International PtX Hub

On behalf of:
Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

IKI International Climate Initiative

Implemented by
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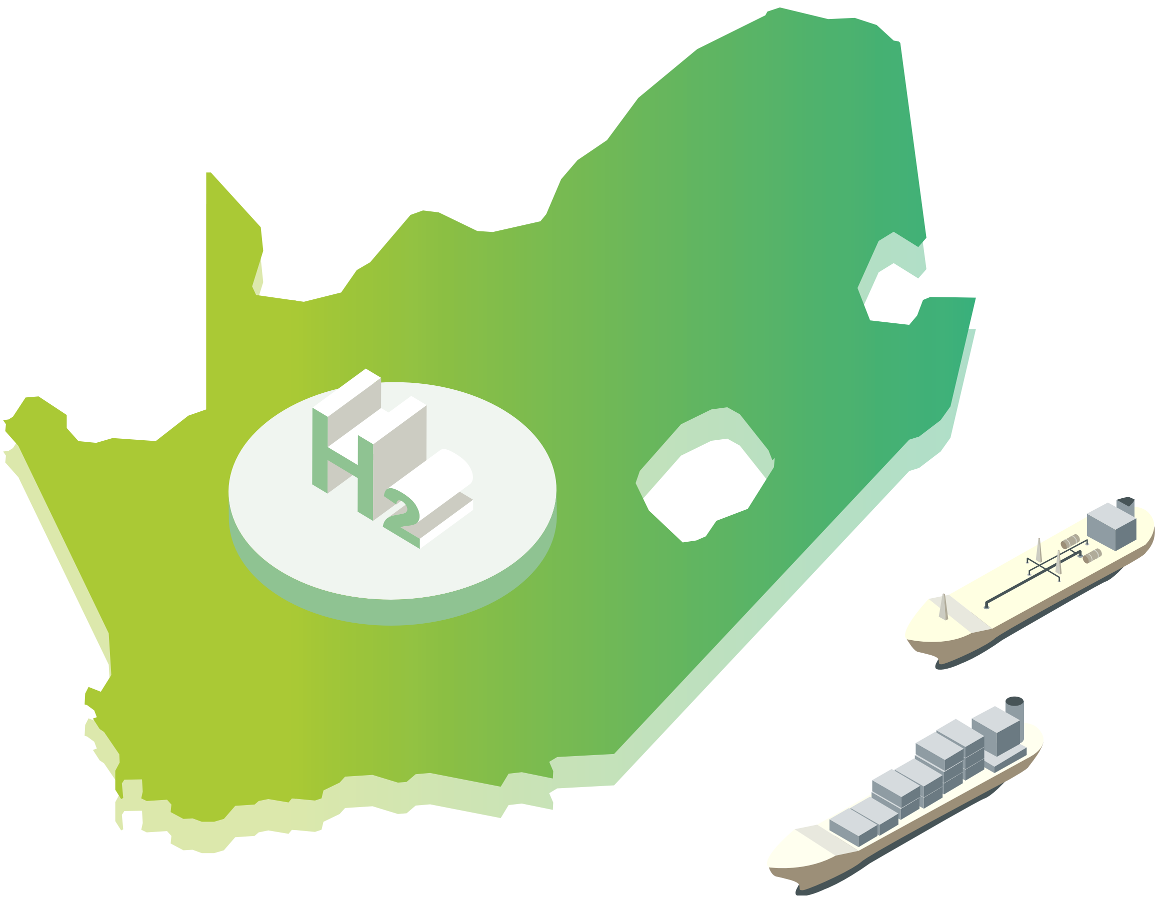
Green Hydrogen in South Africa

Strategic Enablers for a Sustainable and Competitive Economy



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Pretoria, November 2025

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Author Organisations:

Council for Scientific and Industrial Research (CSIR)
Established through an Act of Parliament in 1945, the CSIR is a leading scientific and technology research organisation that researches, develops, localises and diffuses technologies to accelerate socioeconomic prosperity in South Africa. The organisation plays a key role in supporting public and private sectors through directed research that is aligned with the country's priorities, the organisation's mandate and its science, engineering and technology competences

Agora Energiewende
Founded in 2012 by Stiftung Mercator and the European Climate, Agora is a non-profit think tank. Under the umbrella of the Agora Think Tanks, Agora Energiewende, Agora Industry and Agora Agriculture work on the transformation towards climate neutrality, in close collaboration with their sister organisation Agora Verkehrswende. Its mission is to develop scientifically sound and politically feasible ways to make existing energy systems clean and sustainable.

Deutsche Gesellschaft für Chemische Technik und Biotechnologie (DECHEMA)
Founded in 1926, DECHEMA is a non-profit professional society that serves as an expert network for chemical engineering and biotechnology. With more than 5 500 individual and institutional members, it promotes scientific and technical exchange across disciplines, organisations and generations.

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ABBREVIATIONS

AGHA	African Green Hydrogen Alliance
CAPEX	Capital Expenditure
CBAMs	Carbon Border Adjustment Mechanisms
CGH_2	Compressed Gas
CO_2	Carbon dioxide
DRI	Direct Reduced Iron
EECS	European Energy Certificate System
ELTs	End-of-Life Tyres
EIA	Environmental Impact Assessment
FLH	Full Load Hours
FPIC	Free, Prior, and Informed Consent
FT	Fischer-Tropsch
GCCA	Generation Connection Capacity Assessments
GFI	GHG Fuel Intensity
GH_2	Green Hydrogen
GHCS	Green Hydrogen Commercialisation Strategy
GHG	Green House Gas
GTL	Gas-to-Liquid
H2	Hydrogen
HSRM	Hydrogen Society Roadmap
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
JET	Just Energy Transition

JET IP	Just Energy Transition Investment Plan
LCOH	Levelised Cost of Hydrogen
LH2	Liquefied Hydrogen
LOHC	Liquid Organic Hydrogen Carriers
LTAG	Long-term Global Aspirational Goal
MEGC	Multiple Element Gas Container
NDC	Nationally Determined Contribution
NH3	Ammonia
UN	United Nations
PGM	Platinum Group Metals
R&D	Research and Development
RECSA	Renewable Energy Certificate System of South Africa
RECs	Renewable Energy Certificates
PtX	Power-to-X
RWGS	Reverse Water-gas Shift
SABS	South African Bureau of Standards
SEA	Strategic Environmental Assessment
SEZ	Special Economic Zone
SMEs	Small and Medium-sized Enterprises
TVET	Technical and Vocational Education and Training
WACC	Weighted Average Cost of Capital
ISO	International Organization for Standardization
IEC	International Electrotechnical Commission
ZNZ's	Zero- and Near-Zero GHG Emission Bunker Fuels

Executive Summary

The accelerating global push to combat climate change and achieve net-zero emissions by 2050 is transforming energy systems and industrial economies worldwide. As pressure mounts to defossilise carbon-intensive industries and reduce greenhouse gas emissions, green hydrogen and Power-to-X technologies have emerged as essential solutions, particularly for sectors that are difficult-to-abate, such as steel production, shipping, aviation, and chemicals.

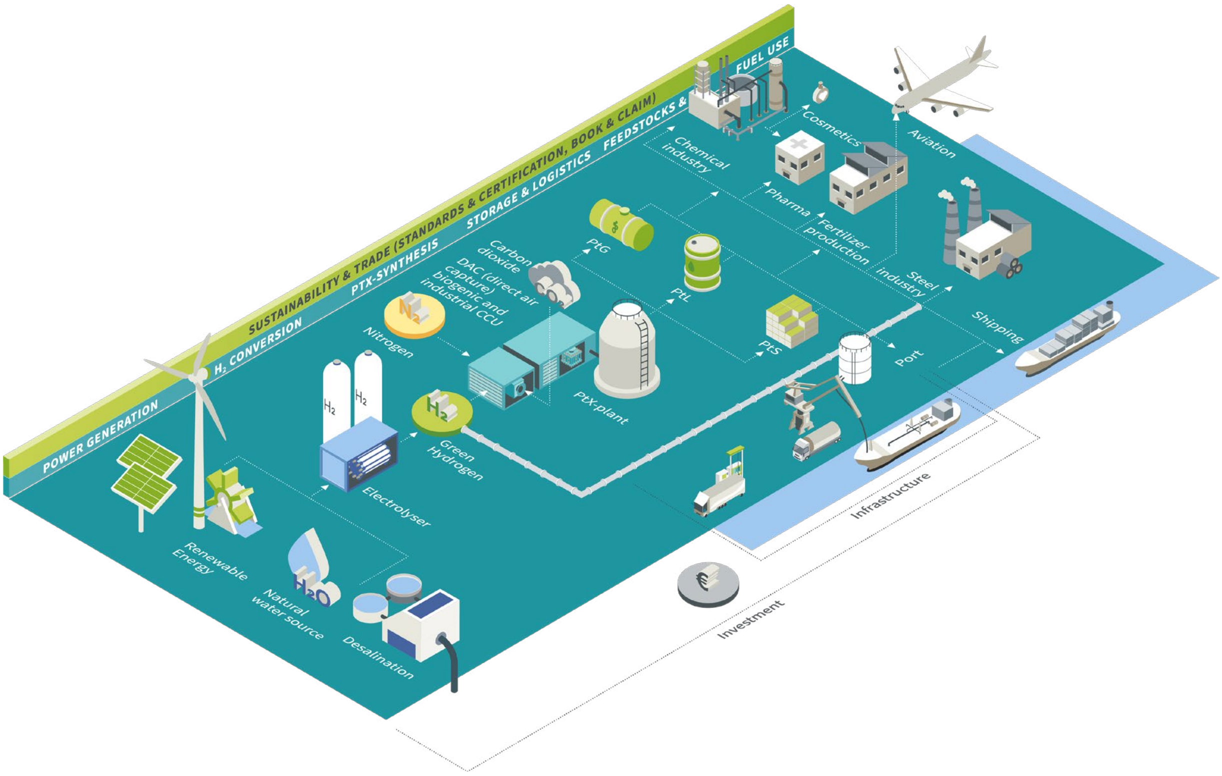
Green hydrogen, abbreviated as GH_2, refers to hydrogen produced through the electrolysis of water using renewable electricity such as solar or wind power. This method emits no carbon dioxide, making it a zero-emission energy carrier. It stands in contrast to grey hydrogen, which is produced from fossil fuels such as natural gas or coal and emits significant carbon dioxide, and blue hydrogen, which is also fossil-based but includes carbon capture and storage to reduce emissions. Among these, green hydrogen is the most sustainable option, and the only form aligned with long-term climate goals.

With the above definition of green hydrogen and how it is unique from other forms of hydrogen, South Africa becomes a key strategic location for the sector and the overall economy. With its vast solar and wind resources, longstanding industrial capabilities, and strategic geographic positioning, the country is uniquely placed to become a key player in the emerging global green hydrogen economy. By producing green hydrogen at scale, the country can support global climate objectives while advancing national goals for energy security, inclusive industrialisation, export development, and economic resilience. This report, titled , brings together twelve thematic papers into a unified strategy for positioning South Africa as a key regional cluster in green hydrogen and Power-to-X. It identifies the enabling conditions, economic opportunities, and policy actions required to transform South Africa's early-mover potential into operational projects and long-term competitive advantage.

Although green hydrogen presents the only viable pathway to defossilise certain hard-to-abate sectors, it is not yet cost-competitive, and its market readiness cannot be assumed. Like solar photovoltaic and wind technologies in their formative years, green hydrogen will require sustained public sector support, policy clarity, and coordination between stakeholders to scale effectively and reach maturity. With this in mind, it is critical for South Africa to avoid two common pitfalls: first, overhyping green hydrogen as a silver bullet that can solve all challenges, and second, falling into pessimism and dismissing it as a failed promise. Instead, the report recommends a balanced and realistic approach, urging public and private sector actors to focus on "no-regret actions", which are interventions that support broader national development objectives while preparing the ground for a competitive green hydrogen industry.

As testament to the abovementioned challenges and potential risks, the global hydrogen sector is currently facing significant challenges that are slowing down deployment of projects. Despite numerous announcements, very few projects have reached operational status, much of the reason for this being attributed to a combination of geopolitical instability, rising capital and interest costs, permitting delays, technology scale-up challenges, a lack of offtake certainty, and insufficient public support mechanisms. Furthermore, too much focus has been placed on long-term international export markets, with too little emphasis on developing robust, domestic green hydrogen ecosystems. In parallel, the political momentum around global net-zero targets has begun to fade in multilateral forums such as the UN COP process. These dynamics reflect a broader innovation trajectory, where new technologies often pass through periods of inflated expectations, followed by disillusionment, and eventually gradual maturity. Green hydrogen is currently in the early stages of this transition. Recognising this, it is vital for South Africa to act now to avoid being left behind and to ensure it can benefit when the sector enters its next phase of real-world deployment and market growth.

Figure 1: Key Benefits of Green Hydrogen



Source: International PtX Hub

The report therefore presents an integrated roadmap across a range of critical domains. These include industrial transformation through green steel and fertiliser production, the development of sustainable fuels for maritime and aviation sectors, the construction of transport and delivery infrastructure for green molecules, and the use of green hydrogen as a catalyst for socio-economic development and job creation. It also covers the establishment of robust regulatory systems, including standards and certification, the execution of national strategic environmental assessments, the advancement of hydrogen diplomacy, and the structured de-risking of projects to enable real investment and implementation. Through coordinated, forward-looking action, South Africa can become a trusted and capable global partner in the green hydrogen transition. At the same time, it can use this opportunity to drive industrial renewal, improve infrastructure, uplift communities, and enhance long-term competitiveness in a carbon-constrained global economy.

1 South Africa's Potential to Produce Cost-Competitive Green Hydrogen

South Africa's exceptional solar and wind resources position it as a global low-cost producer of green hydrogen (GH_2). Beyond export potential, GH_2 offers a strategic pathway for national defossilisation, regional development, and economic diversification. This chapter outlines the techno-economic fundamentals that underpin South Africa's cost competitiveness in GH_2 production and identifies key enablers for scaling.

1.1 South Africa's Green Hydrogen Edge

Global momentum toward net-zero commitments has placed GH_2 at the centre of industrial defossilisation strategies. South Africa's world-class renewable resources, combined with industrial capabilities and port infrastructure, create a compelling case for cost-effective GH_2 production. Strategic policy signals, including the Hydrogen Society Roadmap, Hydrogen Commercialization Strategy and Just Energy Transition Investment Plan (JET IP), underline the country's ambition in this space.

1.2 The Strategic Opportunity

South Africa's abundant solar and wind resources, large tracts of available land (even when considering environmental and social constraints), and a foundation of industrial expertise make it a prime candidate for large-scale, low-cost renewable hydrogen production. As the world transitions to net-zero emissions, GH_2 is emerging as a critical energy vector, not only for domestic energy security and defossilisation, but also for participation in future global trade. South Africa can leverage its comparative advantage to supply cost-effective hydrogen and hydrogen-based products to international markets.

South Africa's deepwater ports including Saldanha Bay, Coega, and Richards Bay, provide a significant logistical edge in the global hydrogen economy. Positioned along major international shipping routes, these ports offer direct maritime access to key GH_2 markets in Europe, Asia, and the Americas. With existing petrochemical and bulk handling infrastructure, these ports can facilitate large scale hydrogen exports with minimal new investment. This reduces CAPEX requirements and enhances the countries' overall renewable hydrogen export competitiveness. Additionally, their proximity to renewable-rich inland regions supports integrated hydrogen corridors, streamlining the supply chain from production to international markets.

1.3 Green Hydrogen Cost Drivers

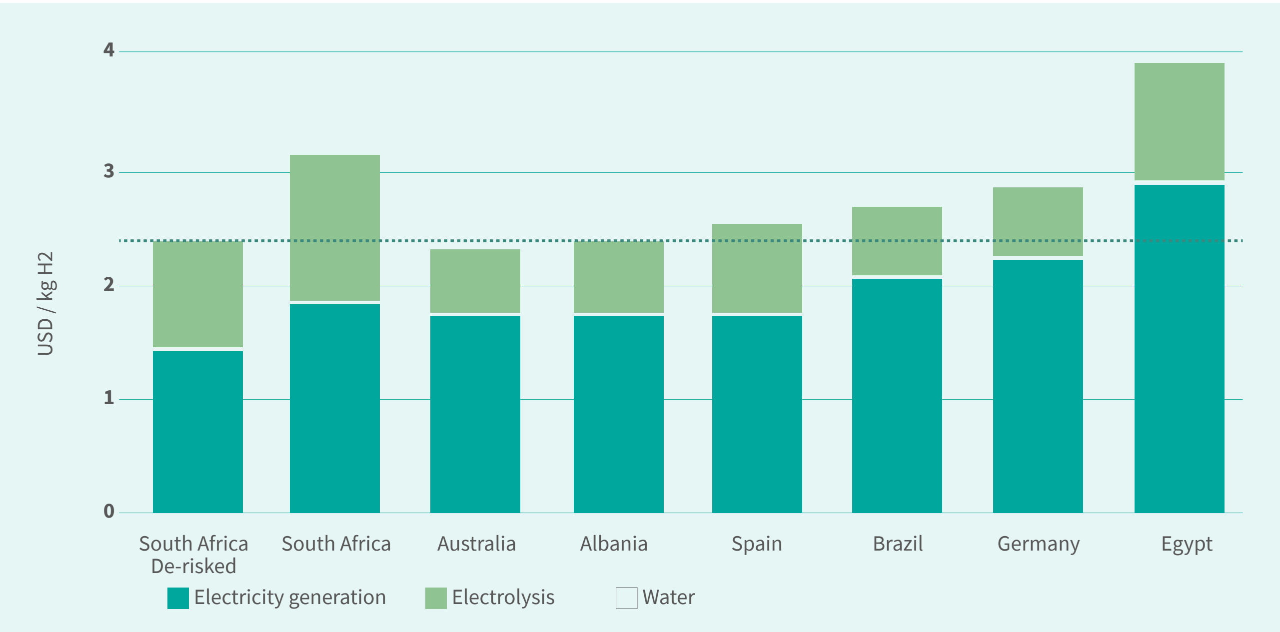
The Levelised Cost of Hydrogen (LCOH) refers to the average cost of producing one kilogramme of hydrogen over the entire lifetime of a production asset, taking into account all capital, operating, and financing costs. It is a key metric used to assess the economic competitiveness of hydrogen projects, as it enables comparison across different technologies and geographies by normalising costs over time and output. The Levelised Cost of Hydrogen (LCOH) is shaped primarily by three key factors:

- Capital expenditure (CAPEX): Upfront investment costs for electrolysers, renewable energy infrastructure, and related systems.
- Full load hours (FLH) of the renewable generation
- Cost of capital, reflected in the Weighted Average Cost of Capital (WACC)

South Africa's renewable potential is particularly strong in the Northern, Western, and Eastern Cape. A 2024 study found that on average, solar PV systems can produce electricity for up to 2,000 full-load hours per year, and wind systems for up to 3,500 hours. In some locations, these figures can reach as high as 1,950 for solar and 4,400 hours for wind (Oeko-Institut, 2024; International PtX Hub & Fraunhofer IEE, 2024). These performance metrics are globally competitive.

In addition to the performance metrics noted above, projections show declining CAPEX for renewable technologies by 2030, USD 368/kW for solar PV and USD 813/kW for onshore wind, placing South Africa on a strong cost footing. When paired with high FLHs, this positions the country among the world's most competitive GH_2 producers (International PtX Hub & Fraunhofer IEE, 2024). Figure 2 below presents a 2030 LCOH projection comparing renewable hydrogen production costs among key producing countries.

Figure 2: Projected 2030 LCOH - GH_2 Production Costs by Country

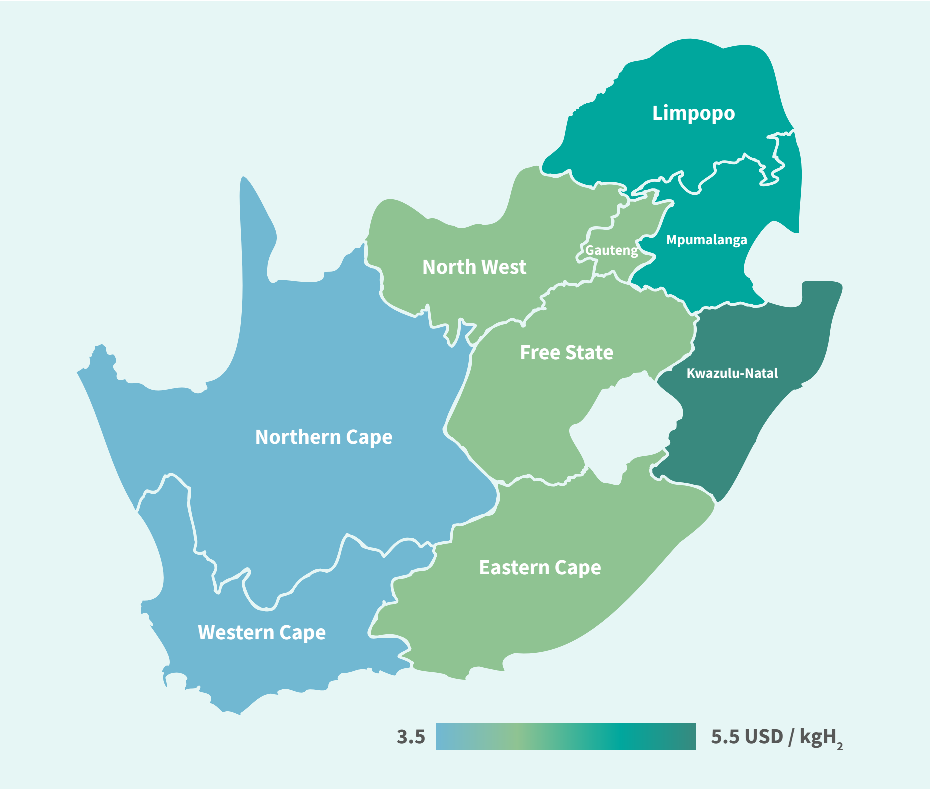


Source: (Oeko-Institut, Agora Industry & Agora Energiewende, 2024)

1.4 Scaling Green Hydrogen: Infrastructure and Spatial Considerations

South Africa's hydrogen production potential is geographically concentrated. The map below illustrates the projected LCOH in 2030 across South Africa's provinces for hybrid solar-wind production systems:

Figure 3: Provincial LCOH Estimates for Hybrid Solar-Wind Hydrogen (USD/kGH$_2$)



Source: (Agora Industry, 2024)

Figure 3 above highlights the following spatial dynamics:

- The Northern Cape Province offers the lowest LCOH (~3.5 USD/kgH$_2$), thanks to its exceptional solar and wind resources and low land-use pressures.
- Western and Eastern Cape provinces are also competitive, particularly for wind-driven production.
- Inland provinces like KwaZulu-Natal, Gauteng, and Mpumalanga face higher costs due to weaker renewables and denser infrastructure competition.

However, grid constraints limit the immediate integration of these regions. Recent Generation Connection Capacity Assessments (GCCA's) show limited or no spare capacity in the Cape regions. Interregional transmission links to the Northern Cape are also insufficient, making the connections from the Northern Cape region to the demand centres crucial to exploit the exceptional renewable capacities in the region.

Financial modelling suggests that failure to expand the grid could result in 10% higher energy system costs by 2050 compared to moderate expansion. Investment in grid and hydrogen transport infrastructure will be essential to unlocking low-cost hydrogen at scale (International PtX Hub & Fraunhofer IEE, 2024). Additional spatial and infrastructure insights are provided in paper 3.

1.5 Realising the Opportunity

South Africa has the rare combination of abundant natural resources, industrial legacy infrastructure, and export access to emerge as a cost-competitive GH_2 producer. With declining renewable costs and strong FLH's, the LCOH outlook is highly favourable. Unlocking this potential will require strategic planning, investor confidence, and targeted grid and export infrastructure development.

1.6 Further Reads:

Policy Paper: Green Hydrogen Competitive Market

PtX Competitiveness Analysis: Renewable Hydrogen Market Potential and Value Chain

2 Power-to-X as a Strategic Business Opportunity for South Africa

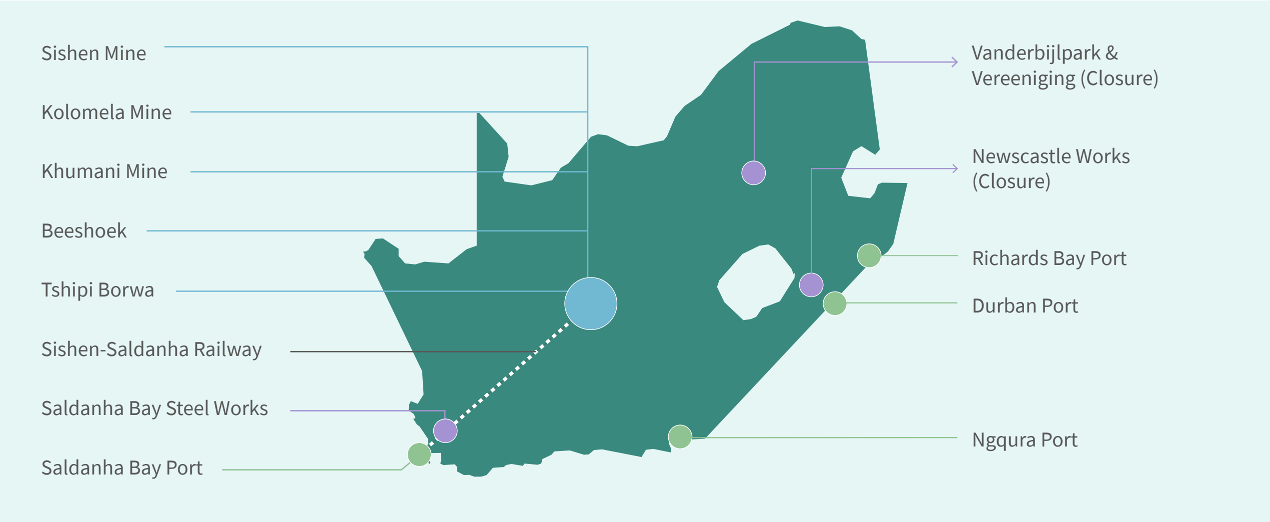
South Africa stands at a critical juncture in its industrial and energy development path. As global economies transition towards net-zero emissions, the demand for low-carbon materials and fuels is set to surge. Green hydrogen (GH_2) sits at the heart of this transformation, not only as an energy vector, but as a platform for industrial competitiveness, food security, and climate leadership. South Africa's world-class renewable resources, combined with mineral wealth and industrial infrastructure, create a compelling case for leveraging GH_2 to create low carbon Power-to-X (PtX) products for both domestic and international markets.

2.1 Green DRI: Industrial Renewal and Export Competitiveness

PtX products offer a versatile range of applications. Green ammonia and Direct Reduced Iron (DRI) are two key examples with strategic potential for South Africa, both domestically and on the global stage. Steel production is one of the largest industrial sources of global carbon dioxide (CO_2) emissions, accounting for approximately 7% of total output (International Energy Agency, 2022). Traditional blast furnace methods depend on coking coal, locking in emissions. In contrast, DRI produced with renewable hydrogen offers a radically cleaner solution. Green DRI eliminates coal as a reducing agent, allowing steel to be made with far lower emissions (Agora Industry, Wuppertal Institute and Lund Universty, 2024).

South Africa's competitive edge lies in a rare combination of ingredients: high-quality iron ore reserves, strong wind and solar energy resources, and existing industrial infrastructure. The "mothballed" Saldanha Steel Works, for example, is equipped with Corex-Midrex technology which with a retrofit can produce hydrogen based DRI and is located near a deep-water port. Integrated rail corridors connect mining areas to coastal hubs, creating a viable corridor for low-carbon steelmaking and export.

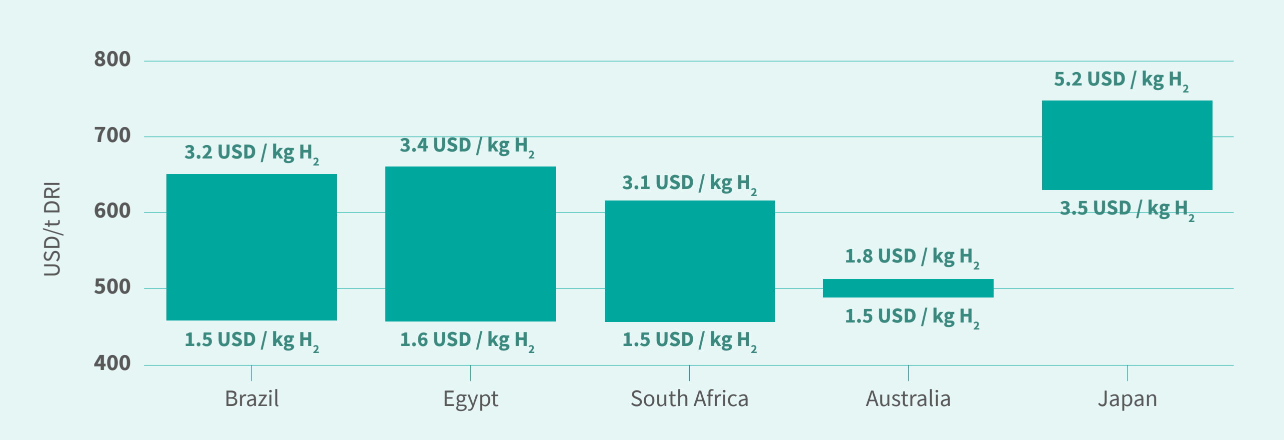
Figure 4: South Africa's Steel Value Chain Infrastructure



Source: (own illustration)

Recent modelling shows South Africa can produce green DRI at globally competitive costs (Oeko-Institut., Agora Industry., Agora Energiewende, 2024). In fact, the country ranks among the lowest-cost producers when compared to peers. In this case, peers are defined as countries with abundant low-cost renewables, significant iron ore deposits and a strong steel sector. Moreover, the modelling indicates that importing green DRI from South Africa for local steel production could lower steelmaking costs in countries such as Germany, South Korea, and Japan by around 20%.

Figure 5: Projected 2040 DRI Production Costs - South Africa vs Global Peers



Source: (Oeko-Institut., Agora Industry., Agora Energiewende, 2024)

By exporting green DRI instead of raw iron ore, South Africa can capture significantly more economic value per tonne and position itself at the forefront of the emerging global green materials trade. As countries adopt carbon border adjustment mechanisms to favour low-carbon imports, South Africa has the opportunity to become not just a resource supplier, but a strategic partner in global defossilisation efforts.

Inclusive development is also a strong opportunity. Reopening the Saldanha Steel Works, for example, could create over 600 direct jobs (Polity, 2022). In Mpumalanga, where coal-related jobs are decreasing, green DRI corridors offer a chance to revive local industries and strengthen the regional economy. These corridors attract investment in renewable energy, hydrogen infrastructure, and transport, which are sectors known for creating many jobs.

2.2 Green Ammonia and PtX Fuels: Enabling Sustainable Transportation and Food Security

Sustainable fuels—like green ammonia, green methanol, and Fischer-Tropsch-based diesel and kerosene—offer a major opportunity for South Africa. Much of the demand for these fuels is expected to come from the maritime and aviation sectors as they work toward meeting global defossilisation targets. This growing market could also help revive existing Fischer-Tropsch facilities, such as Sasol's plant in Secunda and PetroSA's plant in Mossel Bay (see Paper 4). Producing Fischer-Tropsch fuels commercially depends on securing a sustainable carbon source—a key challenge discussed further in recommendation 12. Green ammonia, in turn, is increasingly recognised as a key carbon-free PtX product. It can serve not only as a marine fuel but also as a hydrogen carrier for export markets. This is key to note as both applications are expected to become key cornerstones of the growing green hydrogen economy.

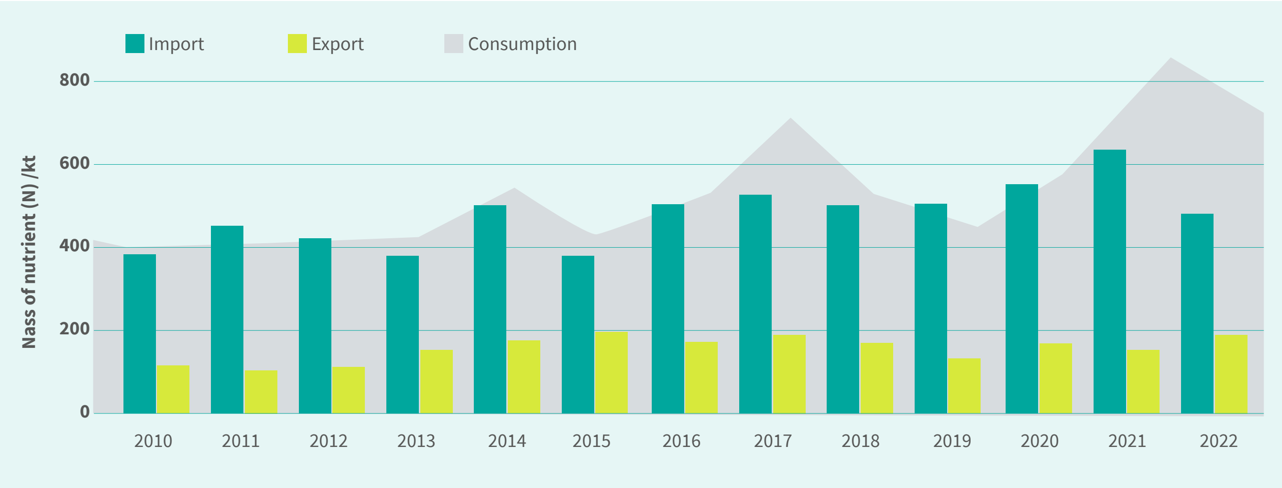
In the maritime sector, green ammonia is gaining attention as one of the most promising alternatives to conventional bunker fuels. As international shipping seeks to align with the International Maritime Organization's (IMO) defossilisation targets, aiming for net-zero emissions by or around 2050, green ammonia offers a scalable, zero-carbon fuel option. Its high energy density, compatibility with existing infrastructure (after adaptation), and ease of storage compared to hydrogen make it particularly attractive for long-haul and deep-sea shipping.

While the market of ammonia as a fuel or hydrogen carrier is still emerging, its strong demand in other established sectors makes it a strategic focus. In 2023, global production reached around 150 million metric tonnes (Statista, 2025) with 70% used for nitrogen fertilisers (International Energy Agency, 2021), which is a critical input for global food security.

To cover this demand today, ammonia is primarily produced using coal or natural gas as both a feedstock and an energy source. This process is highly emission-intensive and tied to volatile fossil fuel markets. In this context, green ammonia offers a promising alternative - reducing emissions while reducing dependence on fossil fuels.

Over the past few decades, South Africa's consumption of nitrogen fertilisers has grown. This demand is currently covered mostly through imports (see Figure 6), which makes the country vulnerable to the consequences of global volatility. For example, following Russia's invasion of Ukraine in 2022, the price of fertiliser increased sharply, putting pressure on local food systems (Vos, et al., 2025). For a region already grappling with climate instability, ensuring fertiliser availability is critical to both food security and economic stability.

Figure 6: South Africa's Nitrogen Fertiliser Consumption, Import and Export Volumes

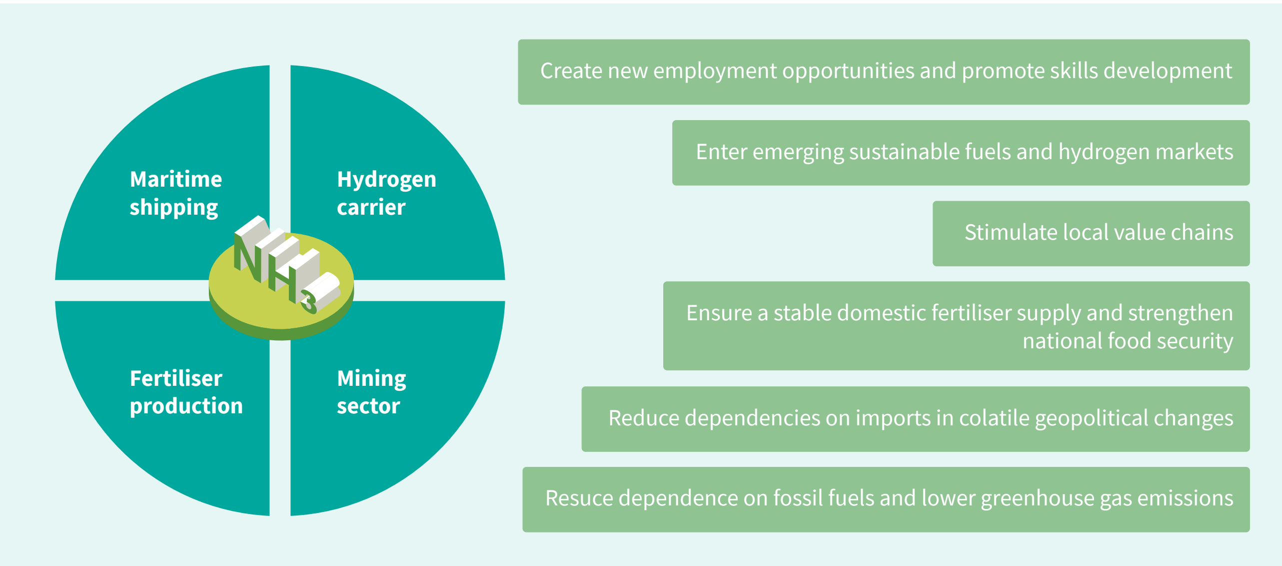


Source: own illustration based on (International Fertiliser Association, 2022)

Produced with GH_2, green ammonia provides a low-carbon alternative to fossil-based ammonia. With abundant renewable resources and chemical engineering expertise, South Africa is well-placed to build a green ammonia industry. This would not only boost exports but also make the domestic fertiliser market more resilient. The developed mining industry in South Africa could also benefit from the local supply of green ammonia-based explosives, creating additional business opportunities

Projects like Hive Energy's plant in Coega (Hive Energy, 2021) and Suiso's facility in Kriel for low-carbon ammonia (Creamer Media, 2025) are already in development, signalling that the transition is not just possible, it is in fact underway. All in all, domestic production of green ammonia has the potential to unlock positive outcomes in different sectors for South Africa, outlined in Figure 7.

Figure 7: Potential Benefits from Green Ammonia Production in South Africa



Source: (own Illustration)

2.3 A Platform for Prosperity and Climate Leadership

By building competitive industries in green DRI and green ammonia, South Africa can create jobs, improve trade balance, and achieve its stated emission reduction Nationally Determined Contribution (NDC) targets.

To realise this vision, South Africa should focus on five strategic actions:

1. Forge Strategic Partnerships for Offtake and Technology Transfer: South Africa should leverage the EU–SA Clean Trade and Investment Partnership and similar bilateral agreements to secure long-term offtake commitments and co-investment in infrastructure and technology. These partnerships can send vital market signals and support the development of standards, certification, and shared innovation platforms.
2. Stimulate Domestic Demand through Green Procurement and Incentives: In the absence of strong carbon pricing in South Africa, green public procurement should be used to create predictable local demand for green iron and ammonia. This can be reinforced through industrial incentives such as tax credits, localisation rebates, and procurement mandates for state-led infrastructure projects.
3. Align Cross-Sectoral Policy to Enable Project Implementation: South Africa must harmonise its green hydrogen strategy with energy, mining, and industrial plans to enable integrated infrastructure and offtake coordination. Alignment with the Green Hydrogen Commercialisation Strategy, Steel Master Plan, Agriculture and Agro-processing Master Plan, and water/logistics strategies is critical to unlock bankable project pipelines.
4. Mobilise Public and Blended Finance to Unlock Investment: The Just Energy Transition Partnership and other concessional funds should be targeted toward green hydrogen projects with high employment and export potential. Blended finance tools—such as guarantees, concessional loans, and public-backed offtakes—can attract private capital and accelerate final investment decisions.
5. Anchor the Transition in Local Jobs and Industrial Value Creation: Green iron and ammonia production should be positioned as pillars of South Africa's just transition, particularly in regions facing coal decline or deindustrialisation. Targeted skills development, local manufacturing incentives, and community benefit-sharing mechanisms can ensure inclusive growth and long-term resilience.

2.4 Further Reads:

PtX Business-Opportunities in South-Africa: Renewable Hydrogen Market Potential and Value Chain Analysis

3 Resource and Infrastructure Benefits of Green Hydrogen and Power-to-X

The production of green hydrogen (GH_2) and Power-to-X (PtX) products in South Africa offers more than just a pathway to defossilisation; it brings a range of unexpected benefits related not only to infrastructure but also to the actual provision of critical resources. Contrary to concerns that GH_2 would compete for South Africa's already scarce water and electricity, these projects can actively contribute to expanding water availability, generating new renewable electricity, and enhancing transmission infrastructure. Together, they help build a more resilient, resource-secure national system.

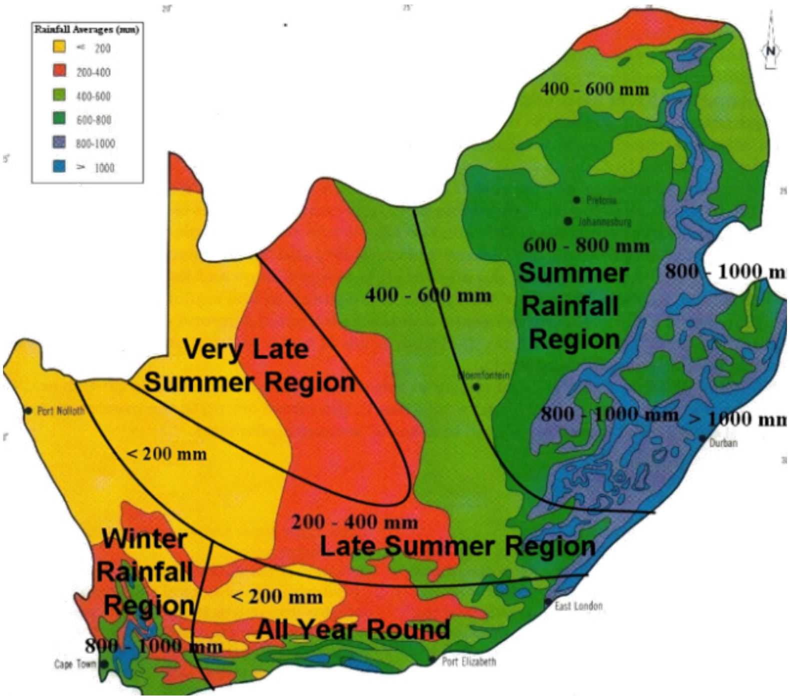
3.1 Unlocking Green Hydrogen Co-Benefits

The production of GH_2 and PtX products at scale in South Africa will bring a number of unexpected benefits, many of which contradict first assumptions. The focus here is on three key benefits: water, electricity and transmission infrastructure.

3.2 Enhancing Water Security in a Drought-Prone Nation

Water is required as a feedstock in the electrolysis process used to produce GH_2. South Africa, however, is classified as a water-stressed country prone to seasonal droughts, the most notable of which was the 2015-2020 Cape Town water crisis. 65% of the country receives less than 500 mm per year, and 21% less than 200 mm as shown in Figure 8 below:

Figure 8: Average Annual Rainfall in South Africa



Source: (GreenCape, 2019)

By 2030, severe water shortages are expected in Gauteng, Mpumalanga, KwaZulu-Natal, and the Western Cape (GreenCape, 2019). In this context, using potable water for GH_2 production would be unsustainable and irresponsible—especially if it competes with communities, agriculture, or ecosystems for scarce resources.

The solution therefore is threefold:

- Water for GH_2 production should not be from potable sources.
- On the coast, it should be sourced via seawater desalination.
- Inland, it should come from the treatment of chemically contaminated water (industrial process water or acid mine drainage, etc.).

Large-scale desalination is already common in water-scarce regions such as the Middle East, where it is essential for urban supply. The biggest barrier to adoption elsewhere is not technology, but financing, as desalinated water is significantly more expensive than traditionally sourced water. In areas like South Africa, where water stress is cyclical rather than permanent, securing investment for desalination infrastructure is difficult without stable offtake guarantees. Utilities revert to cheaper surface water when available, leaving desalination plants underutilised.

GH_2 plants can solve this problem. They require consistent water input, making them ideal anchor off takers for desalination infrastructure. While GH_2 production costs \$3–6/kg, the desalination component is just \$0.02–0.05/kg (IRENA, 2023). This minimal impact enables plants to be oversized, enabling them to produce surplus water that can be supplied to surrounding communities. GH_2 production therefore has a strong potential to enhance water security rather than compromising it.

3.3 Unlocking Grid Value through Renewable Oversupply

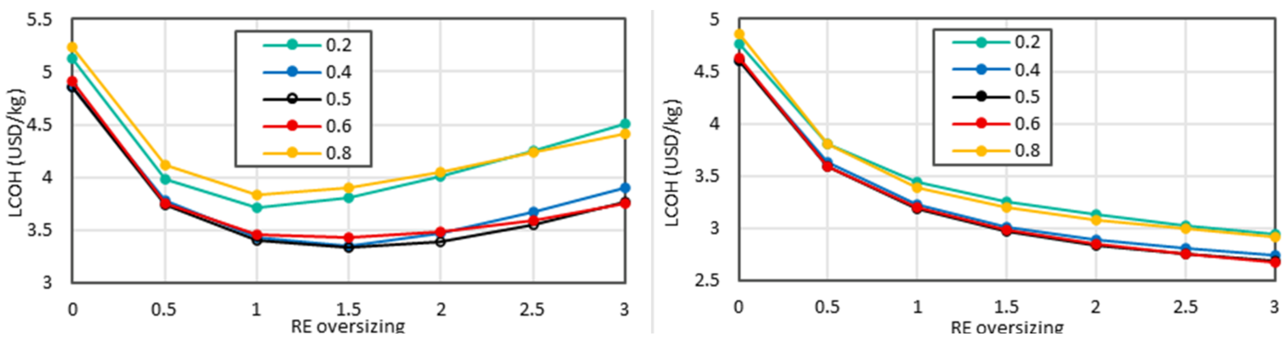
A common concern raised about GH_2 in South Africa is that it could worsen load shedding by consuming already scarce electricity. However, for hydrogen to be classified as “green,” it must be powered exclusively by new renewable electricity—not from the grid and not from existing renewable installations. This principle, known as “additionality,” is enshrined in EU regulations such as the RED II Delegated Act (European Commission, 2023), and echoed in Germany’s National Hydrogen Strategy. As such, GH_2 plants must come with their own dedicated renewable generation (solar, wind, or both) which does not compete with existing grid supply. In fact, this model can actually support the grid.

Electrolysers are high CAPEX items, so to produce GH_2 at the lowest cost, they need to operate as much as possible throughout the year. The more hours the electrolyser runs at full capacity, the more hydrogen it produces, and the lower the cost per unit. This is because the upfront cost of the electrolyser gets spread out over a larger volume of hydrogen.

Power from renewable plants is not only intermittent but also variable. To compensate for this variability, the renewable energy system needs to be built larger than nameplate capacity of the electrolyser, to achieve the required high-capacity factor discussed above. In other words, the solar and/or wind capacity must be oversized relative to the electrolyser. While this leads to periods where renewable output exceeds electrolyser consumption, that surplus electricity can be sold to the grid, thus reducing the Levelised Cost of Hydrogen (LCOH). This excess electricity can assist in the recharging of pumped storage schemes or utility-scale batteries, reducing both costs and emissions.

Figure 9 demonstrates the economics of this oversizing. It compares the LCOH for a 20 MW electrolyser in Mossel Bay under two scenarios:

1. **Islanded (Off-grid):** Here, LCOH decreases as renewable capacity is oversized—up to a point. Beyond this minimum at 100%-150% oversizing (depending on the solar-wind mix, shown here with solar fractions from 20% to 80%), additional generation becomes wasteful, increasing the cost. This is shown by the graph on the left-hand side.
2. **Grid-connected:** With the ability to sell excess power, the LCOH does not reach a clear minimum, but keeps decreasing with added renewable capacity (assuming that the excess electricity is sold at least at the cost it takes to produce it). Oversizing from 150% to 300% can cut LCOH by 20% in the example shown.



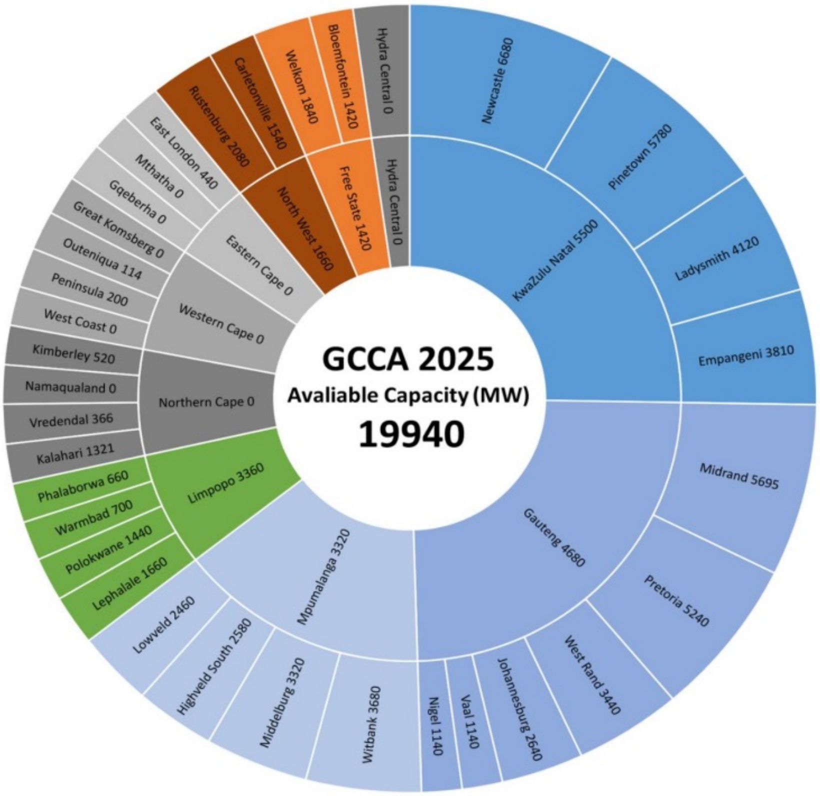
Source: (CSIR & GFA Consulting Group GmbH , 2023)

Thus, far from worsening load shedding, GH_2 projects, when correctly configured, can become allies in South Africa’s energy transition, balancing the grid and supporting renewable integration.

3.4 Catalysing Transmission Expansion for National Benefit

This dynamic links directly to the final critical component: electricity transmission infrastructure. Without adequate grid capacity, even the most well-designed GH_2 projects may be unable to dispatch surplus electricity or receive adequate renewable inputs.

Figure 10: Summary of the GCCA 2025 Results



Source: (Eskom, 2023)

In October 2023, Eskom's Generation Connection Capacity Assessment (GCCA) 2025 warned that there was no remaining capacity for connection of new generation capacity in the Northern Cape, Eastern Cape, Western Cape and Hydra Central supply areas (see Figure 10). This means that the deployment of new power projects precisely in areas that are best suited for renewables and GH_2 is limited.

To address this, Eskom proposed two solutions:

1. **Curtailment:** Temporarily reducing the output from certain generators to create room for others. In 2024, Eskom noted that allowing 10% curtailment could enable new wind capacity to connect 2 680 MW in the Western Cape and 790 MW in the Eastern Cape.
2. **Grid Expansion:** Eskom's 2024 Transmission Development Plan proposes adding 14 494 km of new transmission lines and 210 transformers by 2035, with 5 044 km of lines and 87 transformers by 2029. This is reinforced by the Ministerial Determination of March 2025, which enables procurement of 1 164 km of 400 kV lines and transformers under the Independent Transmission Programme, inviting private capital to co-invest.

GH_2 and PtX projects require robust connections between their renewable sources, electrolysers, and the national grid. If these elements are not co-located, new substations and transmission lines are needed. In many cases, the GH_2 developer can fund this local infrastructure, and then hand it over to the grid operator under a “build, own, operate and transfer” (BOOT) model. GH_2 and PtX projects can accelerate grid expansion investments.

3.5 Further Reads:

Policy Brief: Electricity Infrastructure - Interactions Between Green Hydrogen and Electricity Supply

4 Leveraging Green Hydrogen for South Africa's Economic Resilience and Global Value Chain Integration

The pressure of increasing carbon pricing worldwide is a key driver to secure South Africa's place in the emerging global green value chains. An opportunity exists to rejuvenate existing infrastructure and expertise in South Africa, taking the example of PetroSA's synthetic fuel production in Mossel Bay. Furthermore, mining and processing South Africa's resources of Platinum Group Metals (PGM) into electrolysers and fuel cells needed for the global energy transition is opportune

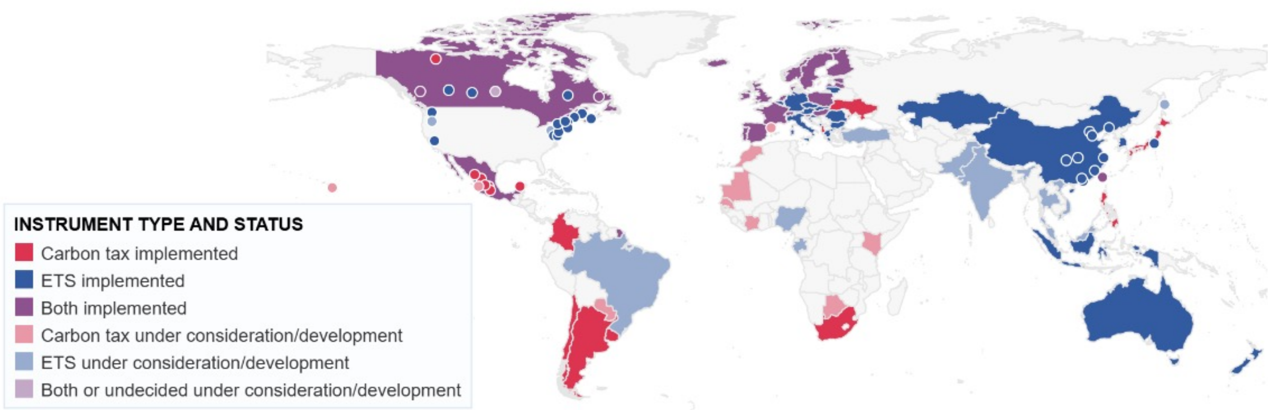
4.1 Increasing Carbon Prices Creates a Business Case for Green Industrial Production

Globally, companies are moving to defossilise their operations, driven by increasing policy incentives and consumer demand. Carbon pricing is on the rise globally: there are 64 carbon pricing initiatives (carbon taxes and emissions trading schemes) in place or planned in 46 countries, covering about 22% of global greenhouse gas emissions (World Bank, 2025). This makes emissions costs a crucial part of global trade.

National carbon pricing has been extended in recent years by Carbon Border Adjustment Mechanisms (CBAM), most advanced in the European Union. The CBAM imposes carbon costs on the embedded emissions of a range of products. Similar policies are emerging in the UK, Australia, and Turkey.

Figure 11: Compliance Carbon Pricing Instruments Around the World in 2025

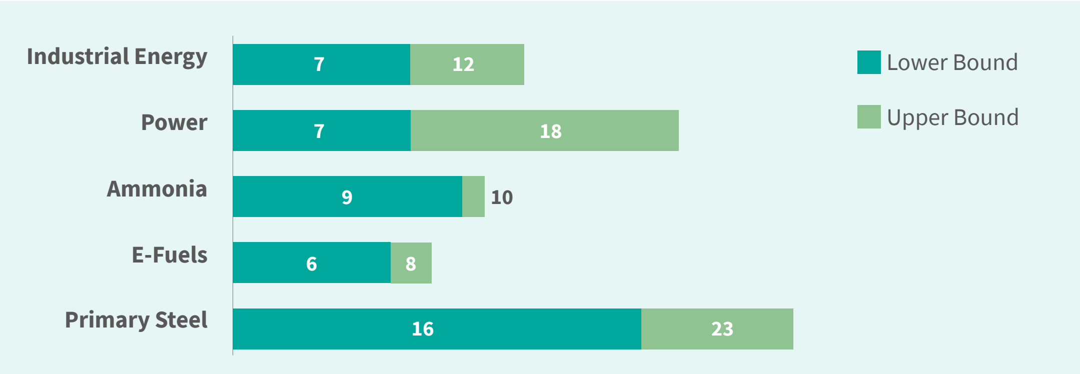
Source: (World Bank, 2025)



As carbon prices rise, industries that adopt low-carbon technologies early can gain a competitive advantage by reducing their long-term carbon liabilities and mitigating the risks associated with future climate regulations. The effective carbon price in South Africa is not yet high enough to trigger steering effects towards low-carbon investments on a large scale. The challenge is to align with these shifting global trade expectations or risk exclusion from growing carbon-constrained markets.

Early alignment now offers key advantages of securing a competitive position in global markets and integration into international value chains, reduced regulatory risk for South African companies and creating a secure environment for green investment.

Figure 12: GHG Abatement Potential Per Application (CO2e/kGH$_2$)



Source: (EUROFER, 2023)

4.2 Green Hydrogen and Power-to-X as Catalysts for Transformation

This is where GH$_2$ and PtX technologies come in: they can complement the efforts of South African companies that are already reducing their emissions by investing in renewable electricity in recent years. For example, Hulamin, Africa‘s largest aluminium manufacturer, and Mpact, the largest paper and plastic packaging and recycling company in southern Africa, are moving towards wind and solar electricity and are increasing their energy efficiency. However, those mitigation efforts can only reduce emissions to a certain extent. Once direct electrification and energy efficiency options have been exhausted, GH$_2$ and PtX offer opportunities to further reduce GHG emissions and establish a new sustainable industry with export potential for green products (Andreoni, et al., 2023).

Opportunities have been identified in:

- Green fuels for aviation and maritime transport as mandated by new emissions reductions
- Strategies by the UN bodies International Civil Aviation Organization and International Maritime Organization (explored in paper 12)
- Direct reduced iron for green steel production (see paper 2)
- Automotive manufacturing (original equipment manufacturing value chains)
- Mining and processing ‘green’ raw materials (meaning produced in a more sustainable and emission-reduced manner)
- Rejuvenating existing Fischer-Tropsch facilities (see paper 5)

4.3 Revitalising Infrastructure and Businesses Through Green Fuels

One particular opportunity to rejuvenate, sustain and strengthen South Africa's energy and petrochemical industries lies in green fuels such as biofuels and synthetic fuels. The latter can be produced from green hydrogen and carbon dioxide from a sustainable source. Key players in synthetic fuels production, such as PetroSA and Sasol, face unprecedented challenges due to the depletion of natural gas reserves, which has led to production halts and retrenchments at PetroSA. The move towards green fuels presents an opportunity for these companies to diversify their energy, feedstock sources and product portfolio, ensuring business sustainability, reducing reliance on fossil fuels and positioning South Africa as a global key regional cluster in renewable energy.

PetroSA, with the fourth largest Gas-to-Liquid (GTL) refinery plant in the world, has struggled with natural gas shortages since December 2020. Equally, Sasol's gas supply from Mozambique is being depleted faster than expected, raising concerns about supply disruptions before 2030. These challenges threaten the livelihoods of thousands of South Africans employed in these industries.

Green fuels provide an opportunity to create jobs, stimulate the green economy and increase South Africa's global competitiveness. By reducing dependence on dwindling natural gas supplies, these industries can build a more resilient and sustainable energy infrastructure. The shift towards defossilisation is increasing and international trade dynamics are increasingly favouring renewable energy products. South Africa can leverage its existing infrastructure, expertise and intellectual property in Fischer-Tropsch processes alongside its abundant wind and solar energy resources to produce these products at highly competitive prices, thereby positioning itself as a global key regional cluster in green fuels technologies.

In terms of policy support, the South African government has taken steps to support the transition to green fuels, evidenced by the approval of the South African Biofuels Regulatory Framework in December 2019. This framework aims to achieve 4.5% v/v biofuels penetration in the national fuel pool with 2% expected to come from first generation biofuel technologies. In 2021, the Department of Energy promulgated the Amendment to the Mandatory Blending Regulations which provide for the 5% v/v minimum concentration of biodiesel blending and between 2% and 10% v/v bioethanol blending. Despite these efforts, the adoption of biodiesel in South Africa has been slow, primarily due to high feedstock costs and the lack of regulatory enforcement. The recent implementation of mandatory blending is set for September 2027, and the challenge is the readiness of the oil industry to roll this out.

In addition to the focus on biofuels, there is an urgent need to develop new policy regulations that specifically address synthetic fuels produced from green hydrogen. Such policies would be key to promote the growth of GH_2 and synthetic fuels technologies in South Africa.

For instance, the South African government must develop and implement new policy regulations that will incentivise companies to invest in green fuels and accelerate the transition to green fuels. By offering clear incentives such as tax breaks, subsidies and funding opportunities, the government can drive the adoption of green fuels while supporting the growth of local industries and job creation.

In addition to the policies, the government should consider subsidies or tax incentives for companies investing in green fuel technologies. This will reduce the price gap between green fuels and conventional fossil fuels encouraging broader adoption. Investment in Research and Development (R&D) is crucial: increased investment in R&D for green and renewable technologies, particularly in the areas of feedstock production and efficient processing, can help reduce costs and enhance the scalability of green fuel production. Research into sustainable carbon sources (see paper 12) must also be prioritised, given the massive quantities required for PtX products.

Figure 13: PetroSA's GTL Plant in Mosselbay, South Africa

Source: (PetroSA, 2017)

4.4 Unlocking Value Chain Growth Through Green Hydrogen and PGMs

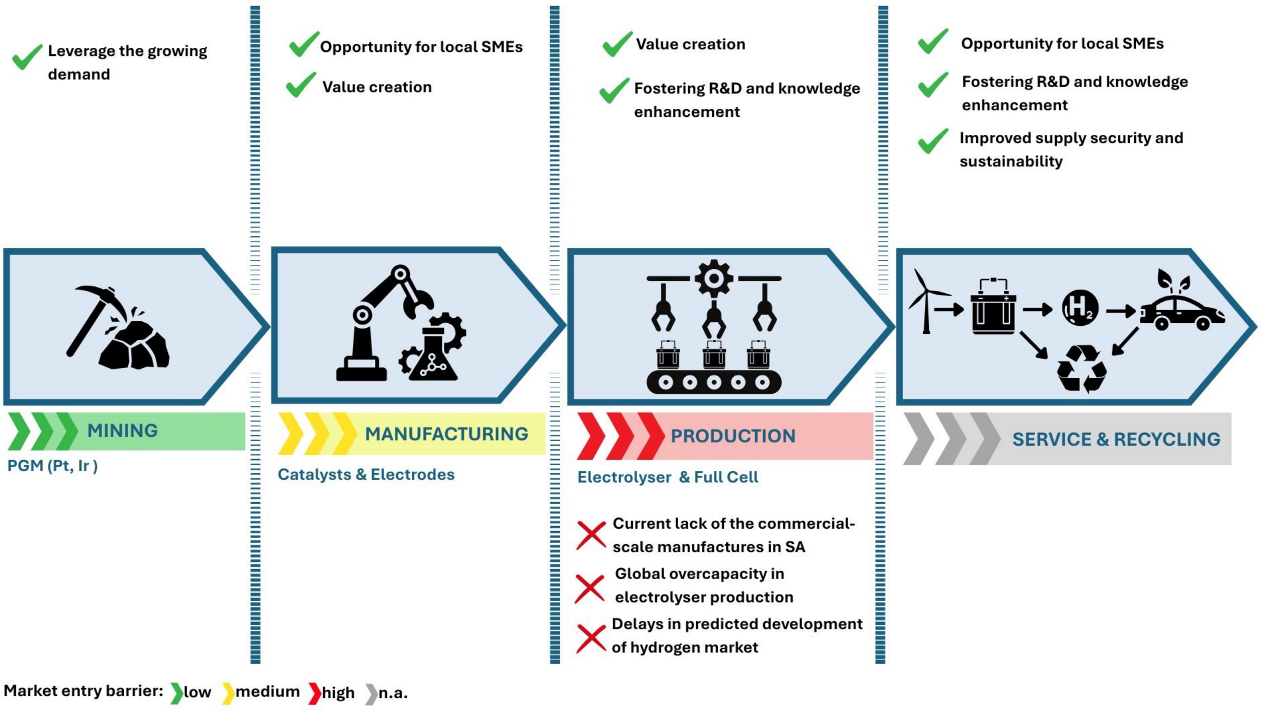
South Africa's mining sector has two opportunities to position itself along emerging green value chains. The first one is greening their existing production by producing low-emission materials for catalysts, green and battery metals, and operating climate-resilient and net-zero sites. Some activities in this direction are ongoing. For instance, Sibanye-Stillwater has commenced construction of 267 MW of renewable energy capacity and aims to operate carbon neutral by 2040 (Heraeus Precious Metals, 2022).

The second opportunity is in the development of new business cases: moving into new value chains by mining raw materials for the Just Energy Transition (JET). This is especially attractive considering the predicted growth of the worldwide water electrolysis capacities (IEA, 2023). This expansion of electrolyser production depends on Platinum Group Metals (PGM), especially platinum and iridium. Furthermore, other technologies along the hydrogen value chain, such as fuel cells, materials for hydrogen purification and storage (Eikeng, et al., 2024), and catalysts for PtX processes, also include PGMs.

South Africa, holding over 90% of global PGM reserves, is well-positioned to benefit from this growing demand. Beyond mining, the country could add value by producing catalysts, electrodes, and even moving further to manufacture electrolysers and fuel cells locally. Companies like Sibanye-Stillwater and Heraeus Precious Metals are already partnering on electrolyser catalysts. The green hydrogen sector also opens doors for smaller firms in equipment servicing and maintenance. Further R&D into PGM recycling from decommissioned electrolysers could strengthen supply security and sustainability, especially as installed electrolysers reach their end-of-life or when the extraction of required PGMs becomes limited.

However, moving up the value chain will be challenging, as South Africa's PGM expertise alone won't overcome the higher downstream entry barriers as shown in Figure 14 below:

Figure 14: Market Entry Barriers for South Africa in Entering PGM-Relevant Segments along the Value Chain



Source: own Illustration based on (GFA Consulting Group GmbH, 2023)

The country currently lacks commercial-scale manufacturing for electrolysers and fuel cells, limiting its competitiveness against established global players. Entering this market will require major investments in infrastructure, technology, and skills. In addition, existing threats in the clean energy technology market must be tracked, such as the observed overcapacity in electrolyser production in China, the EU and the US, and delays in the predicted development of the hydrogen market (PwC, 2025).

To overcome these challenges, forming international partnerships, such as the EU-SA Clean Trade and Investment Partnership, fostering local research into large-scale electrolyser and fuel cell production, and initially focusing on high-value components with lower market entry barriers (e.g., catalysts and electrodes) rather than full electrolyser systems should be considered (GFA Consulting Group GmbH, 2023; DNA Economics, 2023).

4.5 Preparing for Future Carbon-Constrained Markets Now

Supportive policies for GH_2 can protect exports to carbon-constrained markets, offer pathways for sustaining and transitioning existing industries, such as steel, fuels production and the PGM sector, and enable a Just Transition by creating quality green jobs.

4.6 Further Reads:

PtX Business Opportunities in South-Africa: Renewable Hydrogen Market Potential and Value Chains

Policy Paper: The Potential Benefit of Green Hydrogen for the Republic of South Africa

5 Sustainable Maritime Fuels: A Catalyst for Launching South Africa's Green Hydrogen Economy

South Africa, as a Member State of the International Maritime Organization (IMO), is positioned to play a key role in the global shift toward defossilising international shipping, aligned with the 2023 IMO GHG Strategy and its net-zero target by 2050. With its renewable energy potential, strategic coastal infrastructure, and existing Fischer-Tropsch facilities, South Africa has a unique opportunity to not only supply green e-methanol and e-ammonia but also sustainable drop-in maritime fuels – such as e-diesel – to a growing global market, supporting both international climate goals and national industrial development.

5.1 South Africa's Maritime Opportunity

South Africa is strategically positioned to leverage its maritime infrastructure and natural resources, positioning itself as a regional hub in the production and distribution of zero- and near-zero (ZNZ's) GHG emission bunker fuels for the global shipping industry. With its extensive coastline, expanding renewable energy sector, and established maritime infrastructure, South Africa is well positioned to capture a significant share of the growing global demand for sustainable maritime fuels.

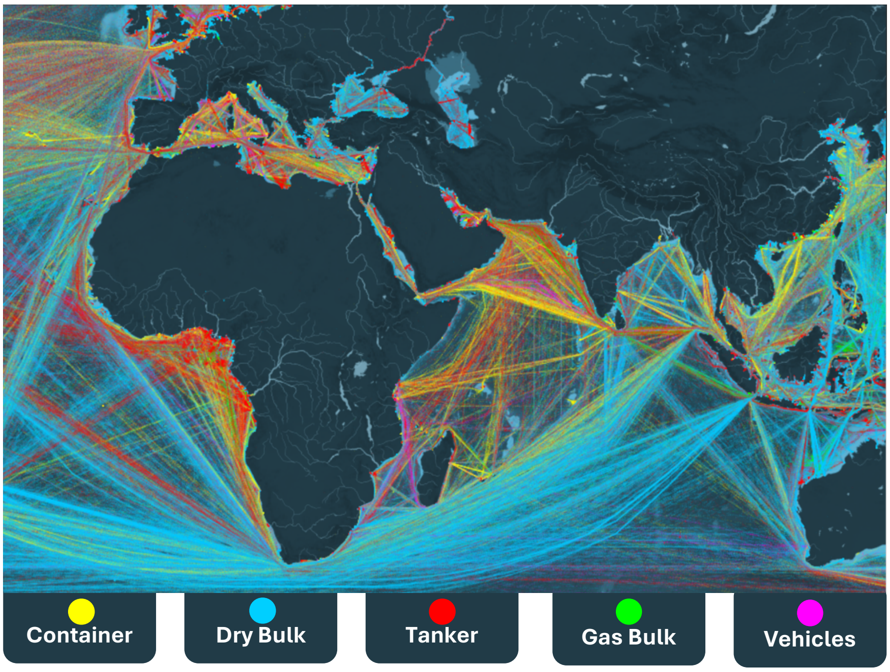
5.2 The IMO Net-Zero Framework: Catalysing Demand for Sustainable Maritime Fuels

South Africa is a Member State of the International Maritime Organization (IMO), a specialised agency of the United Nations Organisation responsible for regulating maritime transport. In July 2023, the 160 IMO Member States adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, which aims at the defossilisation of international shipping, aligned with the goals of the Paris Agreement. The main target of the 2023 IMO GHG Strategy is for GHG emissions from international shipping [are] to reach net-zero by or around 2050 (International Maritime Organisation, 2023).

The 2023 IMO GHG Strategy has since been refined and specified: In March 2025, the IMO's Marine Environment Protection Committee (MEPC) convened for its 83rd session and approved a suite of mid-term GHG reduction measures. These were formalised through draft amendments to MARPOL Annex VI (the main international treaty for preventing marine pollution from ships), introducing a new Chapter 5 that is expected to be adopted at an extraordinary MEPC session in October 2025 and to enter into force on 1 March 2027. Central to this chapter is the IMO Net-Zero Framework, which mandates a stepwise reduction in the carbon intensity of marine fuels on a well-to-wake basis, targeting a 17% reduction by 2028 and a 21% reduction by 2030. Additionally, MEPC 83 endorsed the establishment of a global pricing mechanism for GHG emissions from ships—an economic instrument designed to accelerate the transition to Zero- or Near-Zero fuels. It would add a significant price tag to GHG emissions from conventional fuels while supporting the uptake of ZNZ's via a dedicated Net-Zero fund that is filled from the GHG emission pricing.

The regulations of the IMO are binding and must be enforced by Member States, particularly flag states (where a ship is registered and under which flag it ships) and port states (that exercise control over foreign-flagged ships calling at its ports). The implications of the above are that ZNZ bunker fuels will be required from international ships to meet the above targets and to avoid expensive GHG emission pricing. While the enforcement of the above is an obligation to be met by the South African Department of Transport (DoT) and its subsidiaries, it simultaneously represents an opportunity described in the Hydrogen Society Roadmap (HSRM) and the Green Hydrogen Commercialisation Strategy (GHCS), which is that of making and selling ZNZ bunker fuels from GH_2, obtained by electrolysing water using electricity generated from South African sunshine and wind. South Africa has very good solar and with resources (see paper 1), and the 'Cape Route' is a major shipping route (figure 15), which represents a major opportunity.

Figure 15: Illustration of Shipping Routes around the African Continent



Source: (Kiln & UCL Energy Institute, n.d.)

Different shipping lines are making their fuel preferences known. In 2023, Maersk launched the Laura Maersk, the first green methanol powered container vessel. Since then, about ten dual-fuel green methanol powered vessels joined the fleet, with 18 in total expected on the water by end of 2025. Two Belgian companies, CMB and EXMAR, prefer green ammonia. One technical challenge to green ammonia and green methanol is that vessels and engines need modifications to accommodate them. While the vessels to accommodate these fuels are being built, the market begins at a low base. These latest IMO measures further strengthen the case for South Africa's investment in GH_2 infrastructure, offering both regulatory alignment and a pathway for supplying Zero- or Near-Zero GHG emission fuels to the global fleet.

5.3 South Africa's Preparations for Sustainable Maritime Fuel Production

The leading contenders for GH_2-based bunker fuels are green ammonia and green methanol. Production of both products in South Africa had already been planned in 2022, by different projects. They have achieved, or are close to achieving, Strategic Integrated Project (SIP) status with Infrastructure South Africa (ISA). Some of these projects are located near the coast (see Figure 16), including:

- HIVE (producing green ammonia), Coega, SIP status awarded
- Atlanthia (producing green ammonia), Saldanha Bay, SIP status awarded
- Enertrag Indigen Project (green methanol), Humansdorp, awaiting final project information before registration with ISA

Figure 16: Illustration of SIP-awarded Green Methanol and Green Ammonia Projects

Source: own illustration based on (H2.SA, 2024)

5.4 The Role of Fischer-Tropsch E-Diesel in Reducing GHG Intensity in Maritime Fuels

While GH_2-based Fischer-Tropsch e-kerosene is a known contender for Sustainable Aviation Fuel (SAF), its close relative Fischer-Tropsch e-diesel has, to date, not attracted much attention as a bunker fuel. E-diesel has the advantage, over ammonia and methanol, of being a drop-in fuel. This means that it may be used as it is in the existing global maritime fleet, which contains more than 100 000 merchant vessels. Not only could a vessel owner defossilise without engine and vessel modifications, but a vessel charterer would also be able to defossilise a single voyage carrying a specific cargo, by bunkering with e-diesel. In line with the IMO Net-Zero Framework and its anticipated carbon price of around USD 380 per tonne of CO_2 equivalent emissions, the continued uptake or blending with Fischer-Tropsch e-diesel could become a decisive factor for shipowners. It may determine whether they are exposed to higher GHG pricing or are able to lower the GHG intensity of their fuel mix to meet the required baseline target.

South Africa hosts two Fischer-Tropsch facilities: Sasol's large inland plant in Secunda, which uses coal and gas, and PetroSA's coastal plant in Mossel Bay, originally designed to process offshore natural gas. With offshore reserves now depleted, operations at Mossel Bay have been paused, and the facility is under care and maintenance. While traditional gas resupply options face economic and strategic challenges, this transition opens a significant opportunity of repurposing the existing infrastructure for the production of sustainable fuels. With South Africa's renewable energy potential and growing global demand for green fuels, Mossel Bay could play a key role in the emerging GH_2 and e-fuels economy.

When viewed through the lens of Zero- or Near-Zero GHG emission fuels rather than traditional fossil fuels, the potential of the Mossel Bay facility becomes significantly more promising. This coastal Fischer-Tropsch plant is uniquely positioned as it sits in a region with strong solar and wind resources, lies directly along a major international shipping route, and already hosts a workforce, both current and recently retrenched, with valuable expertise in Fischer-Tropsch synthesis. Importantly, the facility's scale is ideal for repurposing. At 45,000 barrels per day, it is smaller and more manageable than the majority of Western Europe's refineries, making it well-suited for a transition to sustainable operations. Embedded within the site is a 1,000 barrels-per-day pilot plant which is perfectly sized to initiate a green fuel pilot project. If it were to switch to make Zero or Near-Zero GHG emission Fischer-Tropsch e-diesel, it could sell a green drop-in fuel to a large potential customer base, requiring no ship modifications, and move from a national regulated to a global premium market.

5.5 Positioning South Africa as a Global Supplier of Sustainable Maritime Fuels

South Africa has a timely and realistic opportunity to become a key regional player in meeting the growing global demand for Zero- or Near-Zero GHG emission maritime fuels. With its extensive coastal infrastructure, abundant renewable energy resources, and established Fischer-Tropsch technology, the country is well-positioned to supply sustainable fuels that contribute to meeting IMO targets and align with international market trends.

By expanding its focus beyond e-methanol and e-ammonia to include Fischer-Tropsch-based options, South Africa can tap into a premium segment of the green maritime fuel market. This approach leverages existing strengths while responding directly to global demand signals, which offers both economic and climate benefits.

5.6 Further Reads:

Green Shipping Baseline Analysis: Five Critical Dimensions of South Africa's Maritime Transport

Load Connection Capacity Assessment of South African National Ports

6 Pathway for 'Just' Socio-Economic Development

Green hydrogen (GH_2) and Power-to-X (PtX) projects support the global energy transition while offering major socio-economic benefits like job creation and local development. Their success depends on early, sustained community engagement to build trust and social acceptance. Skills development and workforce transformation are vital to realising their full potential in South Africa. Promoting diversity and inclusion, especially for women and marginalised groups, is key to innovation and equitable growth.

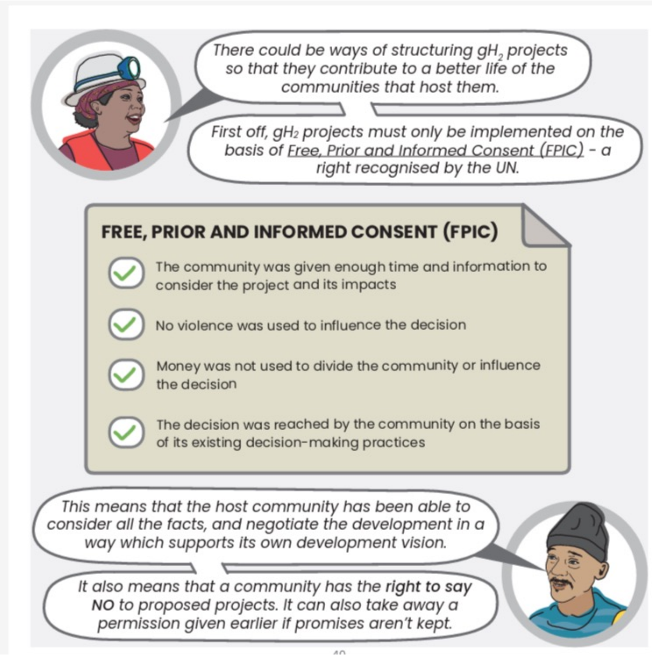
6.1 Driving a 'JUST' Transition

The global transition towards sustainable energy systems is accelerating, with GH_2 and PtX technologies playing a central role in defossilising key industries. For South Africa, these projects present a unique opportunity not only to reduce emissions but also to drive just and inclusive socio-economic development. Realising this potential requires sustained community engagement, targeted skills development, and a transformed workforce that reflects the country's diversity. Empowering women and marginalised groups is essential to ensure broad-based participation, foster innovation, and support equitable growth across communities.

6.2 Social Acceptance and Community Beneficiation Mechanisms

Public participation and social acceptance are essential for the success of GH_2 and PtX projects. To ensure this, project developers need to establish early and continuous engagement with local communities. However, it is important to recognise that some project developers might be reluctant to involve communities early on, particularly when financial investment remains uncertain, as they may worry about raising expectations that might not be fulfilled, if funding does not materialise. As such, adopting a phased engagement approach is essential. This entails starting early discussions that are clear about the project's current status, including possible risks and opportunities or benefits. This fosters trust, transparency, and ownership. Involving the public in decision-making and addressing their concerns enhances social acceptance and mitigates resistance. Effective communication strategies, such as community meetings, media outreach, and interviews with relevant stakeholders can address misconceptions. To help build grassroots understanding and support for the projects from the ground up, it is essential to capacitate communities about green hydrogen development processes, including potential opportunities, implications, risks, and available beneficiation mechanisms, including how they function and how communities can participate. Figure 17 below highlights the right recognised by the United Nations for communities to have "Free, Prior, and Informed Consent (FPIC)" early in the project development phase (Ben-Zeev, et al., 2023). Securing a 'social license to operate' minimises social resistance and ensures long-term project success, aligning solutions with local needs and aspirations.

Figure 17: Talking about GH_2



Source: (Ben-Zeev, et al., 2023)

Figure 17 above shows the principle of free, prior and informed consent (FPIC), a safeguard ensuring that local communities have the right to meaningfully participate in and approve projects that affect their land and livelihoods. To achieve a just socio-economic development pathway, it is imperative to implement concrete mechanisms that ensure surrounding communities benefit directly from green industrial growth. Within the burgeoning GH_2 sector, this necessitates the establishment of structured frameworks for community ownership, the facilitation of direct participation in procurement and supply chains, and the investment in local capacity through targeted skills development. Communities should be perceived not as passive observers, but as engaged stakeholders and active contributors to the energy transition. This can be achieved through transparent governance structures, the reinvestment of project revenues into local development initiatives, and policies that mandate equity participation or benefit-sharing. Community engagement and benefit-integrated project design underscore the importance of embedding community benefits into the core of PtX project planning, rather than treating them as an afterthought.

This approach includes local hiring quotas to prioritise employment opportunities for residents, investment in shared community infrastructure such as roads, schools, or clinics, and targeted community development programmes funded as part of project budgets (Urban Earth, 2025) . By integrating these elements into initial project design and impact assessments, developers can ensure visible, tangible benefits from the outset. Such interventions not only address historical disparities but also build long-term social licenses, mitigate resistance, and foster local economic resilience, which are essential to achieving a just and equitable transition.

6.3 Driving local Economic Growth through Ensuring Equitable and Sustainable Job Creation

The GH_2 sector has the potential to create multiple quality jobs and contribute significantly to South Africa's GDP as more jobs mean increased household incomes and improved quality of life across local economies. According to government-linked analyses, green hydrogen could provide 20,000 to 40,000 jobs annually by 2030–2040, eventually leading to 370,000–650,000 jobs across the sector by 2050, with a more immediate target of 20,000 jobs created within a few years of implementing the Hydrogen Society Roadmap (Department of Science and Innovation, 2021). This addresses one of South Africa's major unemployment challenges through large scale infrastructure projects, hydrogen production plants and other opportunities across the value chain.

As the sector evolves, skills development and workforce transformation will be essential to meet the growing demand for new capabilities. It is equally important to implement targeted upskilling programmes for workers transitioning from other industries, such as the fossil fuel sector, to ensure a just and inclusive shift. The Green Hydrogen Commercialisation Strategy (GHCS) (2023) delineates a prospective workforce planning framework, illustrated in Figure 18, which systematically maps the alignment between anticipated labour demand, education and training pathways, and enabling policy instruments. This strategic framework is designed to ensure a coordinated approach in developing the hydrogen-ready workforce that South Africa will need.

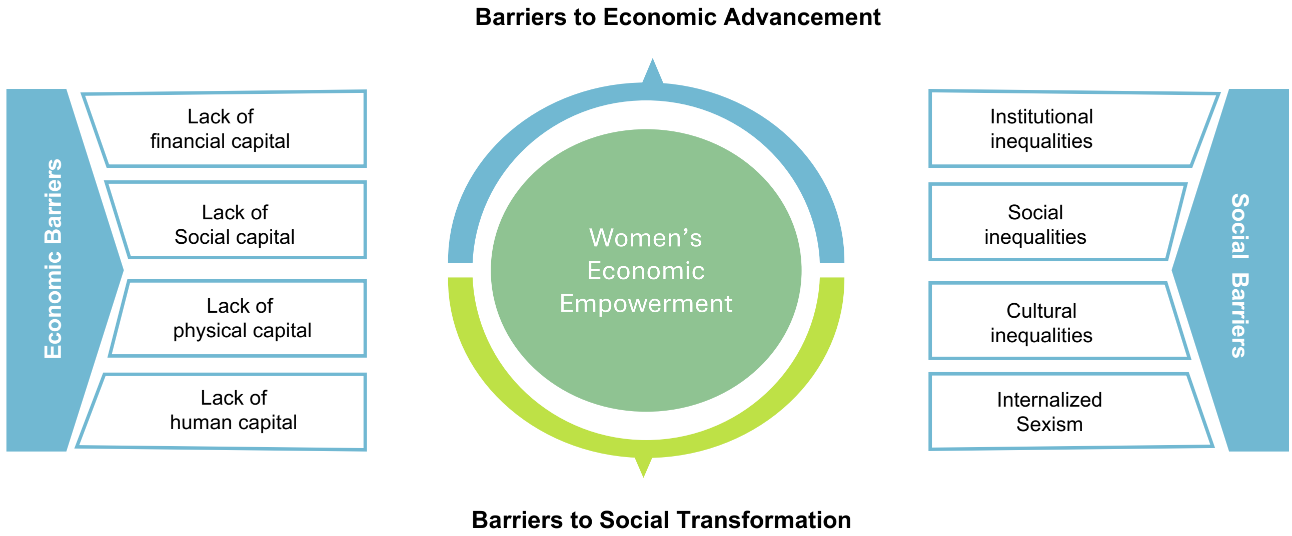
Technical and Vocational Education and Training (TVET) institutions play a vital role in equipping the workforce with skills in renewable energy technologies. Strengthening TVET education ensures that workers, including underrepresented groups such as women and youth, gain the technical expertise needed for employment in the green hydrogen sector. Moreover, fostering an enabling environment through supportive policies, investment conditions, and increased localisation can stimulate job growth. This involves providing advisory services, enhancing investment frameworks, and supporting business development, particularly in small and medium-sized enterprises (SMEs). Such measures ensure that the economic benefits of GH_2 and PtX projects are widely distributed, contributing to social equity and long-term economic stability.

Figure 18: A Holistic Skills Development Approach - Future Workforce Planning

Source: (IDC & DTIC, 2023)

Creating a diverse and inclusive workforce in the GH_2 sector is crucial for driving innovation, equity, and sustainable development. As the industry expands, it is key to ensure equal opportunities for women and other marginalised groups (such as youth) throughout the transition. However, economic empowerment of marginalised groups is currently hampered by both economic and social barriers, as shown in Figure 19 below:

Figure 19: Conceptualisation of Women's Economic Empowerment



Source: (UNIDO, 2021)

To overcome these obstacles, the green hydrogen sector must adopt targeted strategies to promote gender equality and inclusivity. This involves investing in skills development and capacity building programmes specifically designed for women and youth, creating mentorship networks, and implementing recruitment policies that actively address biases. Additionally, tackling structural inequalities, such as enhancing access to funding for women entrepreneurs in the energy sector, can help close economic gaps. Achieving a truly inclusive workforce requires a holistic and well-rounded approach that addresses systemic and cultural barriers, education, policy, workplace culture, and access to equal opportunities.

6.4 Aligning Community, Skills, and Policy for Green Hydrogen Success

The global transition towards sustainable energy systems, driven by GH_2 and PtX projects, offers a transformative pathway to reduce carbon dioxide emissions and promote long-term defossilisation across various industries. These projects provide significant socio-economic advantages, including job creation, local economic development, and increased workforce diversity. Ensuring social acceptance through public participation and community beneficiation mechanisms is essential for their success. Structured workforce planning and skills development, particularly through TVET institutions, are crucial. Additionally, fostering an enabling environment through supportive policies and investment conditions will stimulate job growth and ensure the widespread distribution of economic benefits. Integrating community benefits, effective workforce planning, and inclusive policies is fundamental to achieving a just and equitable transition in the GH_2 sector.

6.5 Further Reads:

Green Hydrogen Mechanisms for Community Beneficiation

Green Hydrogen Community Development Toolkit

Talking About Green Hydrogen

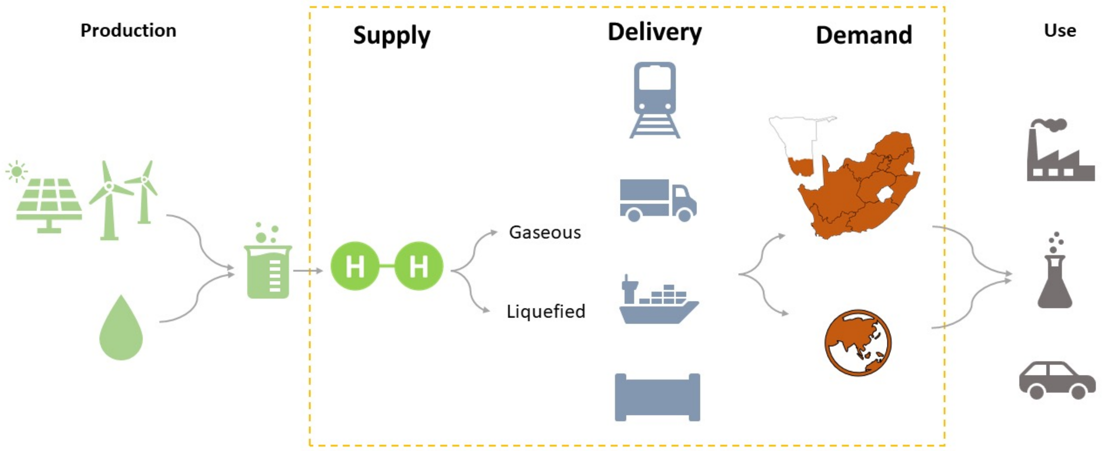
7 Pathway to Green Molecule Transportation Infrastructure

South Africa is preparing for a green hydrogen (GH_2) transition, driven by defossilisation targets and export potential, with logistics costs emerging as a key competitiveness factor. A recent study recommends local production, rail-based inland delivery, and ammonia (NH_3) as the export carrier to minimise costs, though these rely on assumed supply nodes, demand nodes, and delivery costs. To avoid misaligned infrastructure and rising costs, further detailed studies are needed to define a coordinated optimal delivery network and guide strategic investment for long term competitiveness.

7.1 Building Green Hydrogen Networks

Driven by its defossilisation objectives and the opportunity for global exports, South Africa is poised to embark on a shift towards GH_2 (IDC & DTIC, 2023). By 2050, South Africa plans to produce 7 Mtpa of GH_2, with domestic demand ranging from 1.5 to 2.1 Mtpa, and export opportunities from 1.9 to 8 Mtpa (CSIR & GFA Consulting Group GmbH , 2023). Typically, carbon-intensive hydrogen has been produced locally for industrial purposes, but the move towards renewable GH_2, along with an expanding consumer base that includes domestic heavy industry and mobility as well as global markets, require the development of new supply chains and supporting infrastructure. This shift highlights the urgent need for precise spatial mapping of GH_2 supply and demand, followed by the identification of strategic distribution (see Figure 20) to bolster market competitiveness within an ever-changing global environment.

Figure 20: Bulk Delivery of Gaseous and Liquid Hydrogen - Supplier-to-Consumer Focus



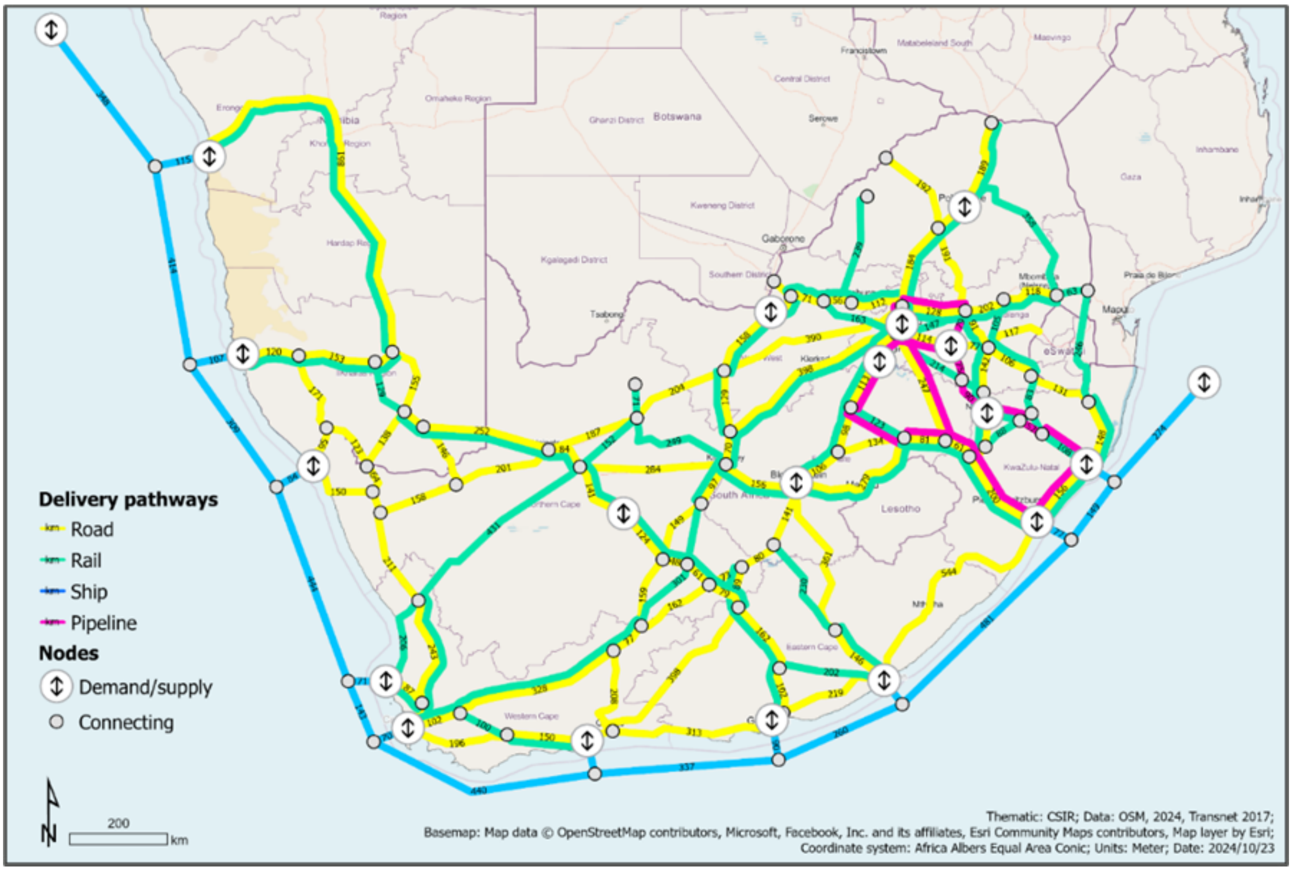
Source: (Zerhusen, et al., n.d.)

7.2 Supply and delivery infrastructure

South Africa has an extensive national rail network, consisting of roughly 30, 400 km of track (Transnet Freight Rail, 2024). Regrettably the rail network suffers from deteriorating infrastructure and unreliable service, leading to a notable decline in the volumes transported (e.g., from 172.65Mt in 2022 to 149.49Mt in 2023). The country's major pipelines are mainly concentrated around Gauteng and Mpumalanga, connecting production hubs, refineries, and the port of Durban. The pipelines transport petroleum for inland markets and methane-rich gas for KwaZulu-Natal (Transnet, 2024).This strategic access to ports on the coasts of South Africa that offers a significant advantage for the country to become a leading exporter. Currently, three ports (i.e., Saldanha Bay, Coega / Ngqura, and Richards Bay) are strategically positioned and in operation for the possible exportation of GH_2, while Boegoebaai situated in the Northern Cape Province is planned to be developed as a dedicated hub (CSIR & GFA Consulting Group GmbH , 2023; Northern Cape Development Agency , 2023).

The major existing pathways for each transport mode are shown in Figure 21 below. In addition to the choice of transport mode, future-ready logistics should also consider the hydrogen carrier type, each of which presents unique challenges in terms of logistics service provision, energy use, and safety.

Figure 21: Potential PtX Delivery Network for South Africa and Namibia



Source: (Zerhusen, et al., n.d.)

The proper selection of the delivery approaches to shape South Africa's GH_2 delivery network is a strategic imperative. The choice of mode is dependent on a variety of factors, including the form or carrier of hydrogen (e.g., gaseous or liquefied hydrogen, ammonia, etc.), the quantity to be transported, the delivery distance, the associated costs, and the availability of the delivery pathway, amongst others. Furthermore, a network (i.e., national) perspective is required to identify the optimal delivery pathway approaches due to the potential for shared infrastructure. This enables coordination between the various supply and demand centres to maximise efficiency and cost-effectiveness by leveraging common transport and storage assets.

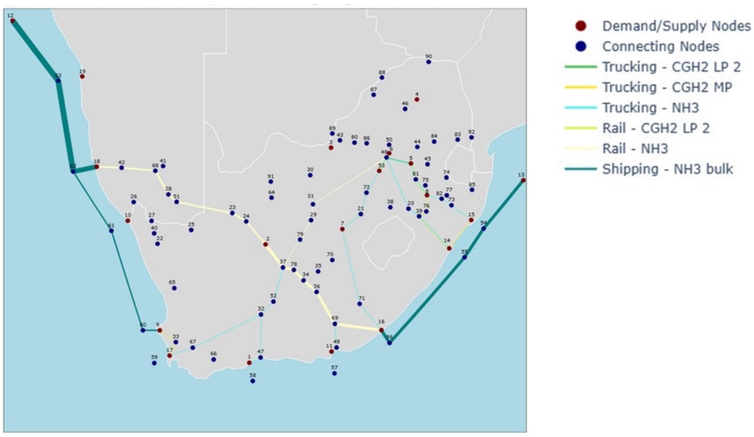
7.3 Green Hydrogen Supply and Demand Centres

South Africa's efforts to develop an optimal GH_2 delivery strategy are currently constrained by the uncertainty surrounding the location of hydrogen supply and demand centres, their respective quantities, and when/if they will materialise. Currently, supply and demand estimates are mostly reported at the national level, while regional or lower-level estimates are required to identify the ideal delivery network. A need therefore exists for a detailed geospatial map delineating supply and demand areas (IDC & DTIC, 2023). It is important to note that incorrectly estimating supply and demand could result in misaligned infrastructure developments with substantial financial consequences (e.g., increased delivery costs resulting in price inflations, value of investments not realising, etc.). Thus, to optimise the roll-out of infrastructure, it is essential to achieve clarity on the spatial, temporal, and volumetric aspects regarding regional hydrogen demand. If these aspects cannot be determined, sensitivity analyses should ideally be completed to assess the impact of different demand and supply scenarios on infrastructure planning and investment decisions.

7.4 Delivery Network Optimisation

A model was developed through a collaboration between GIZ, CSIR, the Rebels Group, and LBST to identify the most cost-effective delivery network across three scenarios. The aim was to ensure alignment among stakeholders and mitigate potential biases in the decision-making process. The model considered the bulk delivery of GH_2 in the form of compressed gaseous hydrogen (CGH_2), liquefied hydrogen (LH2), green ammonia (NH3), and liquid organic hydrogen carriers (LOHC), and was allowed to select single or multi-modal approaches consisting of road, rail, pipeline and/or maritime transport. Three scenarios were investigated. The first scenario considered using only existing infrastructure (i.e., the delivery pathways shown in Figure 21). The remaining two scenarios allowed for infrastructure expansion and were differentiated with the inclusion or exclusion of the Port of Boegoebaai as an operational export hub. Each scenario was evaluated under low, medium, and high hydrogen supply and demand conditions to account for associated uncertainties. Figure 22 shows an example of such an output obtained for a scenario. Similar assessments were produced for the remaining scenarios.

Figure 22: Visualisation of the Model's Results for a Scenario



Source: (Zerhusen, et al., n.d.)

7.5 Recommendations and Insights

The following recommendations have been developed for the integration into national planning and policy frameworks, based on the results of the modeling activity and informed by several underlying assumptions and limitations:

First, unnecessary GH_2 transport should be minimised by prioritising local production of GH_2 wherever feasible, with interregional transport limited mainly to major metropolitan areas such as Cape Town, Durban, and the Vaal Triangle. For inland and corridor delivery, existing north-south rail routes should be leveraged to support early-stage core projects, offering a cost-effective alternative to pipelines in regions where geographic or population constraints make pipeline development less practical. Export routing should remain flexible by assessing port infrastructure along both the West and East Coasts of South Africa and exploring the potential for NH_3 shipping between ports to adapt to evolving export dynamics.

The national export gateway strategy should also be clarified, determining whether South Africa should centralise exports through key 'gateway' ports or distribute them across multiple regional hubs. Infrastructure planning must align with off-taker preferences, allowing demand for specific PtX products, such as ammonia versus CGH_2, to guide the development of supporting transport systems. Additionally, regional collaboration should be strengthened to foster cross-border hydrogen coordination within Southern Africa, with a particular focus on enhancing provincial roles in infrastructure optimisation and coastal export development. A dual-system hydrogen network should be supported, recognising that inland industrial centres like the Vaal Triangle may evolve with a degree of autonomy. These areas must be reliably connected to renewable energy sources via the national grid. Finally, an assessment of South Africa's current infrastructure and regulatory framework for large-scale ammonia transport by road and rail is needed, as NH_3 is expected to become a preferred export vector, and early evaluation will help prevent future delays.

7.6 Optimising South Africa's Green Hydrogen Delivery Networks

South Africa's developing GH_2 sector requires strategic infrastructure development as hydrogen shifts from localised, fossil-fuel-based production to decentralised, renewable generation and international trade (IDC & DTIC, 2023). To adapt to this transition, South Africa needs to focus on flexible delivery infrastructure. The logistics of hydrogen delivery, whether through pipelines, trucks, railways, or maritime transport, will play a critical role in the design of energy systems. Every delivery method (such as green ammonia by rail, liquid hydrogen by ship, etc.) has unique capacities, levels of technological readiness, and economic characteristics (GFA Consulting Group GmbH, 2023). The cost of delivery will increasingly dominate the final price of hydrogen, greatly exceeding the relative delivery costs of fossil fuels (GFA Consulting Group GmbH, 2023). Further development and use of the network optimisation model will be essential to inform policy decisions, prioritise Strategic Integrated Projects, and plan infrastructure effectively to minimise cost.

7.7 Further Reads:

Green Hydrogen Investment: Profiles for South African Industrial Development and Special Economic Zones

8 Green Hydrogen Diplomacy

Green Hydrogen (GH_2) is emerging as a potential solution to defossilising the hard-to-abate sectors. While the cost of producing GH_2/Power-to-X (PtX) products is still relatively high, the inexorable decline in the cost of electricity from renewable sources and improvement in efficiency and cost of electrolysers all bode well for the GH_2 landscape. It is becoming apparent that collaboration within, and between, countries is imperative in unlocking investments to drive the transition to hydrogen-based economy. It would be imperative for developing countries that are depending on the export of GH_2 and PtX to balance competition with cooperation to ensure that they are not marginalised or overly dependent on a few import markets.

8.1 Unlocking South Africa's Role in the Global Hydrogen Economy

South Africa is poised to become a global leader in GH_2 production, leveraging its abundant solar and wind resources, strategic location, and growing international interest. The country's policy frameworks such as the Hydrogen Society Roadmap (HSRM) and the Green Hydrogen Commercialisation Strategy (GHCS), outline a dual-track approach to develop GH_2 for both domestic use and export. The Just Energy Transition Investment Plan (JET-IP) further prioritises GH_2 as a key pillar of South Africa's defossilisation and industrialisation strategy.

This shift aligns with the global climate commitments under the Paris Agreement, adopted in 2015, which aims to limit the global temperature rise to well below 2°C, while pursuing efforts to cap it at 1.5°C above pre-industrial levels (UNFCCC, 2015). Achieving these targets requires countries to reach net-zero greenhouse gas emissions by around mid-century. The agreement highlights the critical role of clean energy technologies, such as GH_2, in supporting overall defossilisation, particularly in hard-to-abate sectors like steel, shipping, and chemicals, where GH_2 offers viable solutions.

The commercial viability of GH_2 however, remains constrained due to high production costs, limited domestic demand and infrastructure bottlenecks (DTIC, 2023). Despite this, South Africa is anticipated to become the second lowest cost producer globally, after Chile. International cooperation is essential to unlocking this potential through trade agreements, infrastructure investment and regulatory alignment.

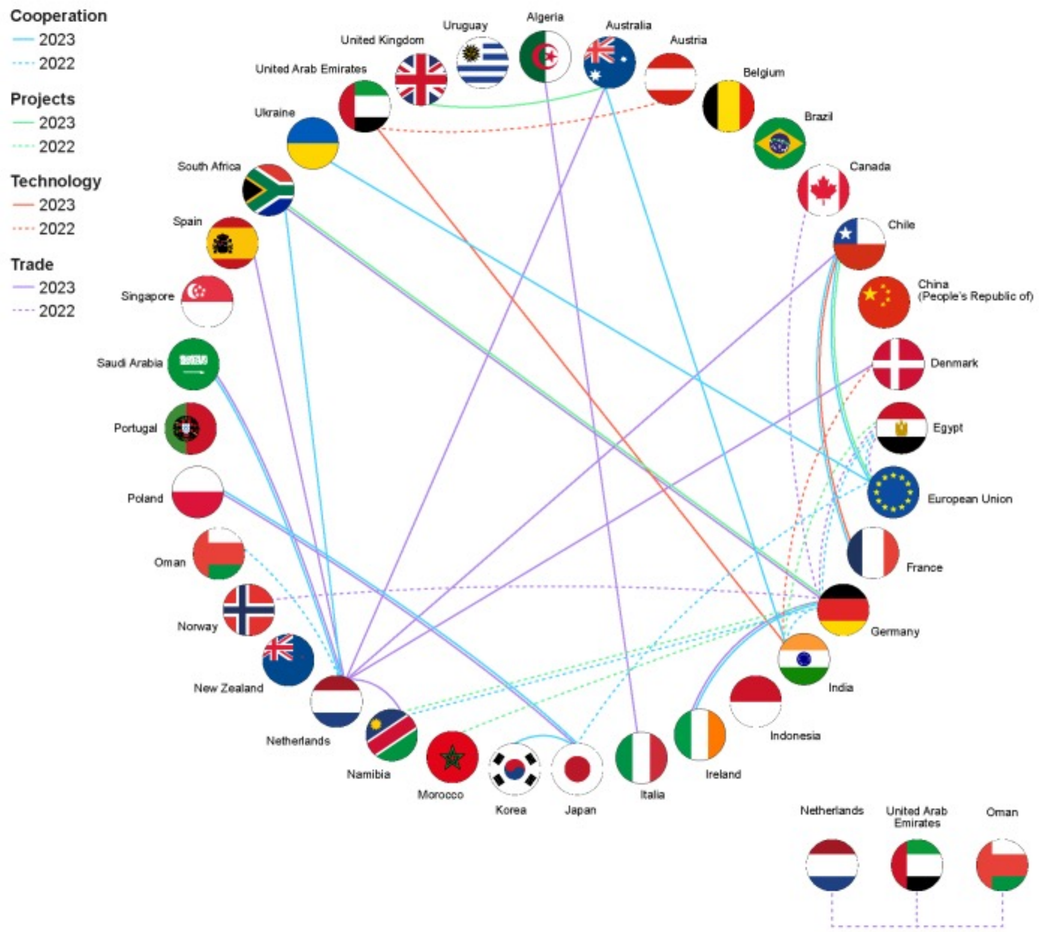
8.2 Diplomatic Partnerships

The global push for net-zero emissions, rising geopolitical tensions and the rollout of Carbon Border Adjustment Mechanisms (CBAMs) by key trading partners makes this an opportune moment for South Africa to accelerate its GH_2 transition. Key developments such as the 2024 European Union's EUR 32 million grant and Japan's strategic partnership signal growing interest in South Africa's potential (IMF, 2024). However, with only 4% of JET-IP funds allocated as grants, debt sustainability remains a concern (ibid). Strategic international cooperation can mitigate these risks by attracting concessional finance and enabling shared infrastructure development.

Collaboration within, and between, countries is therefore imperative in unlocking investments to drive the transition to a GH_2 economy. While it is anticipated that governments will play a role in steering GH_2 investments, there is considerable disquiet about the best approach to intervene in the market. Some governments have implemented climate change mitigation measures that sought to disincentivise the unbridled growth of major GHG emitting industries, inspired by their Nationally Determined Contributions. While these interventions are necessary, however, the concomitant policy instruments to preempt the potential circumvention of these climate change mitigation measures could fragment hydrogen markets, ultimately slow the global energy transition.

International cooperation for the development of a global green hydrogen economy goes beyond just financial support, with emphasis on trade in response to the increasing concerns surrounding energy security and supply diversification. Figure 24 below shows that between 2022 and 2023, governments around the world signed thirty-one hydrogen-specific bilateral cooperation agreements, of which 15 focus specifically on trade. Additionally, hydrogen is increasingly being included in broader energy cooperation agreements. Since 2022, 31 bilateral agreements have cited hydrogen as an area of collaboration (IRENA, 2023).

Figure 23: Co-operation agreements between governments on hydrogen since August 2022



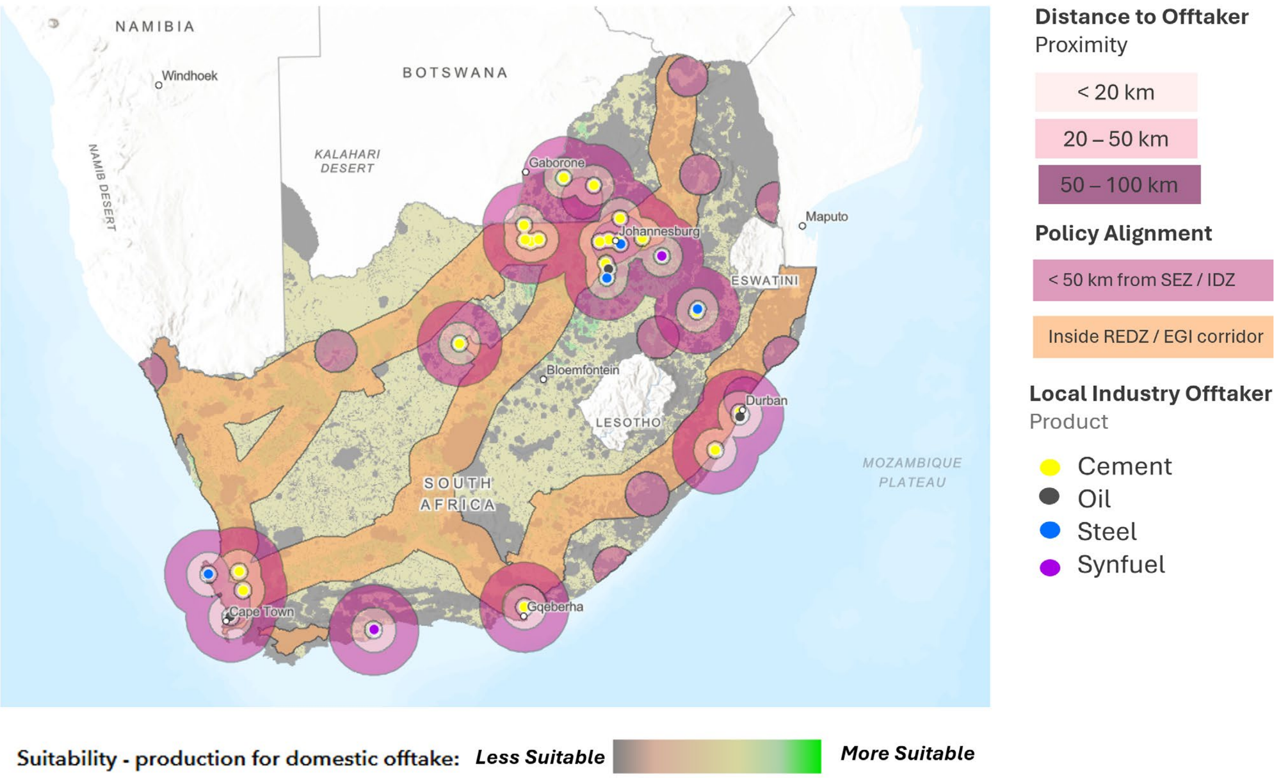
Source: (IEA, 2023)

8.3 Transforming Potential into Policy

While GH_2 is still an emerging sector and is deemed to become a major globally traded commodity, it is projected that the global GH_2 demand could reach 530 million tonnes by 2050, while the export market could be worth US$ 300 billion per annum over the same period (IDC & DTIC, 2023; PwC, 2025). Even with these predictions in place, the sector still faces significant challenges including high upfront costs, limited infrastructure, and copious amounts of renewable energy required to satisfy domestic energy needs while producing GH_2 for export. To maximise the potential of the emerging GH_2 economy, countries like South Africa are emphasising localisation through domestic value addition rather than simply exporting raw hydrogen.

South Africa can act as a strategic gateway between mature hydrogen markets in Europe and emerging economies across the African continent. This positioning is strengthened through active partnerships with the European Union, Germany, and Namibia, which are driving critical infrastructure development, including upgrades to ports, pipelines, and transmission networks essential for large-scale hydrogen production and export. Furthermore, South Africa's participation in the African Continental Free Trade Area (AfCFTA) and Economic Partnership Agreements (EPAs) enhances market access by enabling preferential trade terms and fostering deeper regional economic integration. Figure 24 below shows South Africa's designated hydrogen production zones and strategic infrastructure corridors, illustrating how regional integration and trade partnerships are being spatially aligned to support export readiness and domestic value addition.

Figure 24: South Africa's Green Hydrogen Potential Atlas



Source: (DFFE, CSIR, GFA,, GIZ, 2025)

South Africa's export ambitions hinge on off-take agreements and certification compliance. Just 10% of global hydrogen capacity planned for 2030 has confirmed buyers (BloombergNEF, 2023). Aligning with the EU's Hydrogen Strategy and Africa-EU Green Energy Initiative can facilitate certification and market access. The AfCFTA Investment Protocol provides a framework for green investment and regional cooperation. This investment protocol also bodes well for South Africa's strategic partnerships with Japan, Germany, and the EU. Clear investment promotion frameworks are however needed to attract foreign manufacturers through programmes such as GET.invest and AU-EU Innovation to support co-creation and localisation.

8.4 Leveraging International Cooperation

International collaboration is crucial for GH_2 trade, particularly between resource-rich but industrially underdeveloped countries like many in Africa, and industrialised but resource-poor countries, mostly in Europe. The shift to a low-carbon economy is reshaping global energy dynamics, potentially empowering frontrunners like China and the U.S. due to their mix of GH_2 resources and industrial capacity (Eicke & De Blasio, 2022; Quitzow & Zabanova, 2024). This underscores how the presence of abundant renewable resources in certain regions drives strategic investment and industrial decision-making.

This transformation also carries risks. Geopolitical tensions may rise, asymmetric dependencies may emerge, and legacy producers of ammonia, methanol and steel, lacking domestic hydrogen resources, could become vulnerable. The uneven distribution of economic benefits from GH_2 trade risks widening gaps between the Global North and South, potentially undermining ambitions for green-led industrialisation in developing nations.

Mitigating these risks requires a robust bilateral and multilateral GH_2 trade framework, aligned with climate goals, WTO rules, and trade fairness, that prevent protectionism and retaliatory measures. GH_2 is more than an energy commodity, it is a diplomatic tool, a catalyst for development, and a strategic lever for nations like South Africa. By championing international cooperation and integrating regional and global frameworks, South Africa can not only lead Africa's green transition but also unlock shared prosperity across the continent.

8.5 Further Reads:

African Green Hydrogen Report - Potential to Power: Advancing Green Hydrogen Across Africa

9 Coordinated Action to Reduce Project Risk and Enable Implementation

South Africa holds significant potential in green hydrogen and green iron, but project development is hindered by high perceived risk across regulatory, financial, infrastructure, and social dimensions. To unlock investment and move from strategy to implementation, a coordinated effort is needed to de-risk projects through regulatory clarity, blended finance, spatial planning, and demand certainty. Stakeholder alignment, including government, industry, financiers, and communities, is essential for building an enabling environment.

9.1 From Promise to Projects

While South Africa holds remarkable potential in the GH_2 and green iron value chains, real-world project development remains slow. This is not due to a lack of technical feasibility or economic rationale, but rather a high perception of risk across multiple dimensions. If this risk is not actively managed, South Africa will struggle to secure investment, attract international off takers or build domestic confidence.

Globally, GH_2 investments are gravitating towards locations where governments have created a credible enabling environment, through clear regulations, supportive infrastructure, concessional finance, and strong coordination across ministries and market actors. For South Africa to move from strategy to implementation, a concerted effort is needed to reduce risk, align stakeholders, and build an environment in which complex projects can thrive.

9.2 Understanding the Risk Landscape

Projects in the GH_2 and green iron value chains face a complex web of interrelated risks. These risks exist across every stage of the value chain, from feedstock supply to export logistics, and can severely constrain investment, delay timelines, or block implementation altogether. A useful way to visualise these barriers is by looking at the four key pillars of project development, as outlined in the Green Iron Trade framework: regulatory and policy uncertainty, financial and market risk, infrastructure bottlenecks, coordination failures, as well as social and environmental risks.

Figure 25: Financing Risk Factors for Hydrogen Projects

Contractual / Offtake	Political and Regulatory	Infrastructure	Technology
Demand uncerainty	Policital stability	Supporting infrastructure	Uncertain technology performance
Limited credible off-takers	Regulatory clarity	Existing industrial base	Technology availability (scale up)
Uncertain price	Permitting risk	–	Technical skills availability

Source: (Agora Industry , 2024)

9.3 Addressing Risk Through Structured De-Risking or Risk Transfer

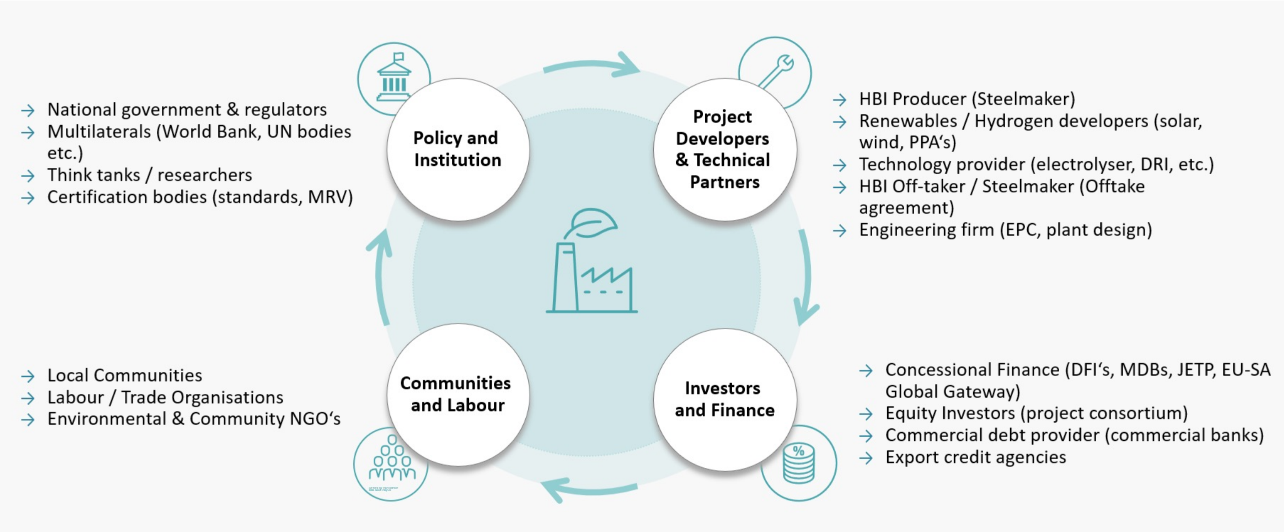
Reducing the risks associated with GH_2 development requires a structured and multi-pronged approach. While governments cannot finance every project, they can significantly improve the investment environment by targeting specific barriers. One key lever is the establishment of clear regulatory and certification frameworks, as discussed further in Paper 10. In South Africa, this means defining GH_2 and its derivatives in law and streamlining permitting and environmental approval processes. Fast-tracking hydrogen and green industrial projects by designating them as "strategic infrastructure" can also help shorten timelines and reduce uncertainty. Integrated spatial energy and industrial planning is another critical enabler. By identifying zones that offer the optimal combination of renewable energy potential, ore supply, water access, and export infrastructure, the government can better prioritise investments in grid upgrades, port expansion, and industrial clustering.

Mobilising blended finance is equally important, as commercial capital is unlikely to flow into first-of-a-kind projects without support. Public institutions can help de-risk private investment through concessional loans, guarantees, and risk insurance as risk transfer, while international donors and development finance institutions have shown interest in contributing, provided there is sufficient coordination to bundle their support into investable opportunities. Finally, anchoring demand through off take agreements is essential. Government-to-government deals, industrial buyer alliances, and long-term contracts as a de-risking mechanism can provide the price stability and market certainty needed to make projects bankable and attract long-term investment.

9.4 The Need for Stakeholder Coordination

The successful implementation of GH_2 and DRI projects hinge not only on technology and finance but also on the effective alignment of key players across the ecosystem. As shown in Figure 26 below, four categories of actors must work together to create the enabling environment necessary for project delivery:

Figure 26: Alignment of Key Actors for Project Delivery



Source: (Agora Industry, 2025, forthcoming)

The successful development of GH_2 value chains depends on coordinated action across a range of stakeholders. National governments, regulators, multilateral organisations, and standard-setting bodies play a critical role in establishing the policy frameworks, certification systems, and regulatory clarity needed to guide investment. Project developers and technical partners, such as steelmakers for example, are essential for integrating GH_2 into ore processing technologies and associated infrastructure.

On the financial front, collaboration between public and private sources of capital is vital. Concessional financiers such as DFIs and JETP donors provide the early-stage capital required to get projects off the ground, while commercial banks, equity investors, and export credit agencies are needed to ensure scalability and long-term viability. Equally important are communities and labour. The inclusion of local communities, labour unions, and environmental organisations in planning and benefit-sharing processes is crucial. Without broad social buy-in, projects risk delays, resistance, or failure to deliver on just transition commitments.

9.5 Practical Intervention to Unlock Projects

Several immediate actions can unlock real-world project development within the next 12 to 18 months. Declaring Hydrogen Industrial Hubs in high-resource areas, complete with pre-permitted zones, streamlined approval processes and strengthening Provincial courses of action, can significantly accelerate progress. Establishing a green iron export pilot that bundles hydrogen production, local iron ore, and port access would demonstrate feasibility and attract investment. A national de-risking facility is also essential to provide guarantees and early-stage capital, reducing investor risk and encouraging participation in first-of-a-kind projects.

In parallel, developing an infrastructure investment pipeline aligned with key industrial zones would ensure coordinated, efficient deployment of critical assets. Ultimately, the transition to a green economy cannot be driven by market forces alone. If South Africa is to lead in the global green hydrogen and green iron trade, it must evolve into a state that can de-risk, coordinate, and enable complex, capital-intensive projects. This requires a shift from broad strategic visions to concrete, bankable, and implementable project pipelines. The country possesses natural resources and the pressing need, what remains is to build the institutional capacity to bridge the gap between ambition and delivery.

9.6 Further Reads:

A Practical Guide to Developing Sustainable Green H2/PtX Projects in South Africa

10 Powering Global Trade: How Regulations, Standards and Certification Unlock Markets

Regulations, codes, standards, and certification serve as key enablers for facilitating global trade in green hydrogen and Power-to-X technologies. As South Africa positions itself as a competitive player in the global hydrogen economy, it stands to leverage its abundant renewable energy resources to drive economic growth, strengthen international trade partnerships, and develop a thriving hydrogen sector. Ongoing initiatives are working to establish a supportive environment for green hydrogen and Power-to-X, including the creation of the SABS Technical Committee and South Africa's active participation in international standardisation efforts such as ISO Technical Committee 197.

10.1 Establishing Standards and Certification for Global Green Hydrogen Trade

Adequate regulations, codes, and standards are critical to governing the production, processing, and application of GH_2 and PtX technologies. In resource-rich countries such as South Africa, scaling up GH_2 and PtX production will be key to achieving climate goals and unlocking export opportunities. Recognising this, key policy frameworks, such as the Hydrogen Society Roadmap (2021) and the Green Hydrogen Commercialization Strategy (2023), highlight the urgent need to address regulatory gaps and remove trade barriers. Certification has also been identified as a vital mechanism to ensure compliance with international standards, boosting investor confidence and enabling South African green hydrogen to compete globally.

To align with global best practices, South Africa actively participates in several international and regional platforms dedicated to harmonising regulations, codes, and certification systems. These include the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE, 2025), an intergovernmental collaboration focused on accelerating the global transition to hydrogen and fuel cell technologies, and the African Green Hydrogen Alliance (AGHA), which supports African countries in establishing public policy, certification systems, capacity building, and financing frameworks for GH_2 production.

South Africa is also engaged with the International Organisation for Standardisation's Technical Committee 197 (ISO TC 197), which focuses on the standardisation of systems and devices for hydrogen production, storage, transport, measurement, and use. At the regional level, it contributes to the work of the African Organisation for Standardisation (ARSO) and the African Electrotechnical Standardization Commission (AFSEC) through the Joint Technical Committee 1 (JTC1), which covers standardisation across renewable energy technologies, including energy storage and GH_2.

In January 2023, the Green Hydrogen Organisation released the Green Hydrogen Standard, providing a globally recognised definition of GH_2. This standard supports efforts by countries like South Africa to establish national definitions and criteria that consider socio-economic, environmental, and safety dimensions. Having a clear, internationally aligned standard ensures transparency and certainty for all stakeholders, confirming that hydrogen is genuinely low-carbon and sustainably produced. These frameworks are essential not only for supporting domestic policy coherence, but also for enabling global trade and ensuring South Africa's GH_2 is market-ready for international export.

10.2 Enhancing Regulations, Standards, and Certification Systems

South Africa has established a robust regulatory framework that integrates both national and international standards ensuring safety and compliance across the hydrogen value chain. However, it needs to be modified to better suit the new use cases of GH_2 and PtX. This is evident in the establishment of a South African Bureau of Standards Technical Committee 197 (SABS TC 197) which focuses on standardisation in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen and its derivatives.

The standards-setting process in South Africa follows a structured approach, as outlined in Figure 25. This figure illustrates the sequence of project stages in developing South African National Standards, along with the corresponding document designation for each stage. At the Preliminary Stage, a proposal for developing a new standard or revising an existing one is registered. If an investigation confirms the need for a standard, a new work item proposal is submitted. During the Preparatory Stage, a working draft is created, followed by the circulation of the committee draft at the Committee Stage. At the Enquiry Stage, a draft standard is established, and once all necessary requirements are met, it advances to the final stage, where it is officially published.

Figure 27: SANS Project Stages and Associated Documents

Source: own illustration based on (DTIC, 2017)

As South African stakeholders work on developing standards for GH_2 and PtX through existing structures, considering the following recommendations will be beneficial:

- Continuous participation in ISO H2 working groups to stay current with emerging hydrogen standards and best practices.
- Participate in the ISO/IEC Joint Advisory Group on hydrogen technologies to help coordinate and align hydrogen-related standards across ISO and IEC committees, ensuring comprehensive and harmonised standards that support South Africa's integration into the global hydrogen industry
- Publish joint permitting guidelines for hydrogen installations and promote knowledge sharing amongst neighbouring countries.
- Promote transparency and uniformity among regulators by harmonising responsibilities, with significant engagement from the relevant government departments such as the Department of Forestry, Fisheries and Environment (DFFE) and the Department of Trade Industry and Competition (DTIC).

10.3 Leveraging Certification Frameworks for Green Hydrogen and Power-to-X in South Africa

South Africa's prior experience with certification schemes, such as the Renewable Energy Certification Scheme (zaRecs, 2025), provides a strong foundation for developing a robust certification framework for green hydrogen and Power-to-X (PtX) products. The Renewable Energy Certificate System of South Africa (RECSA) manages the country's voluntary renewable energy certificate (REC) market, is modeled on the European Energy Certificate System (EECS). EECS, established through collaboration among EU Guarantee of Origin (GO) scheme issuing bodies under the Association of Issuing Bodies (AIB), offers a harmonised system for issuing, transferring, and redeeming renewable energy certificates, ensuring transparency and credibility in renewable energy claims across Europe. South Africa can also draw lessons from globally recognised sustainability certification systems such as Fairtrade and Rainforest Alliance. These schemes emphasise ethical labour practices, environmental stewardship, and responsible supply chain management, principles that can enrich a green hydrogen certification framework by embedding social and ecological considerations.

While REC's present some challenges, such as ensuring temporal and geographic correlation, additionality, storage attribution, and grid impact, these must be addressed during the development of a credible certification scheme. Recommendations for South Africa include adopting or adapting international certification frameworks to meet export market requirements while also reflecting local environmental conditions such as water availability and biodiversity sensitivity. This hybrid approach would enable quicker implementation through international recognition, while ensuring relevance to domestic priorities.

Key opportunities include the integration of RECs into GH_2 certification to verify the renewable origin of the electricity used in hydrogen production, which aligns with the sustainability requirements of key export markets. South Africa could also benefit from regional collaboration with countries such as Namibia to establish a harmonised Southern African Development Community (SADC) GH_2 certification framework, thereby improving regional trade compatibility and market access. Finally, developing quality infrastructure—such as testing facilities—and investing in capacity building for certification processes will be essential. South Africa may also engage in targeted training to localise international certification schemes while building the domestic capability to manage, audit, and verify compliance.

10.4 Regional Standards for Growth

With well-established structures and a wealth of knowledge and experience, South Africa is well-positioned to create a strong foundation for exporting GH_2 and PtX products. These standards and certification recommendations present an opportunity not only to build the groundwork for an export market, but also to stimulate local demand over time. Active involvement in standards-setting processes and regional collaboration will be key to implementing credible certification mechanisms that can drive sustainable growth in the sector.

10.5 Further Reads:

Supporting Sustainable Hydrogen Development: The Role of Technical Standards, Regulation and Sustainability Certification

11 Implementing a National Strategic Environmental Assessment for the South African Green Hydrogen Sector

As large-scale hydrogen projects progress, a proactive and integrated planning approach is essential to ensure sustainable, inclusive, and coordinated development. This may be achieved through a national Strategic Environmental Assessment (SEA) to complement existing strategic assessment and planning initiatives towards understanding and mitigating cumulative environmental risks and aiding informed decision-making. Aligning with ongoing regional SEAs, such as those for Boegoebaai Port and the Namakwa region, can enhance synergy and scalability. Expected benefits include improved spatial efficiency, early risk identification, increased investor and community confidence, and better alignment with South Africa's climate and development goals.

11.1 Strategic Environmental Assessments for Green Hydrogen

The transition to a GH_2 economy presents a significant opportunity for South Africa to drive sustainable industrialisation and enhance economic growth. This transition must be carefully managed to reduce and mitigate environmental and social risks. A Strategic Environmental Assessment (SEA) is a structured process designed to ensure that environmental and sustainability factors are incorporated into the creation of policies, plans, and programmes (Schreiner et al, 2024). A SEA is crucial for South Africa's green hydrogen sector as it provides a comprehensive framework for integrating environmental and social considerations into policy, planning, and programme-making processes, ensuring sustainable, inclusive, and coordinated development.

Unlike Environmental Impact Assessments (EIAs) that focus on specific projects, SEAs address cumulative environmental risks and support informed decision-making at a national scale. Aligning with ongoing regional SEAs enhances synergy and scalability, promoting spatial efficiency, early risk identification, and increased investor and community confidence. This holistic approach better aligns the sector with South Africa's climate and development objectives. Essentially, SEAs aim to embed environmental and social considerations into higher-level decision-making. Figure 28 below illustrates the role of SEA and EIA in the decision-making hierarchy:

Figure 28: Decision-Making Hierarchy for SEA's and EIA's

Source: own illustration based on (IAIA, 2024)

11.2 The Need for a Strategic Environmental Assessment

As South Africa moves toward large-scale GH_2 production, it is critical that this development aligns with the country's environmental sustainability goals, promotes community well-being, and supports economic inclusivity. This is where the SEA becomes critical as it has the potential to play a key role in guiding responsible GH_2 and PtX development by providing a comprehensive framework for informed decision-making. Such an assessment should evaluate all aspects of the GH_2 economy, including infrastructure requirements, potential land use conflicts or synergies, socio-economic impacts, and cross-border linkages—particularly with Namibia—based on plausible future production and export scenarios. It should also identify environmentally sensitive areas to prevent ecological degradation and highlight zones that are suitable or unsuitable for GH_2 development from both environmental and social perspectives.

Additionally, the SEA should assess the availability and sustainability of water resources critical to hydrogen production. By recommending effective planning and management strategies, the SEA can help maximise positive outcomes while minimising negative impacts. Importantly, it should facilitate alignment with national climate and energy policies, promote meaningful stakeholder engagement, and ensure that local communities share in the economic benefits—laying the foundation for an inclusive and sustainable GH_2 sector in South Africa. A national SEA for green hydrogen development in South Africa should align with and consolidate, as far as possible, any parallel and complimentary green hydrogen planning processes.

A national SEA for green hydrogen development in South Africa should support decisions for responsible green hydrogen development by:

- Assessing all aspects of the GH_2/PtX economy, including infrastructure needs, synergistic and competing land uses, socio-economic impacts, and cross-border linkages, such as with Namibia within the context of plausible production and export future scenarios,
- Identifying environmentally sensitive areas to prevent ecological degradation,
- Identifying suitable zones for GH_2/PtX development while highlighting areas where such activities would be environmentally or socially unviable,
- Assessing availability and viability of water resources for green hydrogen production,

- Recommending planning and management strategies that maximise positive impacts and minimise negative ones,
- Facilitating alignment of green hydrogen projects with national climate and energy policies, and
- Facilitating stakeholder engagement and promoting social equity in project development and enable economic benefits for local communities, towards fostering an inclusive and sustainable green hydrogen sector in South Africa.

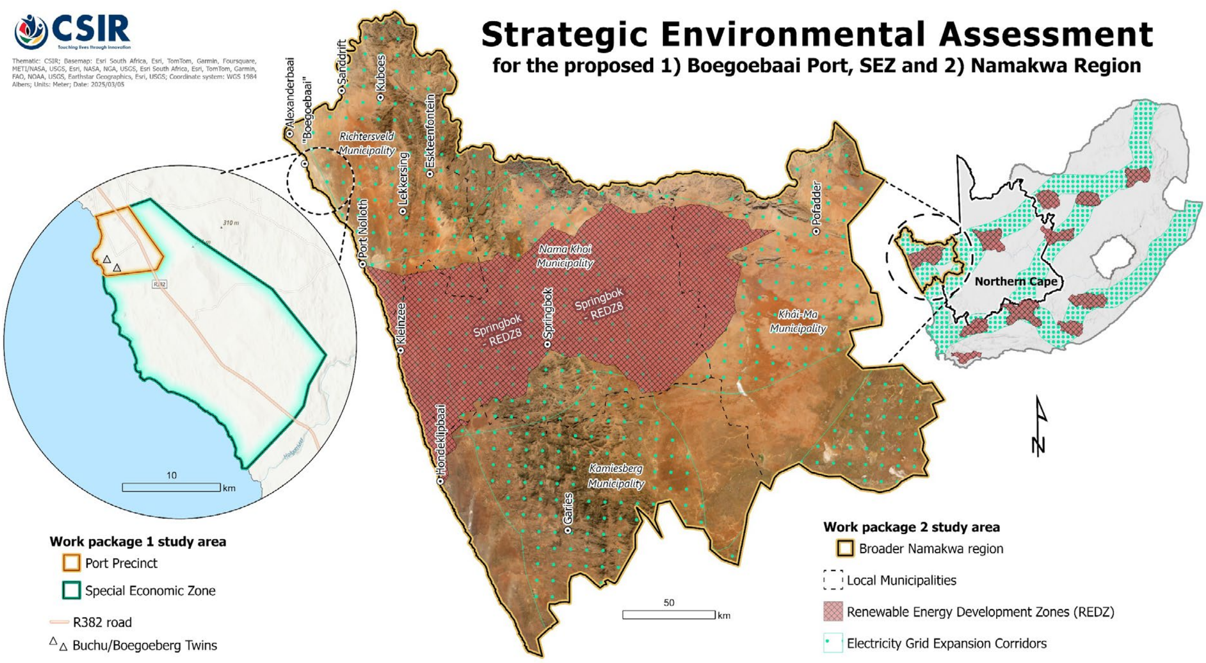
11.3 Key Components of a National Strategic Environmental Assessment

A national SEA for South Africa‘s green hydrogen sector would constitute a high-level, integrated planning instrument that systematically assesses the environmental, social, and economic ramifications of the sector‘s nationwide development. This assessment would include a spatially explicit framework that delineates priority development zones, environmentally sensitive areas, and key infrastructure corridors by synthesising data from existing regional SEAs, national policies, and geospatial tools such as the Green Hydrogen Potential Atlas. Additionally, SEAs should develop GH_2/PtX production and export scenarios, enabling accurate estimations of macro and local socio-economic impacts, potential changes to regional ecology, as well as exploring the links with adjacent industries, provinces, and countries also pursuing GH_2/PtX development, such as Namibia. It would map cumulative impacts, cross-sectoral interactions (including energy, water, land use, and biodiversity), and socio-economic vulnerabilities to inform decision-making at the policy and strategic programme levels. The process would be participatory, engaging national and provincial governments, local communities, industry, and civil society, culminating in a set of strategic recommendations, mitigation frameworks, and sustainability thresholds to guide future project-level EIAs and investment decisions. Ultimately, a national SEA would lay the groundwork for a coherent, equitable, and climate-resilient green hydrogen rollout.

11.4 Alignment with Other Strategic Green Hydrogen Planning in South Africa

Various other strategic planning and assessment processes have been initiated or are being ideated for provinces and regions in South Africa. For example, the CSIR is leading a SEA for the proposed Boegoebaai port, Special Economic Zone (SEZ), and broader development in the Namakwa region. It aims to establish an integrated decision-making framework, in which environmental sensitivity, risk identification, and strategic opportunities, constraints, and management actions will be identified at an early stage (CSIR, 2024). Figure 27 below depicts the study areas for the SEA for the proposed Boegoebaai Port, Special Economic Zone, and broader Namakwa region being developed by the CSIR. While South Africa is currently implementing regional SEAs for areas such as Boegoebaai and Saldanha Bay, it is important to complement these efforts with a comprehensive National SEA. A single, coordinated National SEA is essential to ensure strategic alignment, policy coherence, and sustainable resource management across the entire value chain. It allows government and stakeholders to assess cumulative impacts, inter-regional trade-offs, and infrastructure synergies that cannot be captured within isolated regional studies:

Figure 29: SEA Study Areas - Boogoebaai Port, SEZ & Namakwa Region



Source: (CSIR, 2024)

11.5 Expected Benefits of a National SEA for Green Hydrogen Development

Implementing a national SEA for the GH_2 sector offers South Africa a proactive mechanism to harmonise environmental sustainability with economic advancement. The government should spearhead the GH_2 SEA, leveraging its mandate to coordinate cross-sectoral planning, ensure environmental compliance, and align hydrogen development with national sustainability and climate objectives. Adopting a SEA can delineate zones with high potential for GH_2 development while minimising ecological risks and preventing land-use conflicts, thereby facilitating regulatory approvals and mitigating investment risks. This approach also allows for the early integration of biodiversity considerations, water resource management, and socio-economic requirements into the project cycle, leading to more informed decisions that balance development and conservation.

Furthermore, a SEA can expedite infrastructure planning, such as grid enhancements and transport corridors, by identifying strategic opportunities for co-location, thereby boosting investor confidence and unlocking blended financing. This strategy not only enhances its global competitiveness in the GH_2 market but also promotes a just and resilient development pathway that is inclusive, environmentally sustainable, and future ready.

In essence, a national SEA is a necessary step to ensure that the green hydrogen sector grows in an equitable, responsible and environmentally sustainable manner. By identifying risks, integrating policy frameworks, and engaging stakeholders, South Africa can position itself as a global key regional cluster in responsible green hydrogen while protecting its natural resources and promoting inclusive economic growth.

11.6 Further Reads:

Managing the Impacts of a Green Hydrogen/Power-to-X Economy: An Environmental Impact Assessment Guideline for South Africa

12 Maritime and Aviation Sustainable Fuels: Rethinking Carbon to Kick-Start Markets

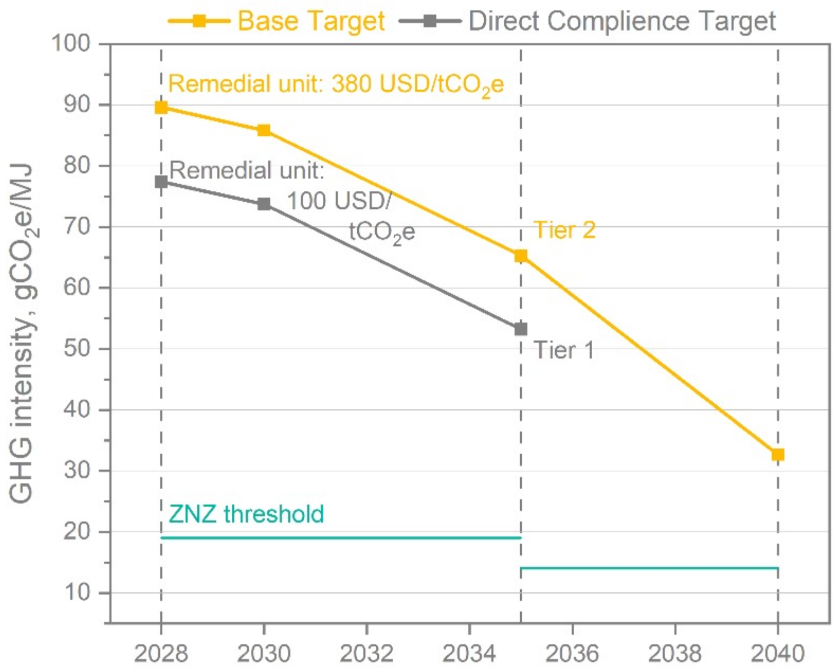
The production of sustainable maritime and aviation fuels—such as e-kerosene and e-diesel via the Fischer-Tropsch process—offers significant potential benefits for South Africa, given its existing expertise and the anticipated demand driven by international regulations. For the production of these fuels, the availability of not only green hydrogen but also a suitable carbon feedstock is essential. This paper shows that to catalyse the development of a sustainable fuel market, it is crucial to remain open to different alternative sources of carbon beyond conventional fossil fuels, such as solid waste.

12.1 Regulatory Forces Fueling the Shift to Sustainable Maritime and Aviation Energy

Commercial aviation and maritime shipping are both hard-to-abate sectors, as they use fossil fuels and have limited options for electrification or other low-emissions technologies. While the Paris Agreement focusses on the national emissions within the territories of states, shipping emissions in international waters is covered by the IMO, and aviation emissions in international airspace by the International Civil Aviation Organization (ICAO). The member states of both IMO and ICAO, as specialised agencies of the United Nations, have adopted defossilisation targets and strategies, which impact South Africa (SA) as a member state (ICAO, 2022; International Maritime Organisation, 2023).

For international shipping, the IMO Strategy on Reduction of Greenhouse Gas from Ships (International Maritime Organisation, 2023) sets clear emissions reduction targets compared to 2008 levels: a 20–30% reduction by 2030, a 70–80% reduction by 2040, and reaching net-zero emissions by 2050. An uptake target of ZNZ emission fuels in international shipping was set at 5-10% by 2030. In April 2025, the IMO adopted two binding regulations to accelerate shipping defossilisation. The first is a Greenhouse Gas Fuel Intensity (GFI) regulation, which sets two fuel intensity thresholds being the Base Target and the more ambitious Direct Compliance Target, both of which become stricter over time. As shown in Figure 28, the Base Target and Direct Compliance Target aim to reduce emissions by 30% and 21%, respectively, from the 2008 baseline of 93.3 gCO_2e/MJ.

Figure 30: IMO GFI Targets and Thresholds for ZNZ Emission Fuels



Source: own illustration based on (ClassNK, 2025)

The second regulation introduces economic penalties for vessels that fail to meet these targets. Ships exceeding the Direct Compliance Target (Tier 1) must pay $100 per tonne of GHG emissions, while those exceeding the Base Target (Tier 2) are charged $380 per tonne of CO2 in addition. These penalties are paid into an IMO Net-Zero Fund.

According to the GFI regulation, the Net-Zero Fund financially rewards ships which adopt the more expensive ZNZ emission fuels, effectively reducing the "green premium" they would have to pay. To qualify for ZNZs, fuels must meet GFI thresholds of 19.0 gCO2e/MJ until 2035, and 14.0 gCO2e/MJ thereafter.

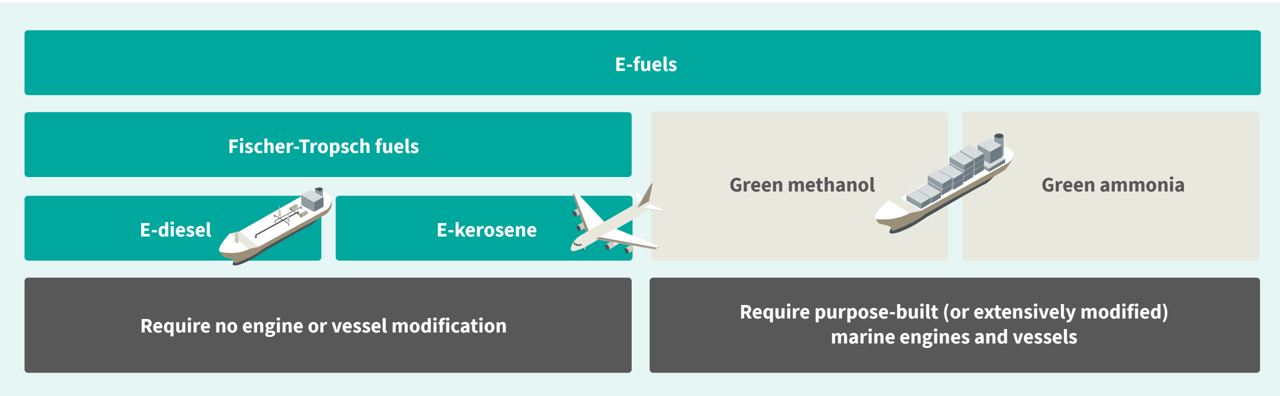
For international aviation, the Member States of ICAO have adopted two positions: a long-term global aspirational goal (LTAG) of net-zero carbon emissions by 2050 in October 2022, and to reduce CO2 emissions in international aviation by 5% by 2030 through the use of sustainable and low carbon aviation fuels and other cleaner aviation energies in November 2023.

12.2 Fischer-Tropsch Fuels 'Made in South Africa' as a Key to Emerging Markets

The IMO and ICAO resolutions provide opportunities for South Africa. At the same time, they impose certain requirements, the achievement of which will come with challenges. The challenge will be making these sustainable fuels available. The opportunity is to create new industries to do so. Two sustainable fuel development pathways exist: biofuels and e-fuels derived from GH_2. Biofuels are the most developed and cost-effective alternative to fossil fuels. However, the fact that Sout Africa is water-stressed (with two-thirds of land being semi-arid to arid) constrains the country's ability to produce biofuels at scale without leading to food competition. Fortunately, SA has excellent solar and wind resources, needed to achieve high-capacity factors for electrolysers to produce GH_2 at competitive costs. Combined with available land, this allows the production of e-fuels at scale.

Fischer-Tropsch (FT) fuels, green methanol and green ammonia are key types of e-fuel (Figure 32). Among them, FT fuels, such as e-kerosene for aircraft and e-diesel for marine vessels, are particularly attractive as drop-in fuels for existing fleet. SA hosts two FT facilities: Sasol's 160 000 barrel per day (bbl/day) facility in Secunda using coal and natural gas as feedstock, and PetroSA's coastal plant in Mossel Bay of 45 000 bbl/day capacity, designed to process offshore natural gas. With offshore reserves now depleted, operations at Mossel Bay have been paused, and the facility is under care and maintenance. Both facilities are mentioned in the HSRM and the GHCS lists Fischer-Tropsch infrastructure and skills as key capabilities and advantages in GH_2. However, as explored in Paper 4, further support of the GH_2 and e-fuel production is needed to make use of this available infrastructure.

Figure 31: Types of e-fuels



12.3 Rethinking Carbon Sources for Fischer–Tropsch: Unlocking the E-Fuel Market

A key issue in producing Fischer-Tropsch fuels at large-scale is the input feedstock. GH_2 is produced using electricity from solar PV and wind to electrolyse water, obtained most likely by the desalination of seawater at the coast or contaminated water inland. The second feedstock, carbon monoxide, must be made from the available carbon source: either solid carbon or as CO2 gas. For a long-term FT sustainable fuel business case, the supply of carbon must simultaneously be ecologically sustainable, available in sufficient quantities, and obtainable at acceptable cost. However, the available sources do not comply with all these requirements (Figure 33).

Figure 32: Types of Carbon Sources Available for Producing e-fuels in SA

		Large-scale availability	Costs	Sustainability
CO_2 gas	**Industrial point sources**	Available	Acceptable at source, incur additional transport costs	Only in the short-term (e.g. until 2036 or 2041 in the EU RED III)
	Direct air capture	Technology is still under development	Expensive	Sustainable
	Biogenic sources	Available but mostly located in KZN	Acceptable at source, incur additional transport costs	Sustainable
Solid carbon	**Solid biomass**	Limited	Acceptable at source, incurs additional preparation and transport costs	Sustainable
	Solid carbon from waste	Available	Acceptable at source, incurs additional transport costs	Individual Life Cycle Accessment required

Despite the challenge, there is a potential way forward. Carbon monoxide for the FT synthesis must be made either by gasifying solid carbon with steam or by reducing CO2 gas in a reverse water-gas shift (RWGS) reactor. Although there are various CO2 point sources available in South Africa, processing of solid feedstock offers a significant advantage in the early stages of the e-fuel market.

Gasification of solid carbon generates both carbon monoxide and H2, reducing dependence on costly H2 from electrolysis. In contrast, the RWGS process consumes GH_2. This transpires that making a given quantum of FT fuel requires three times more electrolysis hydrogen, when the carbon feedstock is CO2 gas (to be reduced) than if it is solid carbon (to be gasified). This impacts the CAPEX for the electrolyser, renewable energy infrastructure and hydrogen storage, affecting the levelised cost of the produced fuel.

Examples of the possible carbon sources are municipal solid waste and end-of-life tyres (ELTs). The latter currently present a disposal challenge, as they are highly durable and non-biodegradable, taking many years to decompose with a danger of groundwater contamination. The use of ELTs as a carbon feedstock provides a tyre disposal solution and a FT carbon feedstock supply solution simultaneously. By applying a Life Cycle Assessment to tyres, the carbon emissions of the production process may be divided between the first application in road transport and the second as liquid fuel. This will result in the fuel having less effective carbon content than unabated fossil fuels, allowing maritime shipping and aviation to meet their defossilisation targets. ELTs may be assigned as an acceptable carbon source for e-fuels for a defined period, in a similar manner to the EU RED III allowing CO2 from industrial point sources for a defined period.

The proposition is therefore made, that prioritising solid carbon over CO2 gas as feedstock in the early stages of the sustainable e-fuels market will make it easier for the FT facilities to pivot to sustainable markets. CO2 gas may be used as a carbon feedstock once the market is established, by which time electrolyser costs will have dropped relative to today.

12.4 South Africa’s E-Fuels Edge

Fischer-Tropsch fuels, such as e-diesel and e-kerosene, play a crucial role in helping international maritime shipping and aviation sectors meet their emission reduction targets in the coming decades. South Africa is well-positioned to benefit from the growing demand for these fuels, thanks to its existing Fischer-Tropsch infrastructure and expertise.

However, the current fossil-based production processes must overcome the challenge of sourcing sustainable carbon for e-fuel production. Potential carbon sources include CO_2 gas from industrial or biogenic origins, CO_2 captured directly from the air, and solid carbon sources such as biomass or non-biomass waste.

Regardless of the source, further processing is required to convert these materials into carbon monoxide - the key molecule needed for Fischer-Tropsch synthesis. In this regard, gasifying solid waste, such as end-of-life tyres, offers a dual benefit: it produces valuable hydrogen as a co-product and addresses waste disposal issues simultaneously. This approach is particularly advantageous in the early stages of e-fuel market development, when green hydrogen remains expensive and limited in supply.

12.5 Further Reads:

Carbon Sources for PtX Products and Synthetic Fuels in South Africa

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