Unlocking Clean Aviation in Africa: Challenges to localising Hydrogen Aviation Propulsion in South Africa

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Abstract:

The global aviation industry has adopted ICAO's Long-Term Aspirational Goal (LTAG) to achieve net-zero emissions by 2050. Hydrogen fuel cell propulsion is recognised as a key enabler of zero-emission aviation. While South Africa has strong potential for green hydrogen production due to its renewable energy resources, the country does have challenges in localising hydrogen aviation propulsion technologies. This paper explores these challenges through the CSIR's H2UAV project, which is a hydrogen powered long-endurance unmanned aerial vehicle (UAV) designed to localise aviation hydrogen propulsion expertise, demonstrate hydrogen propulsion feasibility, and support a roadmap toward decarbonisation in aviation. Challenges identified include underdeveloped regulatory frameworks, limited early-stage funding, infrastructure inefficiencies, and a shortage of aerospace product development expertise. This study draws on global hydrogen aviation trends and proposes mechanisms for overcoming these obstacles in emerging economies like South Africa to boost the implementation of low carbon aviation propulsion technologies.

Keywords: Hydrogen fuel cells; Technology development; Aviation.

1. Introduction

In 2022, the International Civil Aviation Organization (ICAO) adopted the Long-Term Aspirational Goal (LTAG), targeting net-zero carbon emissions for international aviation by 2050 (International Civil Aviation Organization, 2022). Africa's aviation sector operates in a global market and will face increasing regulatory pressure to align with global efforts to meet this goal. This net-zero commitment has increased global investment in multiple sustainable propulsion system alternatives including Sustainable Aviation Fuels (SAF), hydrogen propulsion, as well as electric and hybrid-electric propulsion due to their potential to reduce operational emissions (Roland Berger, 2020). SAF is the most mature alternative, but it currently accounts for less than 1% of global aviation fuel due to high costs and limited production. Efforts to implement SAF in Africa are progressing, with pilot production facilities under development in countries such as South Africa and Ethiopia, and several African airlines conducting demonstration flights using SAF blends (Abate, Malina, & Gonca, 2025).

South Africa has been responding to the global imperative to decarbonise with various initiatives. One of these is the Hydrogen Society Roadmap (Department of Science and Innovation), a strategic plan to develop "an inclusive, sustainable and competitive hydrogen economy by 2050". One of the outcomes of this plan includes the decarbonisation of transport sectors, or which air mobility is one. The Roadmap has initiated projects to produce and export hydrogen. In response to this Roadmap and to galvanise work on aviation applications of hydrogen, the Council for Scientific and Industrial Research in South Africa (CSIR) started the development of H2UAV to demonstrate the feasibility of hydrogen fuel cell propulsion in long-endurance unmanned aerial vehicles (UAVs). This technology-push approach addresses operational needs in infrastructure-limited regions, such as border patrol and pipeline monitoring.

Despite this progress, technology development projects such as hydrogen propulsion systems in South Africa faces barriers. Funding mechanisms for early-stage development are inadequate, leading to interruptions in project continuity. Public procurement requirements inflates the cost of infrastructure acquisition. Regulatory frameworks lacks specific guidance for novel propulsion systems. Unlike the EU and the USA, where regulators have implemented experimental aircraft categories and aviation sandboxes, South African developers operate without formal support for certification of hydrogen systems. The absence of domestic regulatory sandboxes for UAVs contrasts with international efforts such as the UK CAA's 2024 Hydrogen Sandbox initiative, which facilitates controlled experimentation to guide certification pathways (UK Civil Aviation Authority, 2025).

From a technical perspective, hydrogen fuel cells offer a higher energy density compared to batteries, making them suitable for UAV applications requiring long-range, endurance, and flexible deployment. Research shows that fuel cell systems provide significant performance benefits over conventional battery-electric systems, especially in multi-rotor drone configurations (Qadir, Ahmad, Ali, Jan, & Khan, 2022).

The availability of experienced aerospace product development engineers is also limited in South Africa. The H2UAV project relies on expertise from defence-related developments, highlighting the need for cross-sector knowledge transfer. These constraints reduce South Africa's ability to develop and scale hydrogen propulsion systems efficiently. This paper builds on earlier work by (Jamison, Naidoo, & Ramotsabi, 2022), which presented the initial technical rationale for hydrogen UAV development in the country.

Conventional aircraft propulsion systems rely on carbon-based fuels, which release carbon dioxide during combustion and contribute significantly to greenhouse gas emissions. Hydrogen gas offers an alternative energy source that, depending on its source, can achieve zero carbon emissions. In aviation, hydrogen can be utilised in two primary ways:

- Combustion – Burning hydrogen in a modified turbine or piston engine.
- Electrochemical conversion – Using hydrogen in a fuel cell to produce electricity through an electrochemical reaction.

Fuel cells used in aviation are typically proton exchange membrane (PEM) fuel cells or solid oxide fuel cells (SOFCs). PEM fuel cells are more common in aircraft and UAV applications because of their lower operating temperatures and faster start-up times, while SOFCs, which operate at much higher temperatures, are mainly found in specialised aerospace applications, such as space vehicles, due to their high efficiency and fuel flexibility.

In hydrogen combustion, a gas turbine or piston engine is modified to burn hydrogen instead of kerosene. Hydrogen is injected into the combustor, mixed with compressed air, and the fuel-air mixture is ignited, producing high pressure and high temperature gases. The gases expand through the turbine stages to spin the blades and generate thrust in a gas turbine engine or push the piston to produce mechanical power.

Beyond the propulsion sub-systems, hydrogen aviation readiness depends on the supporting infrastructure and operational environment. Airport support for hydrogen systems including storage, distribution, and refuelling is in early stages of development globally. A 2023 review (Bicer, Dincer, Vezzu, & Agostini, 2023) of seven major international airports found no fully implemented hydrogen flight support programmes and significant planning gaps in land use, airside development, utilities, safety protocols, and personnel training. These gaps indicate that the next 5–10 years are critical for infrastructure deployment if hydrogen propulsion is to scale for commercial service by the mid-2030s.

Understanding these propulsion methods is essential when examining the barriers to localising hydrogen aviation technology in South Africa. The choice between combustion and fuel cell systems affects infrastructure requirements, regulatory pathways, supply chain needs, and skills development.

According to Air Transport Action Group (ATAG), global air travel passengers were predicted to grow to approximately 5 billion in 2024, which is an increase of approximately half a billion compared to 2023 (Eurocontrol, 2025). The majority of this growth in air travel will occur in regions with emerging economies, including Africa which is projected to see international traffic increase 5% annually until 2043 (Eurocontrol, 2025). According to Eurocontrol (Eurocontrol, 2025), aviation already supports 1 in every 20 jobs in Africa and the growth of aviation traffic to emerging economies will bring in growth in many sectors including boosting tourism. There is an environmental cost coupled with the increased growth, in 2023, airlines emitted over 880 million tonnes of CO_2, which is approximately 2% of global emissions (Eurocontrol, 2025).

For Africa and South Africa, responding to the International Civil Aviation Organization's (ICAO) Long-Term Aspirational Goal (LTAG) of net zero carbon emissions by 2050 is not only an environmental imperative but also an economic opportunity. Investments in Sustainable Aviation Fuel (SAF), which can reduce lifecycle greenhouse gas emissions by up to 80% compared to conventional carbon fuel, position African nations to become suppliers in the global energy transition while reducing dependence on imported fossil fuels (IATA, 2025). Aligning with global decarbonisation goals also ensures market access in an industry that is under pressure to comply with the regulations.

Aviation is one of the sectors that are hardest to decarbonise. Despite increasing fuel efficiency and other mitigations, aviation's share to transport carbon emissions could rise to 40% by 2050 (International Energy Association (IEA), 2020).

SAF and hydrogen propulsion represent complementary pathways to achieving LTAG goals. SAF can be integrated into existing aircraft and airport infrastructure, enabling near-term emissions reductions, while hydrogen propulsion, particularly fuel cell systems for UAVs and short-range aircraft, offers a true zero-operational-emissions solution for the medium to long term. The H2UAV project positions South Africa to capture early experience in hydrogen integration, system safety, and operations, providing a knowledge base that can be expanded into wider aviation applications.

South Africa's the Hydrogen Society Roadmap (HSRM) (Department of Science and Innovation) and a Green Hydrogen Commercialisation Strategy signal its intent to leverage abundant renewables and PGM advantages for electrolyser and fuel-cell value chains (Cassidy, 2023). Multiple green-hydrogen projects and local fuel-cell firms exist (e.g., Isondo, Mitochondria Energy, Cape Stack, Bambili HyPlat), but several flagship initiatives remain in early stages and face infrastructure and financing challenges (Cassidy, 2023). In contrast, some regions are creating hydrogen aviation sandboxes and pre-certification pathways (e.g., UK CAA Hydrogen Challenge), underscoring the value of regulatory learning-by-doing that South Africa could emulate to accelerate aviation-specific hydrogen deployment (UK Civil Aviation Authority, 2025).

Globally, countries such as Germany, Japan, and the United States are advancing hydrogen aviation technologies through coordinated investments between government, industry, and academia. These efforts are supported by national hydrogen roadmaps, dedicated experimental aircraft programmes, and pre-certification regulatory pathways. By contrast, South Africa's hydrogen aviation innovation system is still in its formative stages. The country has advantages, such as abundant renewable energy resources, substantial platinum group metal reserves for PEM fuel cell catalysts, and increasing global interest in green hydrogen exports, but faces significant barriers in localising hydrogen propulsion for aviation applications.

The H2UAV project plays a critical role as a technology demonstrator. By integrating hydrogen fuel cell propulsion into a long-endurance unmanned aerial vehicle, the project stimulates local capabilities in propulsion/aircraft systems integration, safety procedures, and operational adaptation for infrastructure-limited environments. This positions South Africa to incrementally close the innovation gap with leading hydrogen aviation nations while tailoring solutions to the continent's specific operational and economic needs.

2. Methodology

This paper adopts a qualitative case study methodology to investigate the challenges to aviation hydrogen propulsion development in South Africa, an emerging economy. The research purpose is to use the authors' experience of developing a hydrogen UAV propulsion system as a case study, namely the CSIR's H2UAV program. This practical perspective provides unique insights into the challenges that arise when introducing a complex, safety critical technology development in an ecosystem that does not have the capacity to support it.

The H2UAV project, which integrates a hydrogen fuel cell propulsion system into a long endurance unmanned aerial vehicle, serves as a representative case for identifying gaps in South

Africa’s technological, regulatory, and industrial landscape. The project was selected because it is one of the first attempts to localise hydrogen aviation propulsion capabilities in the country, making it directly relevant to both national innovation policy and global decarbonisation goals.
Data sources for the analysis include:

- Project documentation and design records
- Internal design and testing reports
- National hydrogen and aviation policy frameworks
- Peer-reviewed technical literature on hydrogen aviation technologies and innovation systems in emerging economies; and
- Input from participating in a national working group tasked with establishing an unmanned aerial vehicle (UAV) regulatory sandbox in South Africa. This involvement provides primary, practice-based insight into regulatory readiness, stakeholder engagement, and policy development processes relevant to novel propulsion certification.

The study examines multiple interrelated domains that influence the viability of hydrogen propulsion systems in South Africa. These include:

i. Early-stage funding access and investment continuity

ii.. Regulatory readiness and the absence of pre-certification or experimental frameworks.

iii. Infrastructure and public procurement constraints.

iv. The availability of specialised engineering expertise in product and systems development.

v. National policy alignment with global decarbonisation targets.

vi. Supply chain readiness and local manufacturing capabilities.

vii. Knowledge generation and institutional learning.

viii. Safety and risk governance for emerging aviation technologies.

The analysis of these domains enables the identification of systemic gaps, interdependencies, and leverage points for policy intervention. By combining project-level insights with broader policy and literature-based evidence, including knowledge from ongoing regulatory reform efforts, the study develops evidence-based recommendations for strengthening South Africa’s capability to develop, certify, and scale hydrogen aviation propulsion technologies. The methodological approach is designed to ensure the findings are relevant both to South Africa and to other emerging economies seeking to participate in the global clean aviation transition.

3. Discussion

This section discusses the challenges found in hydrogen propulsion technology development in South Africa, organised according to the eight domains identified in the methodology. Each challenge is examined in the context of the CSIR’s H2UAV project, with reference to comparable challenges documented in the literature.

3.1 Early-Stage Funding Access and Investment Continuity

The H2UAV project has been constrained by limited early-stage funding, with annual internal allocations for propulsion development seldom exceeding ZAR 1 million. In 2023/2, a larger ZAR 2 million allocation for running costs enabled procurement of fuel cells and onboard storage, yet these funds remained insufficient for sustained development and operational testing. This reflects the broader “valley of death” observed in technology development projects between technology readiness level (TRL) 4–6, where high development costs and uncertain market returns deter both public and private investment.

At CSIR H2LEMU which was dependent on a runway for take-off and landing, was the original technology development project with a purpose of proving hydrogen propulsion in flight. This project stalled when the UAV team was poached to join another UAV company. The project was rebooted with a new team, shifting to the fixed-wing VTOL H2UAV was informed by a market survey, which indicated strong commercial interest in UAVs with long endurance (10 hours), runway-independent operation and low noise signature. Similar market-responsive pivots have been crucial in European hydrogen aviation projects, where demonstrators with clearer commercial applications have been prioritised for co-funding. However, even with improved market alignment, risk averse investors have remained reluctant to commit to low TRL aviation projects.

3.2 Regulatory Readiness and the Absence of Pre-Certification Frameworks

South Africa currently does not have a regulatory framework for experimental hydrogen propulsion systems in UAVs. This absence creates uncertainty in planning test flights and delays in securing operational authorisation. It also does not have suitable test-flying sandboxes for non-military UAVs to perform highly experimental tests (although arrangements can be made to use, at high cost, military test ranges in very remote locations of the country).

The CSIR's participation in a national UAV regulatory sandbox working group highlights a possible pathway to address this gap. Internationally, sandbox initiatives, such as the UK CAA's Hydrogen Aviation Sandbox (UK Civil Aviation Authority, 2025) and EASA's Special Conditions for hybrid and fuel cell aircraft (EASA, 2021) have facilitated structured experimentation in low-risk environments while guiding the development of safety and certification standards. Without a sandbox framework, South African UAV developers must get approval from the regulatory bodies on a case-by-case basis, increasing costs and extending timelines.

3.3 Infrastructure and Public Procurement Constraints

Hydrogen propulsion testing requires specialised infrastructure for storage, refuelling, and safe operation. In the H2UAV project, the estimated ZAR 700,000 cost of equipping a dedicated hydrogen lab was avoided by using facilities from another CSIR research group. While cost-effective in this case, private sector developers without access to shared infrastructure would face prohibitive entry barriers.

Further challenges included the need for a high-pressure booster pump to fill 350 bar cylinders from available 200 bar storage and access to high-flow compressors, which was achieved by temporarily repurposing wind tunnel infrastructure. Such infrastructure is not readily available outside research institutions, underscoring the capital intensity of hydrogen projects at low TRLs.

Procurement under South Africa's Public Finance Management Act (PFMA) also introduces inefficiencies. Components often had to be purchased through third-party suppliers at higher prices, and procurement lead times were extended by bureaucratic approval processes. Similar procurement-related bottlenecks have been documented in other state-led technology programmes in South Africa.

3.4 Availability of Specialised Engineering Expertise

The H2UAV project's propulsion team initially lacked direct experience with hydrogen fuel cell systems, requiring months to acquire operational knowledge through hands-on testing. This learning by doing process included diagnosing failures such as a burnt PCB in the fuel cell-battery switching unit and repairs complicated by supply chain delays during the COVID-19 pandemic.

The onboarding of new staff without prior experience in systems engineering further delayed the programme, taking nearly a year to reach a System Concept Review. Such skill gaps are consistent with findings from the African Innovation Outlook, which notes that shortages in specialised engineering disciplines can slow innovation cycles and increase dependency on foreign expertise (African Union Development Agency (AUDA-NEPAD), 2024).

3.5 National Policy Alignment with Global Decarbonisation Targets

While South Africa’s Hydrogen Society Roadmap recognises green hydrogen as a strategic priority, its emphasis is on export potential and industrial applications such as heavy transport and synthetic fuels. Aviation-specific hydrogen applications receive little direct policy support, in comparison to sustainable aviation fuel (SAF), which benefits from coordinated development programmes.

This policy gap stands in contrast to the European Union’s ReFuelEU Aviation Initiative, which integrates hydrogen propulsion into its decarbonisation strategy and includes funding and regulatory mechanisms to support its adoption (European Commission, 2023). Without similar integration into national policy, hydrogen aviation in South Africa risks being overshadowed by sectors perceived as more immediately market ready.

3.6 Supply Chain Readiness and Local Manufacturing Capabilities

All aviation grade hydrogen propulsion components for H2UAV, including fuel cells and storage cylinders, were imported from international suppliers. This reliance on foreign manufacturing not only increased costs due to the rand’s exchange rate volatility but also exposed the project to variability in after sales support.

While some fuel cells performed to specification with strong technical support, units from another supplier suffered persistent performance and thermal management issues, with inadequate resolution from the supplier. This supply chain fragility compared to findings that emerging economies are often “technology takers” in hydrogen sectors, with limited capacity for domestic manufacturing or adaptation to local requirements (Cassidy, 2023).

3.7 Knowledge Generation and Institutional Learning

The H2UAV project shows the critical role of effective knowledge generation in emerging technology adoption, particularly in low funded projects where every design iteration and operational lesson must deliver value. The development of in-house expertise in operating and characterising hydrogen fuel cells, from the safe handling of high-pressure hydrogen to integration in UAVs has become a significant intangible asset for the continuation of this project and future projects.

In the absence of original equipment manufacturing (OEM) led training programmes, mature certification processes, or an established local support ecosystem, this knowledge had to be built from the ground up. Iterative testing, troubleshooting, and component level experimentation were the only viable pathways to capability development. While this approach developed deep technical understanding within the team, it also required substantial time and resource investment that could have been reduced if South Africa had a hydrogen aviation innovation ecosystem with accessible best practices, shared facilities, and specialist training resources.

3.8 Safety and Risk Governance

Hydrogen’s high flammability demands stringent safety protocols for its storage, handling, and operation. Its ignition energy is extremely low, meaning it can be ignited by even small static discharges. When hydrogen burns, the resulting flame is nearly invisible in daylight, which increases the risk of undetected fires and potential injury. These characteristics necessitate comprehensive hazard monitoring, robust leak detection systems, and rigorous adherence to operational safety procedures when integrating hydrogen propulsion into aviation platforms.

South Africa currently does not have regulations for the use of hydrogen in UAVs, and approval processes for such systems remain undefined. This regulatory uncertainty poses risks not only for H2UAV but for any domestic programme seeking to test hydrogen propulsion in flight. ICAO has emphasised the importance of harmonised global standards to enable the safe integration of hydrogen technologies into aviation.

3.9 Way forward

Addressing the challenges identified in this study requires a coordinated approach that combines targeted policy enhancements, infrastructure investment, capacity building, and strategic partnerships. The following recommendations outline a pathway for advancing hydrogen aviation propulsion development in South Africa, informed by the lessons learned from the H2UAV project and aligned with international best practices.

South Africa should create a regulatory sandbox for prototype UAVs that accommodates a broad range of novel designs and propulsion technologies. Such a sandbox would provide a safe and controlled testing environment for UAVs that are outside existing certification categories, enabling developers to validate designs, gather safety and performance data, and refine systems prior to commercialisation. This would benefit projects like H2UAV as well as other innovative UAV programmes, fostering an ecosystem where novel technologies, whether hydrogen, hybrid-electric, or other, can mature toward market readiness. International examples, such as the UK CAA's sandbox framework, demonstrate that flexible, technology-agnostic regulatory pathways can accelerate both product innovation and commercial deployment (UK Civil Aviation Authority, 2025)

From the authors' experience, existing government funding sources generally prioritise projects with low-risk market strategies and shorter timelines to commercialisation. Hydrogen propulsion for aviation is a niche product, has a longer development period and higher technical risk and dependency on regulatory readiness, struggles to secure sufficient support. Compared to established aviation economies, South Africa cannot realistically replicate large-scale grant programmes designed for mature industries in Europe or the United States. Instead, a more practical approach is to establish smaller, targeted funding streams that focus on application-specific development with short turnaround times. These bridge the critical gap between the fundamental research currently supported through initiatives such as Hydrogen South Africa (HySA) and the applied, system-level integration work required to demonstrate feasibility in real UAV platforms. By financing projects that make use of commercial off the shelf (COTS) components, even if they are at lower maturity levels, researchers can rapidly identify technical bottlenecks, generate operational knowledge, and feed lessons learned back into the fundamental research community. Such an approach would not only derisk early-stage development but also accelerate the creation of a domestic innovation ecosystem, where insights from application pilot projects will inform long-term investments in localised fuel cell and storage technologies.

4. Conclusion

Hydrogen propulsion development for aviation in South Africa represents both a technological opportunity and a strategic challenge. The H2UAV project demonstrates that it is possible to adapt and integrate hydrogen fuel cell systems into a long-endurance UAV platform within an emerging economy context. However, the experience also reveals systemic challenges from limited early-stage funding and regulatory uncertainty to infrastructure constraints, supply chain dependencies, and gaps in specialised engineering expertise.

These challenges are not unique to South Africa but are magnified in markets where the innovation ecosystem for aviation is still developing. While South Africa possesses strong renewable energy resources and a hydrogen research base through initiatives such as HySA, the transition from fundamental research to application remains underfunded and under-supported. Bridging this gap will require targeted policy interventions, infrastructure investment, and the creation of regulatory mechanisms that enable safe, iterative testing of novel UAV designs.

The findings from this study underline the importance of institutional learning, strategic partnerships, and a phased approach to technology readiness. Integrating commercially available but immature hydrogen propulsion components into operational platforms can provide valuable feedback to both fundamental research and policy development.

As the global aviation sector accelerates toward ICAO's Long Term Aspirational Goal of net zero emissions by 2050, South Africa's ability to localise hydrogen aviation technologies will depend on its capacity to align technical innovation with market needs, regulatory frameworks, and a supportive funding environment. By addressing the identified barriers, South Africa can position itself not only as an adopter but also as a contributor to the growing global market for zero-emission aviation technologies, ensuring that projects like H2UAV serve as a foundation for broader national capabilities in clean aerospace propulsion.

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