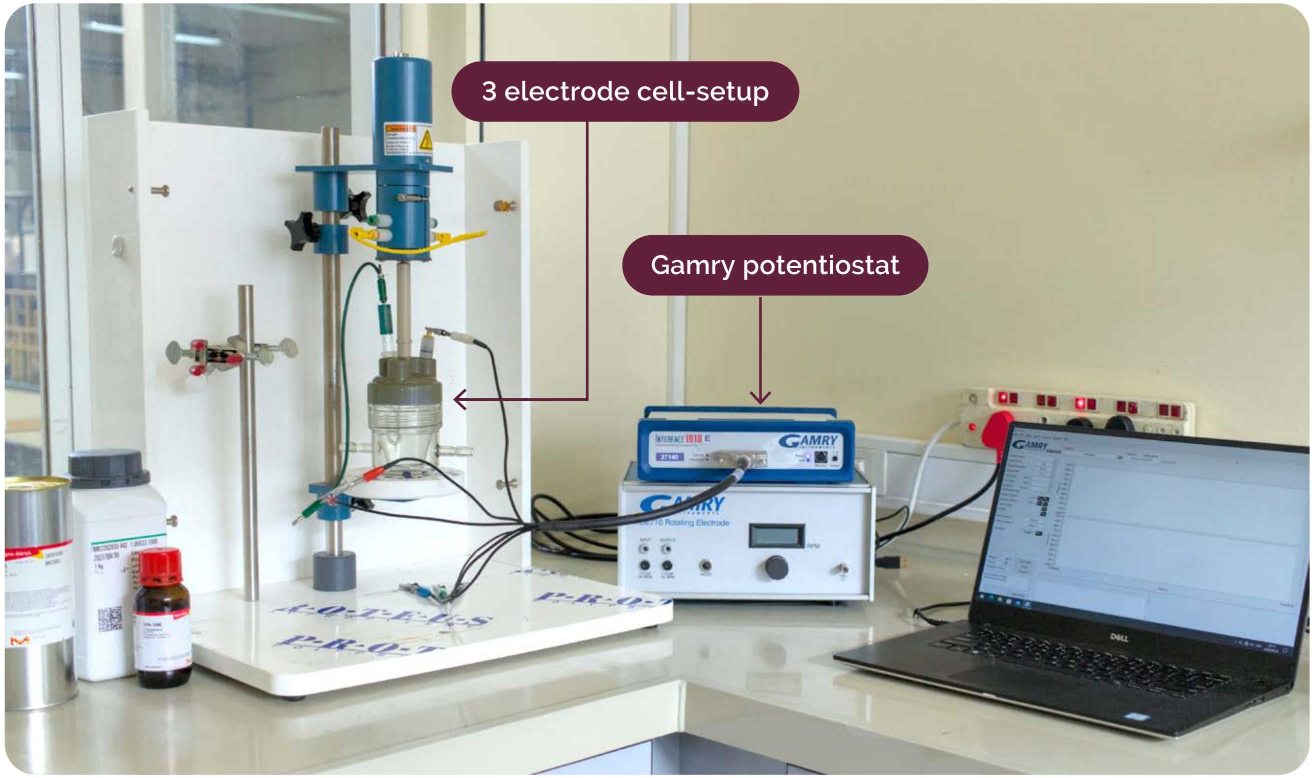
Department of Mechanical and Mechatronic Engineering

Principle Researcher

Prof Prathieka Naidoo (prathiekan@sun.ac.za)

Collaborators

- University of Cape Town
- University of Zululand



Ex-situ 3-electrode cell setup for catalyst electrochemical characterization

ADDITIVE MANUFACTURING OF CELL COMPONENTS

Background

Current methods for manufacturing porous transport layers (PTLs) offer limited manufacturing control over structural morphology and are inefficient in their material use. Novel multi-layer hierarchical/gradient flow fields have shown promise; however, the existing manufacturing methods have limited capabilities in creating optimal porosity gradients. Flow channels in bipolar plates influence performance efficiency but optimizing this design pattern is an ongoing research effort. Traditional methods often prove to be costly and energy intensive.

Current Activities

This research explores laser powder bed fusion (L-PBF), an additive manufacturing (AM) technique, as an alternative approach to PTL fabrication. L-PBF works by spreading a thin layer of metal powder across a build platform, then using a high-powered laser to selectively melt and fuse specific areas according to a digital model. After each layer is processed, the build platform lowers incrementally, a new layer of powder is spread, and the process repeats until the entire three-dimensional object is constructed layer by layer. L-PBF offers enhanced design flexibility while reducing material waste and energy consumption. AM has already demonstrated promise in electrolyser component fabrication, including bipolar plates, liquid-gas diffusion layers, and integrated transport layers.

In collaboration with the Central University of Technology, the following novel platinum–titanium electrodes have been manufactured and tested:

- Novel designs
- Metal additive manufacturing of components
- Manufacturing of 3D printed electrolyser flow fields
- Testing of electrolyser performance

Group Involved

Department of Mechanical and Mechatronic Engineering

Principle Researchers

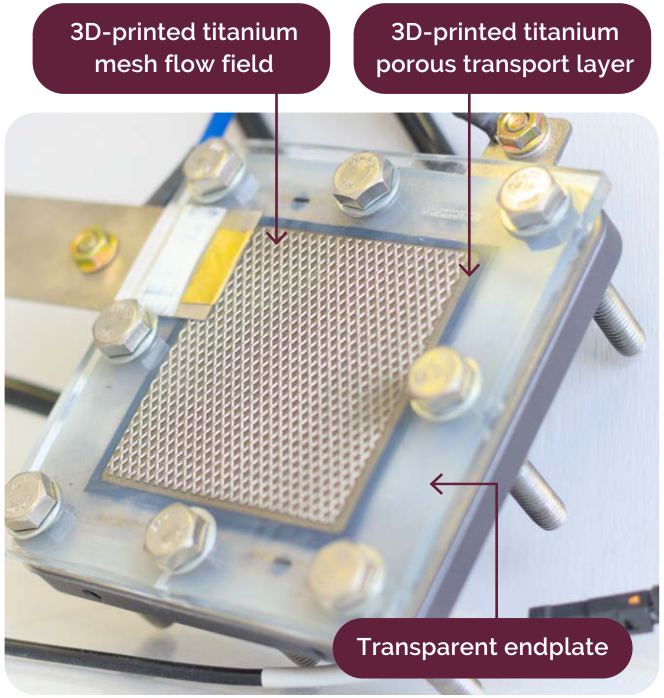
Dr Gerrit Ter Haar (gterhaar@sun.ac.za),
Dr Melody Neaves (melzvanrooyen@sun.ac.za)

Collaborator

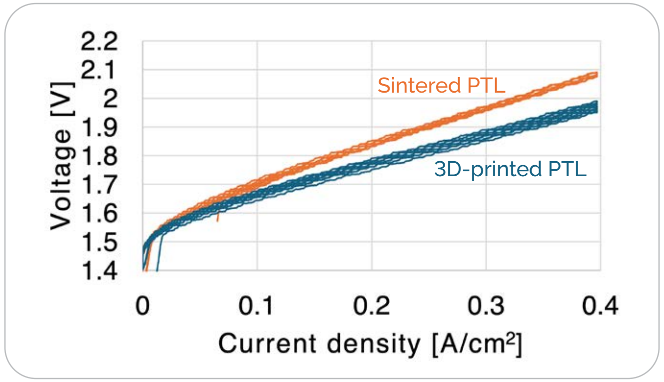
Central University of Technology

Research Output

G. Ter Haar and C. McGregor, "Additive manufacturing of titanium porous transport layers for efficient PEM water electrolysis," Mater. Today Sustain., vol. 32, p. 101219, Dec. 2025 https://doi.org/10.1016/j.mtsust.2025.101219



PEMWE cell with 3D-printed components



Polarisation curves

ANION EXCHANGE MEMBRANE ELECTROLYSIS

Background

A less cost-intensive alternative to PEM is anion exchange membrane (AEM) electrolysis, which is an emerging water-splitting technology that combines the advantages of both alkaline and PEM systems. It uses an anion-conducting polymer membrane and operates in alkaline conditions, allowing the use of non-precious metal catalysts such as nickel instead of expensive PGMs. This reduces costs while maintaining high efficiency and system simplicity. Unlike traditional alkaline systems, AEM electrolysers offer compact designs and fast, dynamic responses, making them attractive for integration with renewable energy sources. Current challenges include the development of durable membranes and stable catalysts that can withstand long-term operation under alkaline conditions.

Current Activities

The current research focuses on the development of advanced nickel-based catalysts for AEM electrolysis. The goal is to improve both activity and long-term stability under alkaline conditions. To achieve this, Ni-based alloy and other PGM-free catalysts are designed to enhance performance and resistance to degradation. Catalyst evaluation is carried out in the three-electrode cell setup featuring a reference electrode, allowing detailed electrochemical analysis by using synergies with the setup in PEM electrolysis.

In the next phase, the optimized catalyst layer and cell configuration will be integrated into a complete AEM electrolyser for cell-level testing. Initially, the system will operate with deionized water to establish baseline performance. Later experiments will explore the use of wastewater streams containing ammonia as an alternative feedstock, aiming to assess their impact on efficiency and material stability. This approach supports the development of more sustainable and cost-effective hydrogen production technologies.

Group Involved

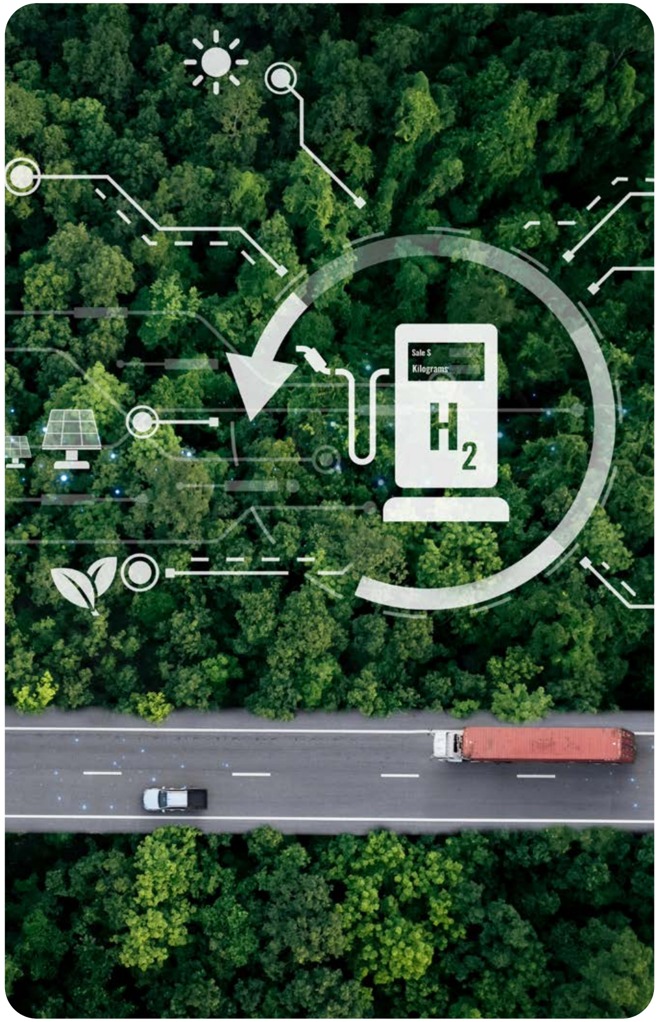
Department of Chemical Engineering

Collaborator

University of Zululand

Principle Researcher

Prof Prathieka Naidoo (prathiekan@sun.ac.za)



ALTERNATIVE PRODUCTION METHODS

PHOTOELECTROCHEMICAL WATER ELECTROLYSIS

Background

Photoelectrochemical (PEC) water-splitting technologies promise to improve on traditional PV-powered electrolysis methods in terms of sustainability, efficiency, and cost. This is achieved by completing the photo-absorbing and electrochemical steps at a single photoactive component. However, prototype testing beyond lab-scale is limited due to challenges in producing large photoelectrodes. The global research community is focused on synthesizing high performance and stable materials as well as outdoor testing of kilowatt scale prototypes.

Current Activities

Research at the Department of Mechanical and Mechatronic Engineering investigates the integration of concentrating solar optics with PEC devices, negating the need for large photoelectrodes and reducing the levelized cost of photoelectrochemically produced hydrogen. Research activities include:

- Developing solar concentrators for integration with PEC hydrogen production
- Outdoor testing of an integrated concentrator PEC solar hydrogen production system

Group Involved

Department of Mechanical and Mechatronic Engineering

Principle Researcher

Prof Craig McGregor (craigm@sun.ac.za)

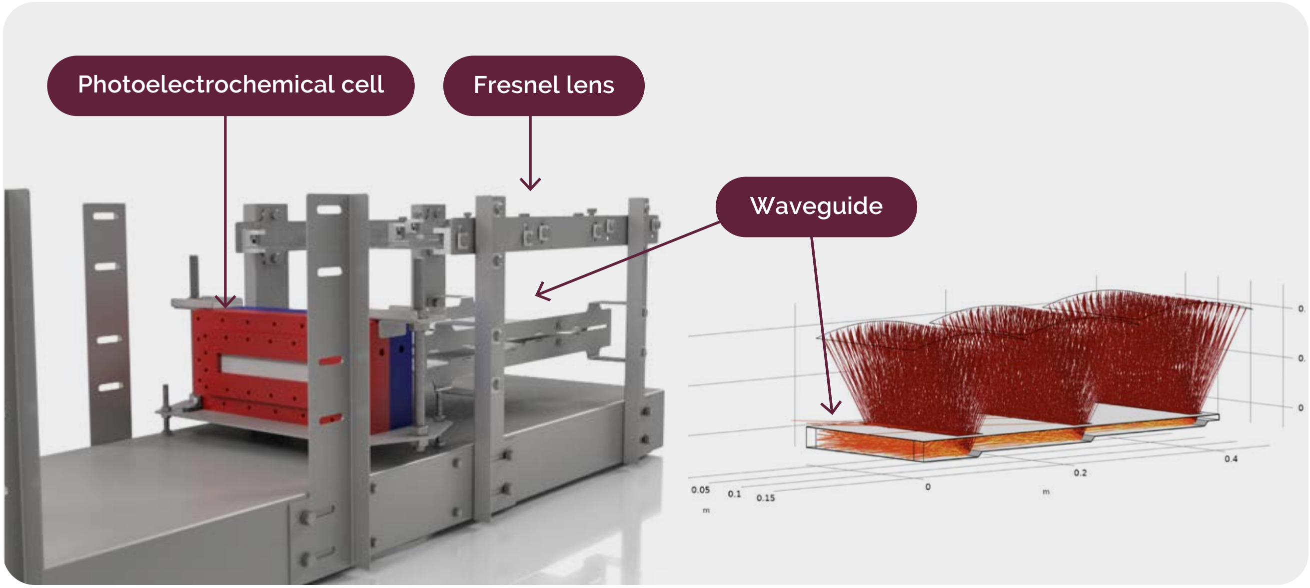
Collaborator

Imperial College London

Research Output

G. H. Creasey et al., "Up-Scaling Solar Hydrogen Production: Development and Demonstration of Photoelectrochemical Reactors," ECS Meet. Abstr., vol. MA2024-02, no. 59, p. 3927, Nov. 2024

https://iopscience.iop.org/article/10.1149/MA2024-02593927mtgabs



Left: *Photoelectrochemical reactor system* ***Right:*** *Raytrace simulation of waveguide*

PHOTOCATALYSIS DEVELOPMENT

Background

The research is focused on developing photocatalytic hydrogen-producing pathways as an alternative to standard electrolysis, both from water and hydrogen carriers such as alcohols. Photocatalysis has the advantage of directly harnessing sunlight for chemical conversion, but catalytic efficiency currently remains low, and catalyst lifetime must be improved substantially to make the technology affordable enough to compete with electrolysis. Our work specifically investigates the use of copper coated onto TiO_2 as photocatalyst, which is significantly more affordable than employing platinum-group metals. Preliminary results indicate that copper has superior selectivity compared to platinum when producing H_2 from primary alcohols, which is a promising pathway for further development. The work is collaborative and has benefitted from inputs by the University of Ghana and the Technical University of Munich. The aim is to expand on the initial work and continually improve catalyst lifetime and efficiency to make the technology more economically viable.

TiO2 nanoparticles with varying metal additives (from: Master thesis by Mr Van Den Berg, 2024, Cu and Pt loaded TiO2 for H2 production via photocatalytic ethanol reforming)

Group Involved

Department of Chemical Engineering

Principle Researcher

Prof Neill Goosen (njgoosen@sun.ac.za)

Collaborator

University of Ghana, Technical University of Munich

BIOGAS PYROLYSIS

Background

Hydrogen has emerged as a promising clean energy source, with applications in various hard-to-abate sectors such as transport, shipping, cement, and steel. The currently adopted hydrogen production processes, however, are carbon-intensive. Hydrogen production, catalytic methane decomposition (CMD), has gained much attention as a low-carbon pathway, because it produces solid carbon instead of CO_x gases, thereby reducing emissions. Moreover, waste biomass streams, such as agricultural residues and municipal waste, can be used as biomethane feedstock, offering further environmental benefits. The waste biomass undergoes anaerobic digestion to produce biogas, which primarily contains methane (50–75 vol%) and carbon dioxide (25–50 vol%). Other minor impurities, such as nitrogen and hydrogen sulphide, are also present, so biogas upgrading and purification are required.

Current Activities

This project focuses on biogas sourcing and upgrading, selecting the best-suited feedstock within a South African context and the necessary upgrading processes. Furthermore, experimental CMD tests will be conducted to optimize the catalyst design for CMD. Stakeholder engagement is taking place with the Council for Scientific and Industrial Research (CSIR) to ensure that the process design is compatible with existing South African biogas infrastructure. Thermal modelling of the CMD process will also be conducted, such that sustainable heat sources can be identified and heat recovery maximized. Lastly, an optimal hydrogen purification process will be selected to ensure that the hydrogen produced satisfies stringent hydrogen fuel standards.

Group Involved

Department of Chemical Engineering

Principle Researcher

Prof Prathieka Naidoo (prathiekan@sun.ac.za)

Collaborator

Centre for Scientific and Industrial Research (CSIR)

MICROBIAL PHOTOBIOREACTORS

Background

Microbial photobioreactors are specialized systems designed to harness the metabolic capabilities of microorganisms, such as algae and bacteria, under controlled light conditions. These bioreactors are pivotal in the field of biotechnology for producing biofuels, bioplastics, and other valuable biochemicals. The concept revolves around utilizing light as an energy source to drive photosynthetic and other light-dependent microbial processes. This technology is particularly significant in addressing global challenges such as renewable energy production and environmental sustainability. By converting sunlight into chemical energy, microbial photobioreactors offer a green alternative to traditional chemical processes, reducing reliance on fossil fuels and minimizing carbon footprints. The integration of genetic engineering and advanced materials science has further enhanced the efficiency and scalability of these systems. At SU, researchers are continually innovating to improve the performance and economic viability of photobioreactors, making them a promising solution for sustainable industrial applications.

Current Activities

Under the guidance of Prof Robbie Pott, the research on microbial photobioreactors is advancing rapidly at SU's Chemical Engineering Department. The team is focused on developing novel biotechnology that enhances the efficiency of microbial processes for sustainable bioproducts. Current activities include the design and optimization of photobioreactors, such as continuously stirred reactors as well as tubular photobioreactors for biological hydrogen production. Additionally, they are exploring the immobilization and application of R. palustris, a purple non-sulphur bacterium capable of biological hydrogen production through photofermentation. Current investigations into exploiting natural sunlight as a source of illumination are underway, with the goal of decreasing operational costs of biological hydrogen production by eliminating the need for energy-intensive artificial illumination. Techno-economic analyses are also conducted to assess the current economic viability of state-of-the-art biological hydrogen production through photofermentation. These studies highlight where further research and field advancements are required to improve upon the industrial economic viability of this process. This multi-disciplinary approach combines chemical engineering, molecular biology, and applied microbiology to push the boundaries of bioprocess engineering and contribute to more sustainable industrial practices.

Group Involved

Department of Chemical Engineering: Bioprocess Engineering Group (BPEG)

Principle Researcher

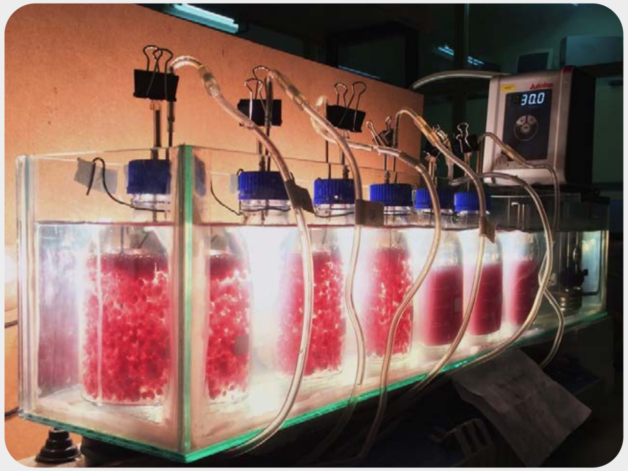
Prof Robbie Pott (rpott@sun.ac.za)

Collaborators

- Exchange collaboration between the University of Padova (Italy) and Stellenbosch University
- University of East Anglia (UK)
- University of Manchester (UK)

Research Outputs

Publications in Fuel, Journal of Biotechnology, Bioprocess and Biosystems Engineering and more.



Top: *Photofermentation using immobilised Rhodopseudomonas palustris Bench-scale.*

Right: *Thermosiphon photobioreactor used for biohydrogen production*

II. STORAGE AND USAGE

Hydrogen integration in biorefineries

Background

A biorefinery is a concept derived from conventional refineries that process various types of biomasses and the biogenic CO_2 derived from them, using thermal, chemical, biological, physical, or combined conversion methods to produce chemicals, biomaterials, advanced biofuels, and innovative food ingredients. Some biorefinery processes for biomass or biogenic CO_2 use hydrogen as a raw material to produce chemicals (e.g. 1,2-propanediol, methanol, sorbitol, methyl tetrahydrofuran, tetrahydrofuran, gamma-valerolactone, 2-methylfuran, cyclohexane, and cyclohexanone), bioplastics (polylactic acid, polyethylene), and sustainable aviation fuels. In addition to providing access to various kinds of biomass materials (molasses, lignocelluloses), sugar mills provide an ideal opportunity for utilization of biogenic CO_2, including fairly pure CO_2 from bioethanol distilleries and less-pure CO_2 from biomass-fired cogeneration systems. When combined with green hydrogen, biogenic CO_2 offers a pathway to decarbonize the chemical and fuel sectors while supporting global energy needs.

Although the aforementioned processing options will benefit financially from the use of low-cost, fossil-based (grey) hydrogen, the replacement of grey hydrogen with green hydrogen to enhance environmental sustainability remains crucial. Sugarcane biorefineries using green hydrogen, typically integrated with sugar mills and associated facilities that produce biogenic CO_2, have shown environmental advantages but often suffer from poorer economic performance due to the increased cost of production. Green hydrogen is typically obtained by either importing or self-producing renewable electricity for electrolysis in these biorefineries; some process residues are also suitable for anaerobic digestion or gasification, followed by reforming and purification of bioderived green hydrogen. Finding markets willing to pay a premium for improved decarbonization potentials of hydrogen-derived products is critical to commercial feasibility of these biorefineries.

Group Involved

Department of Chemical Engineering

Research Output

A. M. Petersen and J. F. Gorgens, "Flowsheet analysis of bio-derived hydrogen as a surplus product at sugar mills and associated biorefineries from processing residues," Int. J. Hydrogen Energy, vol. 49, pp. 225–237, Jan. 2024.

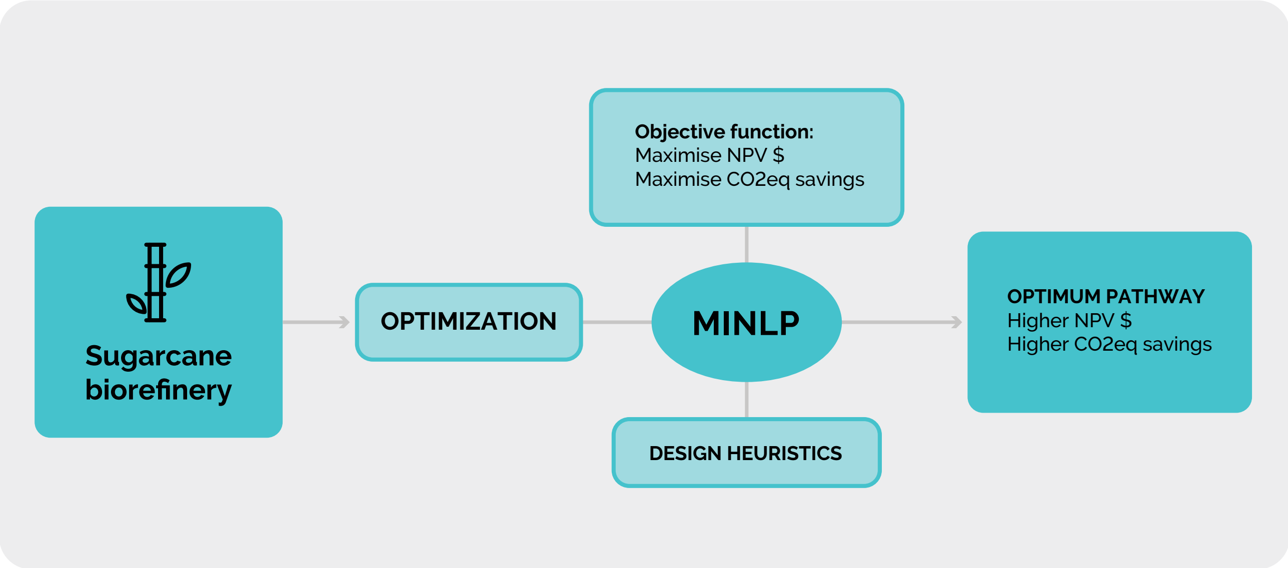
https://doi.org/10.1016/j.ijhydene.2023.07.311

Current Activities

Given these challenges, the **first (current) research project** focuses on optimizing sugarcane biorefinery processes that use biomass materials in combination with green hydrogen and exhibit a trade-off between economic and environmental performance. Mixed-integer nonlinear programming (MINLP) will be used as the optimization strategy to determine an optimal pathway that provides a balance between its economic and environmental performance. This will be carried out by first defining the multi-objective functions, for which the economic objective function may involve maximizing both the net present value (NPV) and the equivalent greenhouse gas emissions savings (measured in CO_2 equivalents) for the environmental objective function. The multi-objective model will be formulated to capture the interactions between these two objectives by incorporating decision variables and constraints that influence both economic and environmental performance. Solutions of a particular process will be determined for a defined number of design scenarios, distinguished by certain processing aspects such as pretreatment and bioconversion methods used, and separation technologies employed. The optimum pathway will reveal a higher NPV for the same or higher equivalent CO_2 emission savings, or alternatively, higher equivalent CO_2 emission savings for the same or higher NPV.

Principle Researchers

Prof Johann Görgens (jgorgens@sun.ac.za),
Dr Jeanne Louw (jeannelouw@sun.ac.za)



Summarized methodology for optimizing sugarcane biorefinery processes using MINLP

The second project entails conducting comparative techno-economic and environmental performance evaluations of a sugarcane biorefinery integrated with biogenic CO_2 conversion with green hydrogen. Using an Aspen Plus® process simulator, several biorefinery processes to produce methanol, sustainable aviation fuel, formic acid, and dimethyl ether are rigorously simulated. Both direct CO_2 hydrogenation and indirect routes via methanol and syngas-mediated steps are explored. The study also compares hydrogen supply options, assessing the use of imported green hydrogen versus on-site production via plant-derived or externally sourced renewable electricity. Capital cost, operating cost, and profitability of scenarios such as minimum selling price will be used to ascertain the differences in the economic performances of various technical variations and configurations. Life-cycle assessment will be used to determine the environmental robustness of the biorefinery scenarios. The quantities and likely market prices for carbon credits (green premiums) will link the environmental and financial aspects of these scenarios. The results would provide valuable insight into the preferred biorefinery configuration, considering process selection that is both financially viable and environmentally beneficial.

Principle Researchers

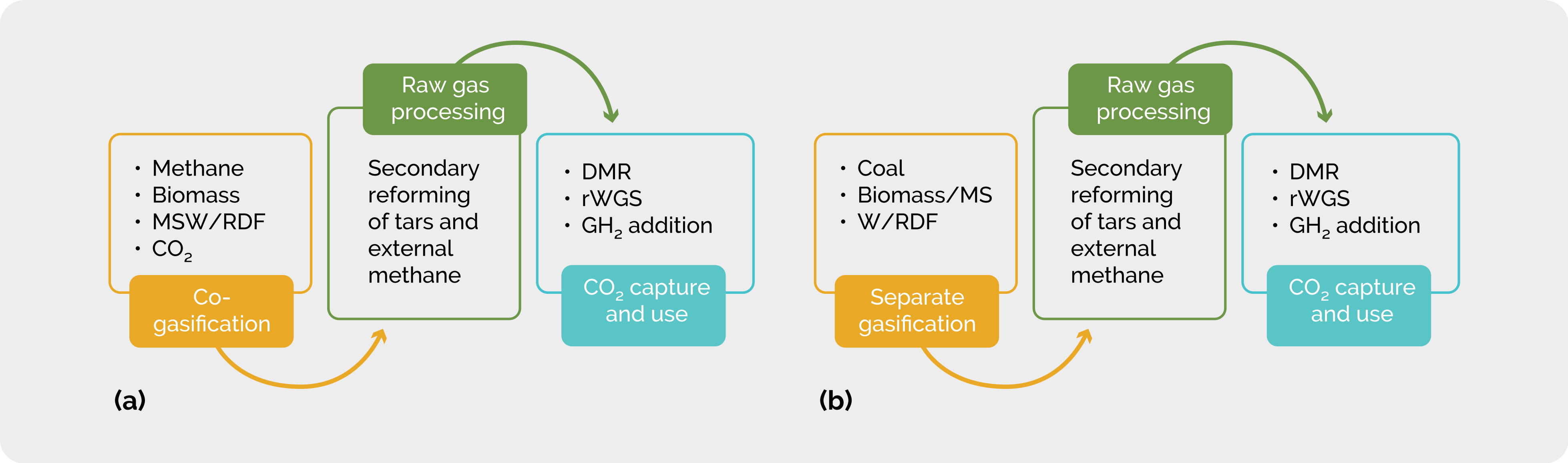
Prof Johann Görgens (jgorgens@sun.ac.za),
Dr Eunice Sefakor Dogbe (esdogbe@sun.ac.za)

A third research activity considers the stepwise, incremental replacement of coal in South African synthetic fuel manufacturing facilities with a range of alternative carbon sources to produce hydrogen-rich syngas. The goal is to propose the most financially and environmentally viable transition from the current use of coal as only gasification feedstock to alternative sustainable carbon-sources and green hydrogen. Aspen Plus® simulation models of a wide range of co-gasification process scenarios are explored for technical, economic, and environmental synergistic benefits. This methodology will account for expected future decreases in green hydrogen costs and expected increases in carbon taxes driven by environmental policies. Subsequently, promising process configurations will be identified for medium- to long-term renewable energy transition.

The gasification scenarios combine the co-gasification of coal with sustainable carbon, steam methane reforming (SMR), dry methane reforming (DMR), and green hydrogen from water electrolysis. Biomass, municipal solid waste and refuse-derived fuel (MSW/RDF), biogas, natural gas, and captured CO_2 are considered for either co-gasification with coal, or separate/dedicated gasification, in a pressurised, fixed-bed updraft, bottom-ash gasifier, as indicated below. The resulting raw gases are combined and undergo a similar co-reforming process in both approaches. A combined steam and dry methane reforming system is proposed, where SMR and DMR are arranged in a series–parallel configuration. The raw gas from the gasifier is co-reformed with methane from natural gas or biogas in SMR unit, producing raw gas that is subsequently cleaned in acid gas removal (AGR) unit. The captured CO_2 is then processed with either methane in DMR or green hydrogen in reverse water gas shift (rWGS) to produce additional syngas that is combined with clean syngas from SMR unit. In the case of green hydrogen addition, hydrogen is mixed with clean syngas from DMR to optimize the H_2/CO ratio, with the green hydrogen produced through water electrolysis powered by renewable electricity.

Principle Researchers

Prof Johann Görgens (jgorgens@sun.ac.za),
Dr Jeanne Louw (jeannelouw@sun.ac.za)



***(a)** Co-gasification and **(b)** separate gasification process integration approach*

Combustion of Hydrogen–Hydrocarbon fuel mixtures

Background

The continued global use of gas turbines in the production of electricity and power is due to the high power-to-weight ratio, operational flexibility, and reliability of these machines. With the advent of renewable fuels, a gas turbine's inherent fuel flexibility can expedite the deployment of said fuels at an industrial scale through the existing infrastructure.

The use of hydrogen has gained interest over the past decade, specifically as green hydrogen, which is a vector for renewable energy. As a pure fuel, hydrogen is well researched within gas turbines, and there are contemporary demonstrations at the micro-gas-turbine (MGT) scale. However, technology to produce green hydrogen is at a low level of readiness, which means that the industrial supply will not meet demand for some time. Therefore, the current research, globally and at SU, is in the use of hydrogen–hydrocarbon mixtures.

Current Activities

This programme investigates the performance and emissions characteristics of gas turbine combustors using clean hydrogen fuels and hydrogen–hydrocarbon mixtures, addressing these key research questions.

Current activities include developing 3D and 1D numerical models of MGT combustors as well as the experimental evaluation of combustor and MGT performance during mixed and hydrogen fuel operation. The programme leverages the CSIR Centre for High Performance Computing (CHPC), an experimental dual-shaft MGT system, advanced diagnostic tools, and a dedicated laboratory for mixed-fuel combustion studies.

The project is led by Mr Chaz Fenner (PhD candidate in Mechanical Engineering), under the supervision of Prof Johan Van der Spuy and Prof Ryno Laubscher. Future work is currently being planned for 2026, involving research into ammonia-fuelled combustors for propulsion, numerical investigations of combustor design methods, and land-based combustors fuelled by hydrogen-methane mixtures.

Group Involved

Department of Mechanical and Mechatronic Engineering

Principle Researcher

Prof Ryno Laubscher (rlaubscher@sun.ac.za)

Research Output

R. Laubscher, P. Rousseau, L. Malan, and E. De Villiers, "Thermofluid process simulation of wet biomass and ammonia co-firing in an industrial watertube boiler," Proc. Inst. Mech. Eng. Part A J. Power Energy, vol. 239, no. 2, pp. 400–416, Mar. 2025

https://doi.org/10.1177/09576509241309040

Biogas Upgrading Programme

Current Activities

This programme aims to investigate the integration of clean hydrogen in biogas upgrading processes, focusing on biomethanation, CO_2 hydrogenation, and methane cracking. The research will contribute to developing renewable and sustainable fuel sources, support waste management, and promote circular economy practices. The programme will explore modular and scalable biogas upgrading units for small-scale operations, enhancing methane production by injecting excess renewable electricity from power-to-gas systems. The research will focus on novel materials and methods for gas separation to enrich methane content and facilitate hydrogen injection, coupling these processes with renewable technologies.

Deliverables include optimized biogas upgrading processes with an experimental test rig, experimental data on integrating clean hydrogen, and scientific publications. The programme will position SU as a leader in sustainable biogas upgrading technologies, contributing to renewable energy generation, waste management, and reducing greenhouse gas emissions. Well-equipped laboratory facilities are essential to achieve these goals, enabling the development of necessary skills and collaborations to advance biogas upgrading with clean hydrogen technology.

Principle Researcher

Prof Prathika Naidoo (prathiekan@sun.ac.za)

Group Involved

Department of Mechanical Engineering

Collaborators

- UCT HySA Catalysis
- Green Cape
- Cape Town Biogas
- Anaergia

Development of a scale-model hydrogen-propelled train

Background

The global transition towards sustainable transportation has increasingly highlighted hydrogen fuel cells as a promising zero-emission alternative for powering various modes of transport, including rail systems. These fuel cells, particularly proton exchange membrane fuel cells (PEMFCs), are recognized for their potential to reduce carbon footprints and support long-term environmental goals. As interest grows, challenges such as optimizing efficiency, ensuring safe on-board hydrogen storage, and extending operational range have become critical areas of focus. This broader context underscores the need for innovative solutions that can demonstrate the feasibility of hydrogen-powered locomotion, paving the way for scalable and eco-friendly rail transport technologies worldwide.

Current Activities

Key activities include (1) designing and selecting subsystems for a 1/3-scale hydrogen powered train, integrating components such as a hydrogen tank or steam-methane reformer, PEM fuel cell, DC/DC converter, battery energy storage, and four permanent magnet DC motors; (2) conducting heat transfer and energy analysis to enhance system performance; (3) sizing the system to optimize hydrogen consumption and improve fuel efficiency; and (4) testing the prototype on a 1–2 km track to evaluate speed, range, and overall performance under real-world conditions. Safety protocols follow NFPA 55 standards, ensuring robust integration and safe operation of all components.

Group Involved

Department of Mechanical and Mechatronic Engineering; Gibela Engineering Research Chair

Principle Researchers

Prof Craig McGregor, Mr Pieter Conradie (pieterc@sun.ac.za)

Collaborator

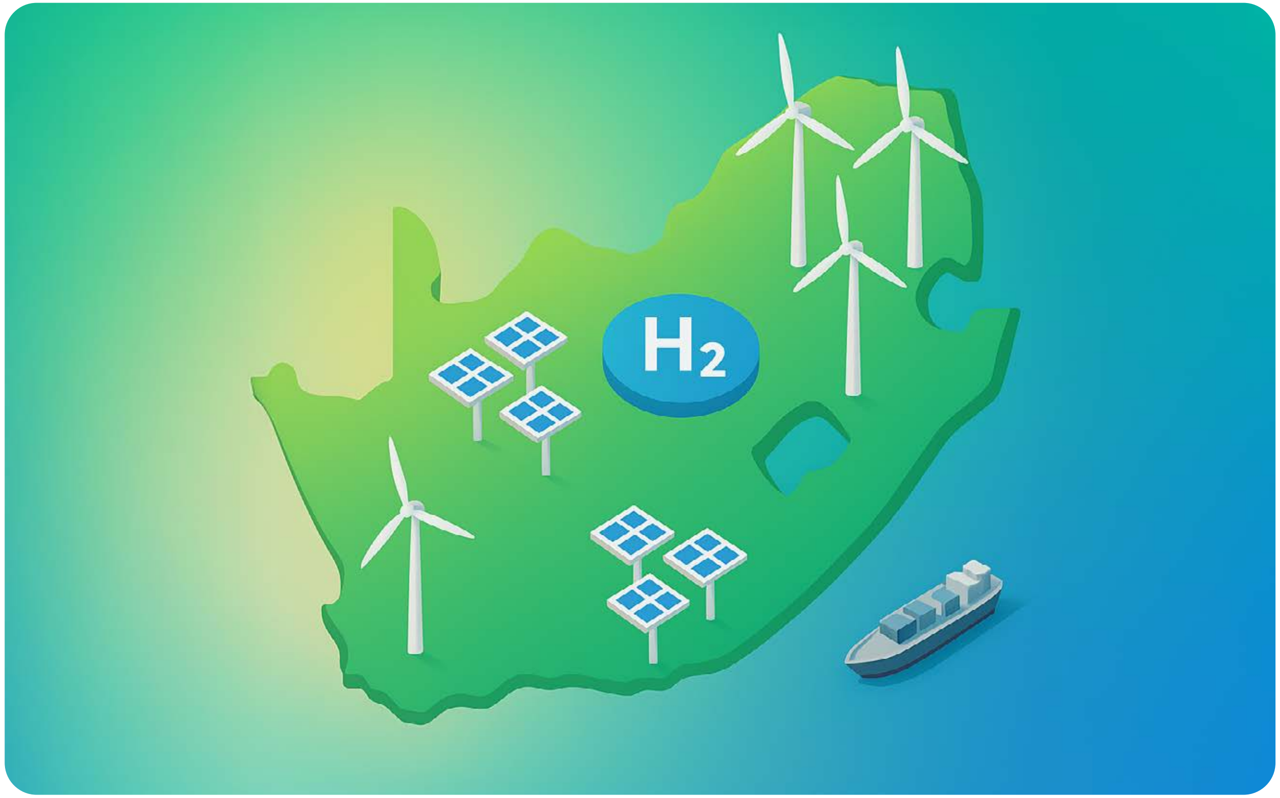
Winelands Light Railway

INFRASTRUCTURE AND SYSTEMS MODELLING OF HYDROGEN ENERGY NETWORKS

POWER-TO-X SYSTEMS INTEGRATION

Background

South Africa's energy system is constrained by aging coal infrastructure, rising fossil fuel import dependence, grid capacity limitations, and increasing pressure from international trade partners adopting carbon pricing mechanisms. However, the country holds several strategic advantages for green Power-to-X (PtX) development, including excellent solar and wind resources, land availability, existing Fischer-Tropsch infrastructure, and a mature iron and platinum mining sector. South Africa is thus well positioned to participate in the emerging green PtX markets by leveraging its natural and industrial strengths. As the global hydrogen shipping trade market is projected to experience substantial growth, export opportunities have been identified alongside domestic demand in hard-to-abate sectors such as iron and steel production, as well as aviation and shipping.



Current Activities

The project, led by Fraunhofer IEE in collaboration with SU's Centre for Renewable and Sustainable Energy Studies (CRSES), evaluates cost-effective and technically viable transformation pathways for the production and utilization of green hydrogen and other PtX products in South Africa, focusing on their role in industrial applications, domestic energy security, and export markets. The research aligns renewable energy expansion with growing domestic and export demand for green electricity, hydrogen, ammonia, and synthetic fuels. The project develops and uses a high-resolution, sector-coupled, open-source energy system model (PyPSA-RSA-Sec) to analyse different PtX adoption scenarios aligned with national policies and plans. Key aims include identifying no-regret investment options, infrastructure requirements, and enabling measures to scale up PtX production and renewable generation capacity. The study also seeks to close knowledge gaps in existing modelling literature, develop open-source tools for future analysis, and support long-term strategic planning for South Africa's evolving energy landscape. To meet future energy and feedstock demands in various sectors across the energy system, different scenarios for renewable energy and PtX expansion are evaluated. As such, the uncertainties of South Africa's energy transition can be explored, trade-offs assessed, and critical enablers identified, while being aligned with its climate and green hydrogen ambitions.

Group Involved

Centre for Renewable and Sustainable Energy Studies

Principle Researchers

Storm Morison, Prof Bernard Bekker (Centre for Renewable and Sustainable Energy Studies)

Collaborator

Agora Industry, GIZ

Publication

Fraunhofer IEE, Agora Industry, Stellenbosch University (2024). Power-to-X Allocation Study for South Africa: Power-to-X to enable and advance the long-term transformation of South Africa's Energy System. PtX Hub. Available at: https://ptx-hub.org/publication/ptx-allocation-study-south-africa/

INFRASTRUCTURE & CAPACITY DEVELOPMENT

Laboratory upgrades

The Department of Mechanical and Mechatronic Engineering has initiated extensive laboratory upgrades to establish world-class facilities dedicated to hydrogen research and development.

Dedicated hydrogen research workspace

Our newly established dedicated workspace for hydrogen research provides a specialized environment for both electrolysis and fuel cell investigations. The facility incorporates advanced gas detection sensors and safety systems designed specifically for hydrogen research.

High-current electrochemical impedance spectroscopy

The laboratory has acquired a Gamry Reference 3000 potentiostat with 30K booster, delivering exceptional performance for fuel cell and electrolyser characterization:

Key Capabilities

- High-current testing up to ±30 Amps with 300 kHz bandwidth
- Electrochemical Impedance Spectroscopy (EIS) measurements from 10 μHz to 300 kHz
- Precision measurements in the nano-ohm range for low-impedance devices
- Microsecond-level current pulses for advanced testing

Research Applications

This instrumentation enables PEM electrolyser and fuel cell research, including performance optimization using novel catalyst materials, durability assessment through accelerated testing, investigation of different porous transport layers, and diagnostic analysis to identify rate-determining steps. EIS provides non-destructive, real-time insights into electrochemical processes, allowing researchers to separate and quantify phenomena such as membrane resistance, charge transfer kinetics, and mass transport limitations – supporting high-impact publications and graduate research projects.

Industrial-Scale PEM Electrolyser

Through collaboration with the University of Cape Town, we have access to a **Hogen Series 2 S40 PEM electrolyser.**

Specifications:

- Hydrogen production: 1.05 Nm^3/h at 99.999+% purity
- Delivery pressure: 13.8 barg
- Power consumption: 6.7 kWh/Nm^3 of hydrogen produced
- Load-following technology for variable power input research

Research Impact: This industrial-scale platform enables scale-up studies, system integration research, and performance benchmarking against commercial standards. The UCT collaboration creates opportunities for joint research projects and shared expertise, enhancing publication potential and industry partnerships.

Upgraded Hydrogen Combustion Laboratory

The combustion lab features new testing infrastructure including:

- Advanced fuel delivery systems with new piping designed for hydrogen
- State-of-the-art gas analyser for real-time combustion product monitoring
- Comprehensive temperature monitoring systems
- Enhanced safety systems with integrated gas detection

These upgrades support research into hydrogen combustion characteristics and clean combustion technologies, enabling undergraduate and graduate research projects with direct industry applications.

Research outcomes and partnerships

The upgraded facilities support:

- **Academic Excellence:** Journal publications, conference presentations, and graduate thesis projects
- **Industry Collaboration:** Technology validation, consulting opportunities, and student internships with hydrogen technology companies
- **Student Training:** Hands-on experience with industrial-standard equipment and advanced analytical techniques essential for careers in the growing hydrogen industry

These investments position H_2GEN as a recognized centre of excellence in hydrogen research, creating opportunities for meaningful contributions to clean energy technology development.

Educational impact

H_2GEN is committed to advancing hydrogen education and research through comprehensive educational programmes. Our educational impact encompasses both formal learning opportunities and cutting-edge research initiatives that prepare students and professionals for the emerging hydrogen economy.

Through the CRSES, specialized short courses designed for industry professionals and researchers are offered, while the H_2GEN research programme provides extensive opportunities for undergraduate and postgraduate students to engage in pioneering hydrogen research. These programmes bridge the gap between academic knowledge and practical application, ensuring that graduates are equipped with the necessary skills to drive South Africa's transition to a sustainable hydrogen future.

Short course programmes

The CRSES currently offers two short courses on hydrogen technologies, designed for industry professionals, government officials, students, young academics, and researchers seeking to understand the role of hydrogen in energy transition. These courses attract participants from across Africa and around the world:

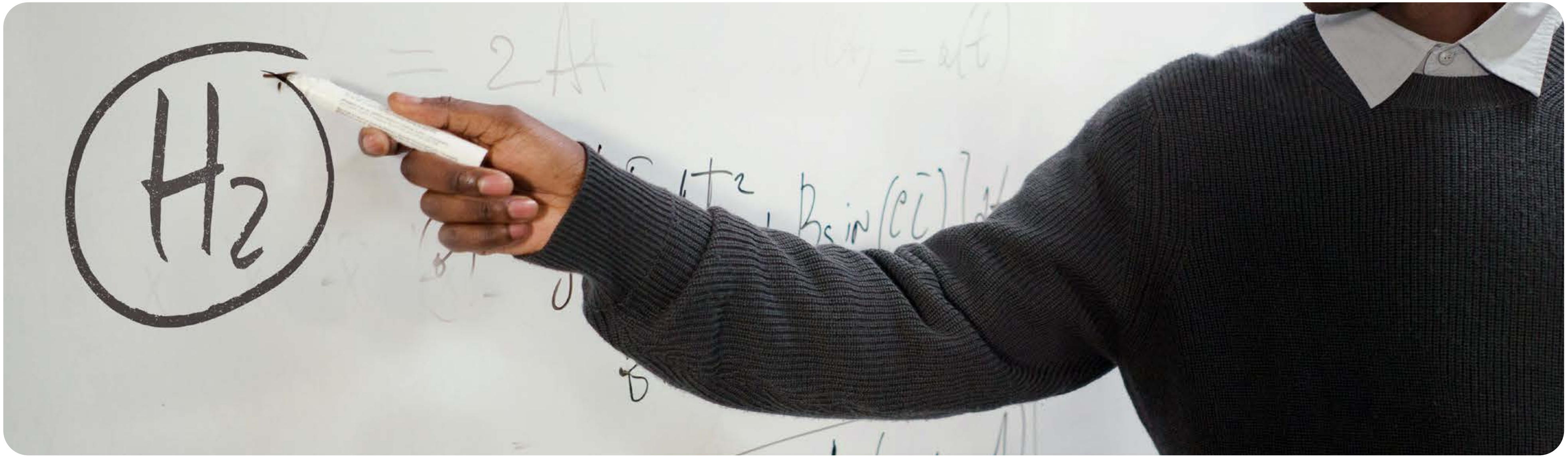
- **Hydrogen in the Energy System:** A systemic view of energy systems with a specific focus on hydrogen.
- **Green Hydrogen Project Engineering:** Combining the available and developing technologies for green hydrogen production, distribution, storage, and end-use with the principles of designing, funding, and successfully implementing fit-for-purpose green hydrogen projects.

For more detailed information, please visit the CRSES website: https://www.crses.sun.ac.za/short-courses/

Research projects

H_2GEN offers multiple opportunities for research projects to students in their undergraduate or postgraduate (MSc or PhD) studies from various disciplines, including chemical, mechanical, electrical and industrial engineering, chemistry, energy system studies, economics and data science. Students have the option to conduct external research projects at industrial companies or collaborate with international partners under the supervision of one of our researchers. Through these partnerships with industry and international institutions, students gain real-world experience that enhances their employability in the rapidly growing hydrogen sector.

For more information on partnership opportunities, available student projects, or to discuss collaboration, please contact Paul Thiele (H_2GEN Programme Coordinator) at h2gen@sun.ac.za or the direct contact of the respective research field you are interested in.



GET IN TOUCH

General inquiries:
h2gen@sun.ac.za

Program director:
Prof Craig McGregor
craigm@sun.ac.za

Program coordinator:
Paul Thiele
pault@sun.ac.za

Fraunhofer

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