GREEN HYDROGEN COMMERCIALISATION STRATEGY FOR SOUTH AFRICA

FINAL REPORT

30 November 2022

Table of Contents

Introduction and Background

Achieving global Net Zero by 2050 has been estimated at a cost of $130 trillion by IRENA, making the energy transition possibly the single biggest global growth opportunity. Although prompted by climate change, the global energy transition is now clearly being driven by technology innovation and commercial returns.

Global energy models are shifting from the historic reliance on extraction and processing of fossil fuels to future models based on converting and storing free and abundant natural energy resources. The need for transportable and tradable green energy molecules is a critical part of satisfying future global energy demand as well as decarbonising hard to abate industries and is driving the growth of a new global energy market for Green Hydrogen (GH).

Scientific modelling shows that the world will exceed the 1.5 degree warming scenario targeted under the Paris agreement. This is increasingly broadening the demand side energy transition focus to accelerate supply side interventions, including curtailment of fossil fuel investment as well as accelerated supply side development of GH.

This bodes well for South Africa, with abundant renewable energy resources and provides significant economic growth opportunities through:

a) Production and export of GH into future global green energy trading markets
b) Production and domestic use of GH to decarbonise South Africa's economy, and
c) Development of industrial capability in the manufacturing and supply of equipment used in the global GH value chains.

This offers a significant commercial opportunity for South Africa to develop a new green energy economic sector to drive growth and development, improve energy security and to transition to a low carbon economy and society. However, it also presents a series of challenges for stakeholders to ensure that this important lever to transition the economy to a lower carbon intensity is also aligned to the National Development Plan (NDP) and the need for inclusive participation in this new sector.

Further important context to developing GH production capability is the South African Government policy and approach to decarbonising South Africa's economy. In this regard, the Government has mandated the Presidential Climate Commission (PCC) to oversee a Just Transition of South Africa's economy to lower emissions in line with our Nationally Determined Contribution (NDC) under the Paris Agreement climate change goal of 1.5 degree C warming scenario. This national commitment towards decarbonising the economy is in line with global standards and has important bearing on the scale and timing of domestic production of affordable GH.

A comprehensive strategy will outline the commercial opportunity and development approach for a viable GH industrial sector, able to service both export as well as stimulate domestic demand and the right behaviour to meet sectoral decarbonization targets. Establishing such a new long-term industrial cluster and capability will however require bold policy and government support aligned to support private sector driven investment in infrastructure at a time where South Africa is battling low economic growth and fiscal weakness. Securing international support and financing through bi-lateral and commercial arrangements where developed nations need to secure long-term security of GH supply and South Africa's need to drive economic recovery through green economic infrastructure that will also address the triple challenges will be key to the country securing an early mover market position.

In response to such GH economic development opportunities, Minister Ebrahim Patel established a South African GH Panel (GHP) in June 2021. Eight work clusters with designated research teams were identified and tasked with undertaking assessments of the respective parts of the hydrogen value chain. The first interim report of the GHP was delivered to Minister Ebrahim Patel on 13 August 2021. This report builds on the findings of the interim report and focussed on the following core Work Packages with the main objective of developing the first iteration of South Africa's GH commercialisation strategy:

Figure 1.1: 5 Core Work Packages of GH Commercialisation Strategy

This Green Hydrogen Commercialisation Strategy (GHCS) provided input to the Green Hydrogen Sector section of the Just Energy Transition Investment Plan (JET-IP) that was approved at Cabinet in October 2022.

Commercialisation strategy vision and objectives

This Green Hydrogen Commercialisation Strategy (GHCS) builds on the strong foundation of the work undertaken by the Department of Science and Innovation (DSI) with respect to its HySA programme and the recent development and publication of the Hydrogen Society Road Map (HSRM).

A GH commercialisation strategy must align to national objectives whilst being responsive to competitive market drivers and success factors. The report outlines significant opportunities and benefits that can be derived for South Africa and suggests options and focused actions. It is important to note that recommendations are made based on relative ranking of multi-criteria and qualitative analysis as the detailed technical and financial quantitative modelling typically required for investment decisions has not been developed at this stage.

South Africa's GH Vision must incorporate key strategic design principles to ensure a long term sustainable and vibrant sector design:

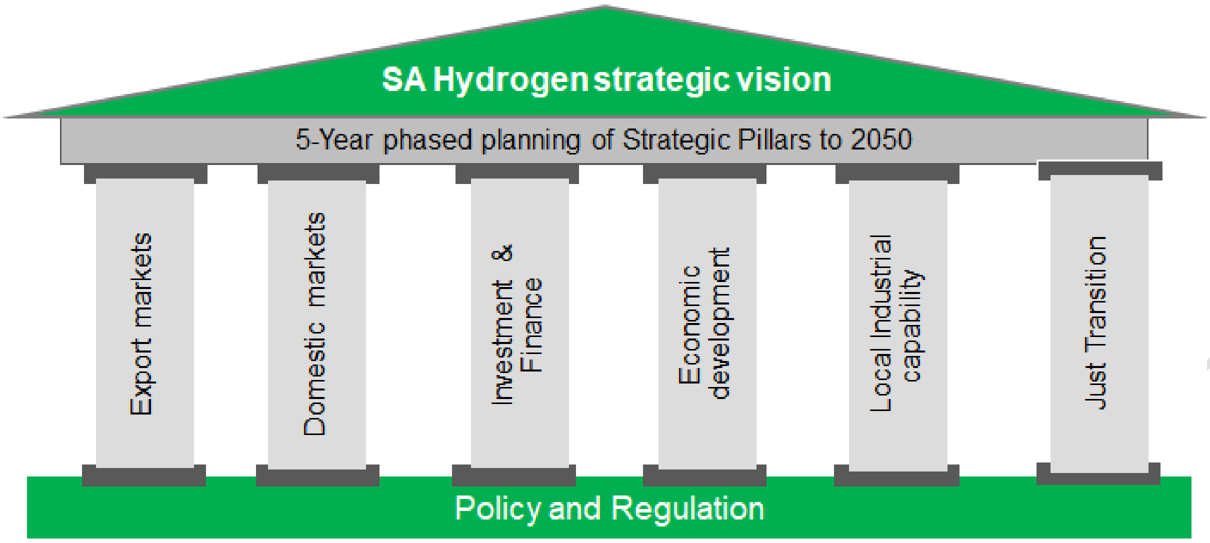


Figure 1.2: SA Hydrogen Strategic Vision - Developing a globally competitive, inclusive and low carbon economy by harnessing South Africa's entrepreneurial spirit, industrial strength and natural endowments.

The following strategic objectives should be considered in pursuit of South Africa's GH Strategic vision outlined above:

1. **Export Markets: secure long-term global market share and competitive trade position:**
   - Strategically position South Africa as a preferred and reliable provider to key markets, specifically EU/ UK, leveraging trade relationships and government support.
   - Secure global market and offtake MoUs with national procurement programmes such as H2 Global.
   - Expedite an export pilot project to ensure SA is seen as a serious global player and achieves early market entry.
   - Progress international strategy.

2. **Domestic Markets:**
   - Introduce supportive policies and a regulatory framework for GH that aids GH price parity to increase domestic GH demand.
   - Support research and development in hydrogen mobility applications, specifically focussed on Heavy Duty Fuel Cell Vehicles.
   - Demonstrate feasibility of GH applications in hard-to-abate sectors such as non-ferrous metals, green steel, and cement in order to foster short term pilot projects and long-term commercialisation.

3. **Investment & Finance: Foreign Direct Investment and low-cost green finance:**
   - Secure strong inflow of foreign direct investment and outflow of GH exports by means of comprehensive hydrogen incentive packages such as, tax incentives, grant schemes and reduced import surcharges on technology options.
   - Establish a regulatory and market framework to drive investment in South Africa's GH economy.
   - Define a key set of "catalytic" infrastructure projects that will frame the national GH strategy and enable private sector leaders to roll out their strategies whilst meeting Government's longer-term objectives for inclusive economic growth.

Such projects should be declared as Strategic Integrated Projects (SIPs) by the Department of Public Works & infrastructure (DPWI).

- Define government role and financial investment and support for pilot projects in order to expedite and enable private sector investment. Such projects could be declared as Strategic Integrated Projects (SIPs) through Infrastructure South Africa (ISA).

4. Economic and socio-economic development:

- Contribute towards reaching South Africa's emission reduction goals as per the Peak, Plateau, Decline Emissions Trajectory Range reflected in the NCCRP and NDP. This should include the contribution GH production can make to future NDC targets South Africa will need to consider in 2025 and beyond.
- Focus on decarbonising hard-to-abate industrial sectors in SA economy, by aligned sectoral carbon budgets with the role that GH can contribute to mitigation and financial support required for transition without prejudice.
- Ensure integration of renewable energy through a robust GH sector and regulatory framework that has a positive influence on energy security and domestic energy prices. E.g.
- Incorporate non-financial criteria in procurement processes that support socio-economic development, skills transfer, local supply and enterprise development, and opportunities for local ownership
- Develop training and skills development programmes to support job creation within the GH sector.

5. Local industrial capability and participation

- Implement projects to develop skills and achieve localised industrialisation for key parts of the GH value chain. Invest and implement research and development programmes.
- Understand the potential for industrialization of the renewable energy manufacturing supply chain through an aggressive GH strategy. This should involve alignment of the Masterplans in process in the renewable energy, steel and automotive sectors as well as relevant Phakisa processes (e.g., oceans).
- Create partnerships and joint ventures to secure investment, technology partnerships, and long term demand off-take agreements.
- Work closely with the Department of Science and Innovation and Department of Higher Education and Training to drive the identified skills action plan.

6. Consider the need and role of a Just Transition:

- Analyse and plan for a Just Transition, ensuring appropriate public and social dialogue and understanding.
- Quantify the commercial and economic impact and sustainability of industrial sectors as they invest in decarbonising their businesses through the energy transition.
- Ensure appropriate training and skills development programmes to limit job losses and support employment as industry sectors decarbonise.
- Engage in a social dialogue between workers and their unions, employers, government and communities in order to ensure that GH development contributes to climate change mitigation as well as adaptation.

1 Salient points of literature review

Within the above context of global decarbonisation, GH has been a global focal point due to the versatile nature as an energy carrier and its ability to decarbonise value chains, products, and economies. Multiple literature sources have identified the rationale for use of GH given its versatile applications and production processes. The most sustainable and priority production method is through electrolysis of water using renewable energy to split the water molecule into hydrogen and oxygen. Countries with favourable renewable energy locations are likely to become net exporters of GH or related GH vectors such as ammonia and those that do not have such favourable conditions are likely to become net importers. This will prompt a global market for GH that will unlock new trade relationships and opportunities.

Multiple countries and regions have published their net-zero targets, featuring GH as a key strategic mechanism to contribute towards decarbonisation. As of 2021, more than 30 countries have published a hydrogen roadmap highlighting over 200 hydrogen projects with governments committing to over $70 billion in public funding (Hydrogen Council in collaboration with McKinsey & Company, 2021). As part of designing a South Africa GH commercialisation strategy, a literature review of such published information has been undertaken to identify common themes and insights. Appendix A outlines the Literature Log and further detail with key takeaways are summarised below.

Key Takeaways:

General

- GH is unilaterally confirmed as a critical energy carrier required to achieve net-zero compliance across the globe. Focus is largely centred on hard-to-abate sectors but dependent on long term price reductions, wider energy user applications are likely.
- The global market for GH is only starting, but key countries are already positioning for market share and starting to break ground on projects. The race for first-mover advantage is thus well under way and South Africa is lagging other competing countries which are Morocco, Ukraine, Saudi Arabia, Chile, and Australia to name a few.

Strategy Formulation

- There are over 30 national strategies published for hydrogen. Some of these include countries which are potential net importers. However, for South Africa, it is important that we reference strategies of countries best suited to be net exporters such as Australia and Chile as these countries will compete with South Africa for net import global demand.
- Using carbon pricing to balance the scales in favour of GH above conventional fossil fuels is proposed by multiple country strategies and may be a useful leverage point for South Africa.
- Every country's GH strategy is unique to the local conditions, production, and sector targets. Some key common themes are highlighted below:
    - o Scale of assets and infrastructure required to meet desired targets. This is an important planning step for South Africa. The pace at which scale is reached is crucial as well as choosing optimal locations for initial projects with the resources and ability to expand in the future.
    - o Opportunities for sector-coupling. This relates to optimising gas and electricity infrastructure to deliver low-cost GH. This will be key for South Africa’s global competitiveness.
    - o Key local market focus areas, for example Australia will focus on heavy road transport and manufacturing processes. The strategy for South Africa should

include key focus areas for prioritisation into the market, for example sustainable aviation fuel or steel production.
    - A commercial model assessment inclusive of opportunities and the role of the state to reduce risk. The role of the state is key for the success of GH in South Africa to reduce country risk and attract private investment.
    - Policy and regulatory assessments. This is vital for the GH strategy to ensure a clear and streamlined path for GH production.
    - Identifying key focus areas for Research and Development to improve technologies and identify initial projects. This will play an important role for localisation in South Africa over time through directed research to provide technological advantages; and
    - A social licence assessment – looking at the holistic impact of the new GH market on domestic socioeconomics. This is key for a South African strategy to ensure a smooth adoption of GH production and a just energy transition.

Demand

- The global demand figures for GH are well-documented, but with much less certainty on the local production vs import mix. These numbers are continuously being updated as countries commit to net-zero. It is therefore critical to continuously watch the relevant signposts for updates. Countries with limited natural endowments will create import demand nodes, mostly the EU, Japan and Korea, who have formed strategies detailing their need for hydrogen in the next 20-30 years outlining the volumes required and preferred landing prices. This sends a clear message to potential export countries to move fast. Although global demand is estimated between 300-500 Mt of low-carbon hydrogen by 2050 (Industry Research Report, 2021), with approximately 10% expected to form global trade vs own country production. South Africa also has a domestic demand for GH; however, the demand figure is not consistent between sources and ranges between 1.9 mtpa – 6 mtpa. This is explored in Section 2.

Supply Chains

- The creation of hydrogen hubs is being explored as part of Australia's national strategy to produce hydrogen at a globally cost-competitive price.
- Countries identified as supply nodes with established gas pipelines to demand nodes will have an advantage to be more cost-competitive, as this brings down the cost of hydrogen transportation as reported in EU hydrogen policy (2021). Some of these countries are looking to blend their natural gas supply with GH in their pipeline infrastructure according to EU hydrogen policy (2021) and Australia's Hydrogen Council (2021). South Africa, on the other hand, is at a disadvantage due to the limited pipelines across the country. An investigation into the feasibility of a more robust pipeline is required.
- A clear distinction between the role of the state and the role of the industry is required across the value chain to anchor investment into infrastructure.

Value Chain and Equipment

- Across literature it has been well-established that electrolyser costs are too high to compete with other hydrogen production methods like grey or blue hydrogen production. Countries have therefore allocated significant investment into GH in order to make GH more cost competitive. Bloomberg New Energy Finance estimates that US$150 billion of government support funding will be needed worldwide to halve the cost of producing GH over the next 10 years.

Gaps identified in literature requiring additional research:

- Identification of sector-coupling opportunities. This relates to the gas and electricity sectors co-optimising the delivery of low-cost GH. This would include exploring how the existing and potential gas infrastructure could complement GH production.
- Techno-economic analysis around the optimal mix in the South African energy system between electrons (electricity) and molecules (GH) transportation (i.e., transmission /distribution vs pipeline infrastructure) between production and load centres aligned to export, decarbonization and energy uses of GH.
- Additional research should be conducted to strengthen GH's contribution to a just transition. This includes socio-economic aspects such as the promotion of air quality, black economic transformation, youth and women development and skills development.
- A clear breakdown of the job and skills requirements needed and how GH can contribute to enhancing job creation in South Africa.
- Understanding unique South African challenges such as electrical infrastructure constraints.

Based on a review of other foreign National Hydrogen strategies, the following critical elements were identified as leading and best practice and should be developed in detail in future phases of South Africa's GH strategy and master plan:

- Direct investment by the state
- Economic and financial support mechanisms
- Legislative and regulatory measures and policies
- Setting of standards and priorities
- Research and development
- International strategy

2 Hydrogen Demand Analysis

Unlike fossil fuel energy models, the scale of GH production is technically limitless assuming free and abundant renewable energy feedstock and sufficient scale of installed equipment. The cost of the capital-intensive conversion process however creates a commercial limitation based on affordability and price competition to the end user application. Large, energy intensive economies with lower quality natural resources and space limitations will tend towards net-importers, while countries with strong renewable resources and efficient infrastructure will tend towards being net exporters of GH. The EU and Japan are predicted to be the largest global import nodes of GH, which will have important bearing on an optimal South African demand mix of export and domestic production.

Domestic demand uptake will largely be driven by price parity and scale (mass adoption in for example a fleet management company) with incumbent fossil fuels plus any carbon related taxes. GH production that can be located with applications such as mining where the cost of distribution infrastructure can be avoided will be the earliest to achieve price parity. Longer term demand will grow with market maturity and will rely on reducing production cost, expanding infrastructure and using carbon markets and other incentives to sustain price parity.

2.1 Export demand drivers

All industrialized countries are planning to develop GH production capacity but as referenced above those with lower renewable resources will remain net importers. Accelerated national Net-Zero commitments will also stimulate imports where higher carbon pricing systems such as the EU emissions trading system (ETS) provide a significant green premium to incentivise imports. The Net-Zero commitments are borne out of the need to decarbonise due to policies (e.g., carbon taxes) and mandates (e.g., blending of GH into natural gas pipeline systems) that require decarbonisation be applied to supply chains and production processes to enable relative competitiveness. The uneven renewable energy endowment spurs trading of GH between countries / regions.

This highlights that GH exports have higher market risk as there is competition with other exporting countries as well as local production. The projected net-import demand scenario indicates that approximately 10% of total global demand will be traded between countries and is shown below.

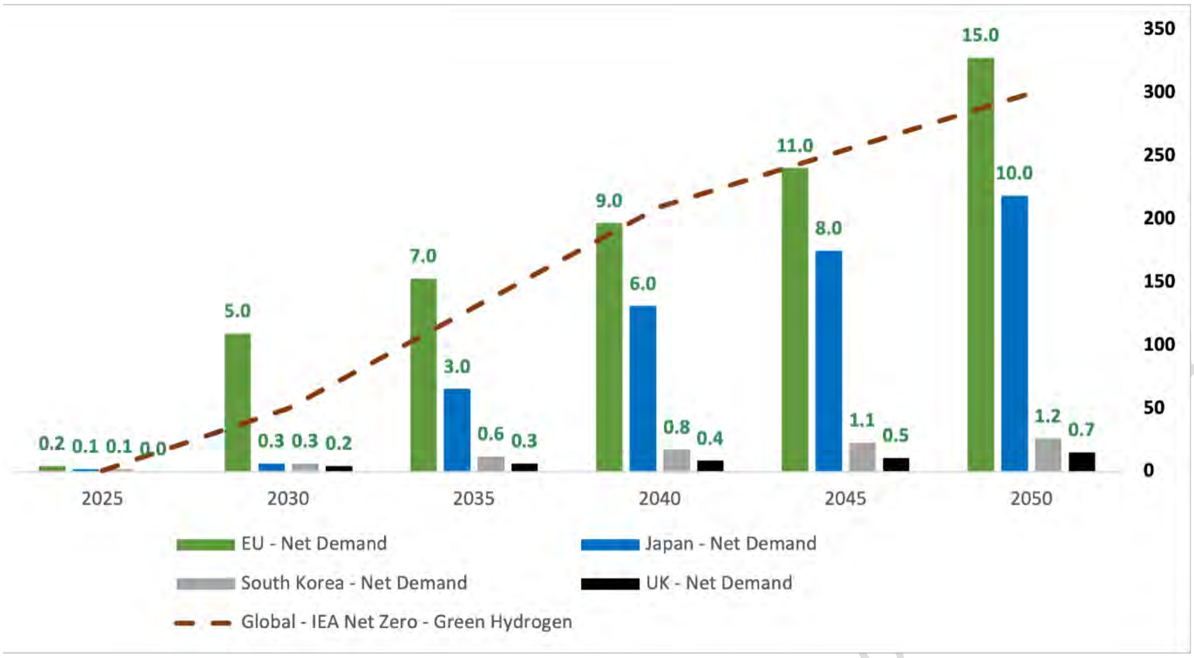


Figure 2.1: Average Net Imports by Country/Regions vs Total Global Demand (Mt GH)

In order to establish the potential size of South Africa's GH exports the International Energy Agency's (IEA) Net Zero GH Scenario to 2050, referred to Figure 2.1 has been used to compare market share relative to total net import demand for different scenarios:

- European Union: Originally the EU intended to import from 2030 between 5-10 Mt of hydrogen and from 2050 between 11-15 Mt of hydrogen was forecast to be imported into Europe. **Recently based on the REPowerEU plan (18 May 2022), Europe has increased GH demand projections planning to import 10mtpa by 2030 which was previously planned for 2050.**

- Japan: from 2030 Japan is expected to procure 0.3 Mt of hydrogen annually and is currently focused on various initiatives to develop this supply chain. Beyond 2030 imports are expected to ramp up to 5 to 10 Mt per annum.

- South Korea: imported GH demand is expected to be 0.3 Mt per annum from 2030 and 1.2 Mt per annum from 2050.

- United Kingdom: imports of as much as 0.7 Mt by 2050 are anticipated depending on the development of domestic hydrogen production from offshore wind.

Summing up expected demand from the primary import markets it is expected that the import market for hydrogen will be between 14 and 27 Mt per annum by 2050.

2.1.1 South Africa export demand potential

Many studies have been undertaken recently assessing the potential export market for hydrogen, notably: IHS Markit Super High Road; an Industry Research Report; Engie – South Africa Hydrogen Roadmap, which indicated a 2% share of the global market for hydrogen and was evaluated against the IEA "Net Zero" scenario; and Sasol, which provided a "Moderate" Scenario and "Ambitious" Scenario. These studies indicate a significant variation in the quantum of exports relative to the total market for imports globally. An assessment of the import market for GH (27 Mt per annum) based on the various studies is provided in Figure 2.2.

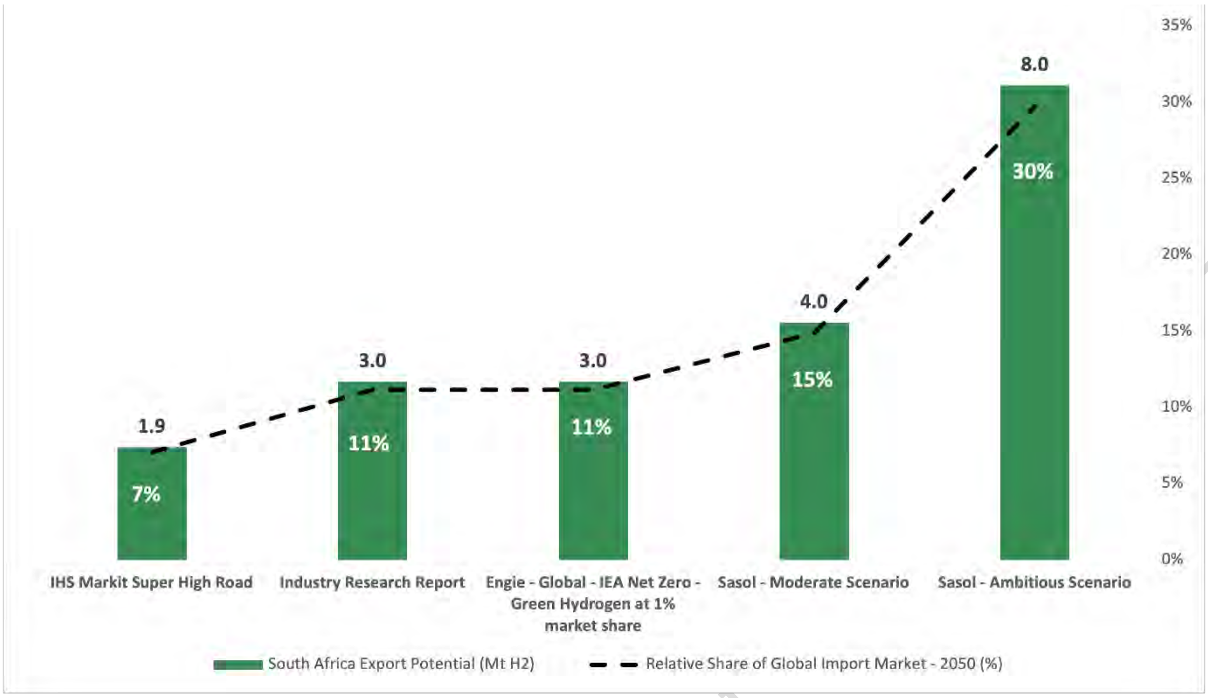


Figure 2.2: South Africa - Export Market Assessment Based on Share of Global Import Market to 2050

Analysis of global net exporters has been completed using the 1.9mtpa scenario or ~7% of the global import market as a SA base, with the relative market shares of exporting countries, being determined using the global hydrogen model developed by PwC and the International Energy Council, which uses public domain parameters such as renewable resource, land space, proximity to markets, investments required in infrastructure and stated policies and programmes to determine relative competitiveness in the global export market (refer to Figure 2.3). What is evident is that at higher South Africa export scenarios, increased market share is required (Figure 2.2), which requires a more competitive offering to other exporting countries and who are potentially better positioned to South Africa.

If technology and learning rates advance significantly to bring GH costs down to 2050, making GH lowest cost relative to grey and blue hydrogen or fossil alternatives oil or gas, this production could be entirely GH.

At close to 10% market share, South Africa must compete directly with Morocco, Russia, Chile and the UAE, and at more than 15% with Saudi Arabia and Australia. To increase global market share, South Africa will therefore require significant interventions by government, public sector institutions, and the private sector as a unified effort to drive value chain efficiency and lower cost.

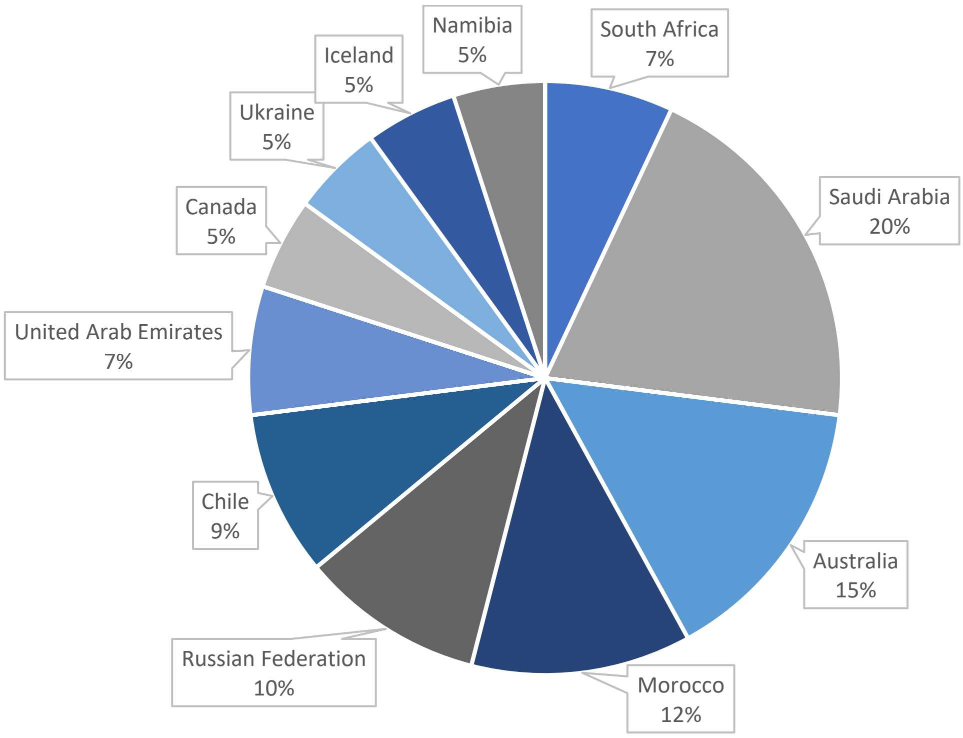


Figure 2.3: Assessment of Market Share Potential (%)

2.1.2 Developing competitive South Africa exports

Refer to Figure 2.4 for the current forecast of South Africa's price evolution from 2025: $3.82-$4.12/kg, 2030: $2.94-$3.24/kg, 2040: $1.47-$1.76/kg, 2050: $1.18-$1.47/kg.

South Africa, without interventions by government and the private sector, is not as well placed as Middle East and Australia to compete for the GH markets in Japan and South Korea. This is largely due to closer proximity allowing for lower logistics costs, early mover advantage and the already strong established relationships in the energy value chain between these countries where Australia and the Middle East currently supply into the energy ecosystem in Japan and South Korea.

Despite these challenges, these countries may seek to diversify supplies of energy, and South Africa could target GH sales to East Asian markets. Blue hydrogen will compete with GH in the Japanese market, as Japan has already commenced the importing blue ammonia. Many global GH value chain participants are active in South Africa and are investigating participation in the GH value chain in South Africa.

South Africa's primary market will most likely be the EU and the United Kingdom. There are significant initiatives already undertaken by the EU to enable and facilitate GH imports, including with South Africa. The European Union, notably Germany, have already introduced policy, indicated a willingness to pay a premium price through the implementation of long-term (10 year) supply agreements to stimulate GH, ammonia and Power-to-X market development in specific jurisdictions. KfW, the German Development Bank, on behalf of the German government launched a €200 million (R3.4 billion) concessional financing initiative in June 2021 seeking to catalyse the development of a GH economy in South Africa.

It must be noted, however, that South Africa will face significant competition for this European Union market from Morocco and Ukraine, which have already announced initiatives for GH with the European Union, as well as Russia and Iceland. Namibia, due to its historical ties to Germany, will also collaborate with South Africa

Focusing on the supportive policies and creating a regulatory framework that encourages cost competitiveness will allow South Africa to play to win in the global GH landscape.

Below figures demonstrate the implicit price competitiveness of South Africa over time, based on the global GH model developed by PwC, International Energy Council and Energy Research Institute.

A more detailed cost build up has been developed specifically to compare South Africa to Morocco, who is considered a key competitor for the EU/UK market.

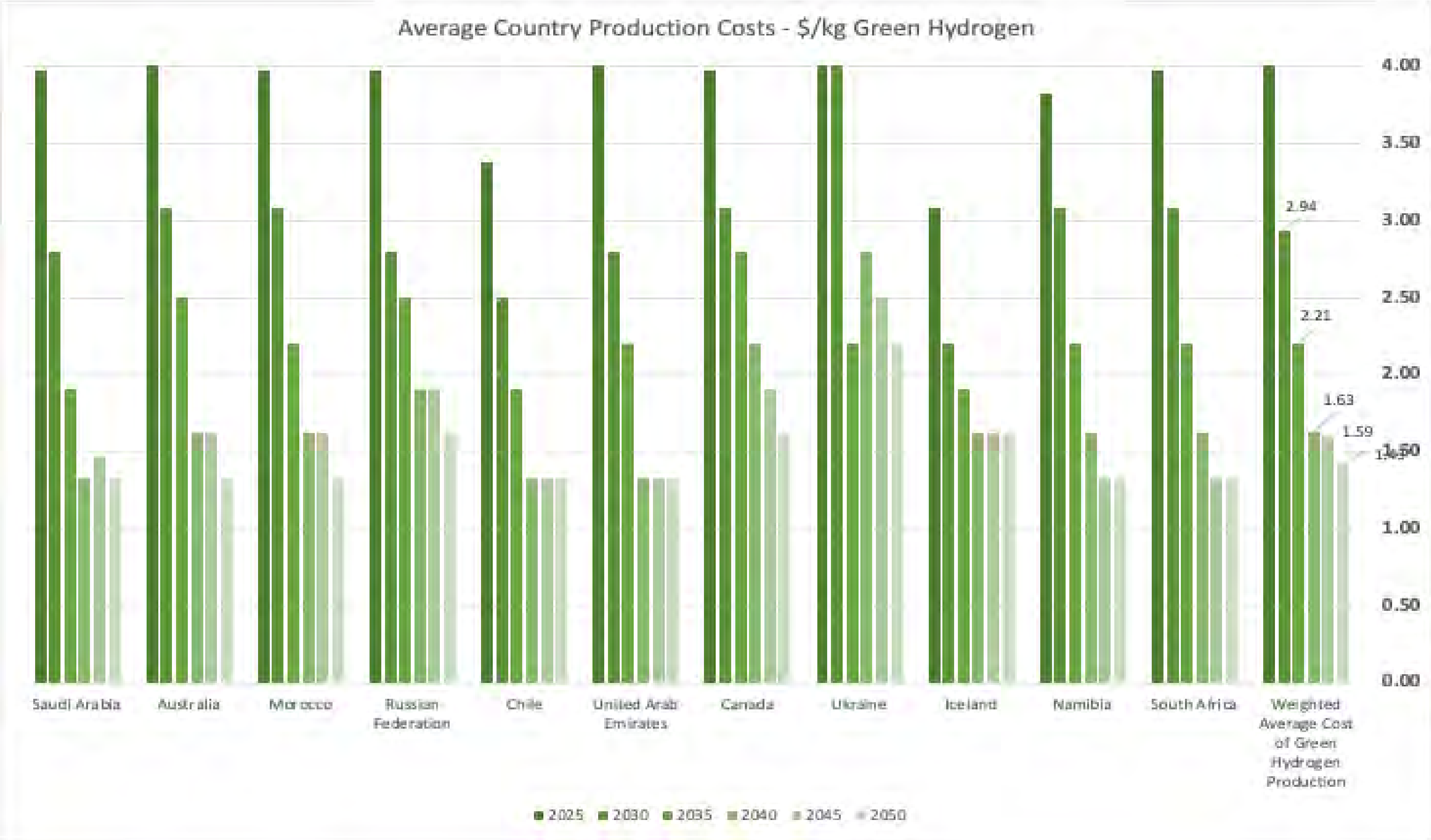


Figure 2.4: 2025-2050 – Average Forecast GH Prices of Exporting Countries (US$/kg H_2)

Key insights

- Morocco's proximity to the EU, which will become a major demand centre, makes it a potential Tier 1 exporter while South Africa is a Tier 2 exporter due to its distance from potential demand locations.
- This initially translate to a price difference of $1.3/kg between Morocco and South Africa. South Africa can make up Morocco's first mover advantage through financing interventions - Tax incentives, Carbon subsidies, preferential funding, and GtoG* arrangements.
- **At 2025, hydrogen will cost $4.5 - 6/kg**. Focus should be on export as export price is competitive and domestic use hasn't reached commercial parity, where projects will be limited to pilot use cases.
- **By 2030, hydrogen will cost $3.5 - 4.5/kg.** Export remains competitive to the following markets - EU, Americas, India. However, domestic use is competitive for heavy mobility applications but remains limited due to the cost of distribution and refuelling infrastructure.
- **In 2040, hydrogen will cost $2 - 3.5/kg.** This will allow South Africa to flex between export and domestic use as exports continue to be fulfilled while domestic use expands as hydrogen infrastructure comes online.
- **South Africa's hydrogen will could break the $1/kg mark in 2050.** At this stage, South Africa's focus will be on the domestic market as hydrogen capabilities become diversified and scaled up. South Africa will continue to stay in the export market but won't be reliant.

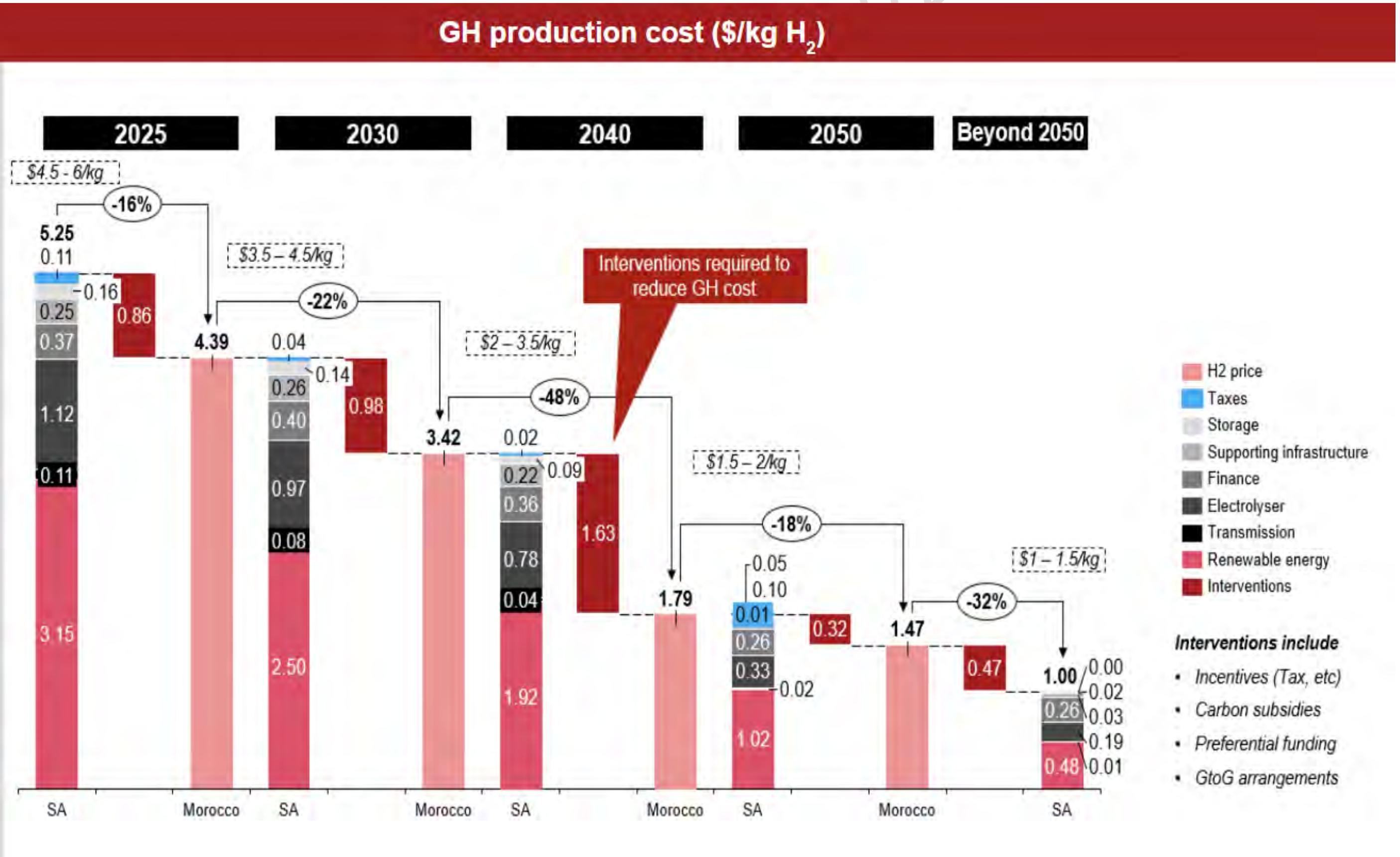


Figure 2.5: Measures to Improve Competitiveness and Possible Effects on Price (2030 - 2050)

2.1.3 Implicit exports through marine bunkering

Oil products currently dominate the shipping sector, and the current use of hydrogen-based fuels in shipping is accordingly very limited. Ships do not use ammonia as fuel today, but oil and gas products (containing the equivalent of ~3.5 Mt hydrogen) is used to fuel ships, and if the volume of international shipping triples by 2050 under current trends, this demand from shipping will increase to the equivalent of ~10.5 Mt of hydrogen per year by 2050. To meet the emission targets of the International Maritime Organization (IMO), ~25% of shipping will be fuelled by green ammonia or methanol equivalent to 15 Mt green ammonia, utilising (2.6 Mt of GH) by 2050.

South Africa's access to both the Indian and Atlantic oceans could enable the country to secure an 8-10% market share of the global ammonia fuels market for shipping, equivalent to 0.8 to 1.0 Mt per year of GH (4-6 Mt of green ammonia) by 2050 (Figure 2.6).

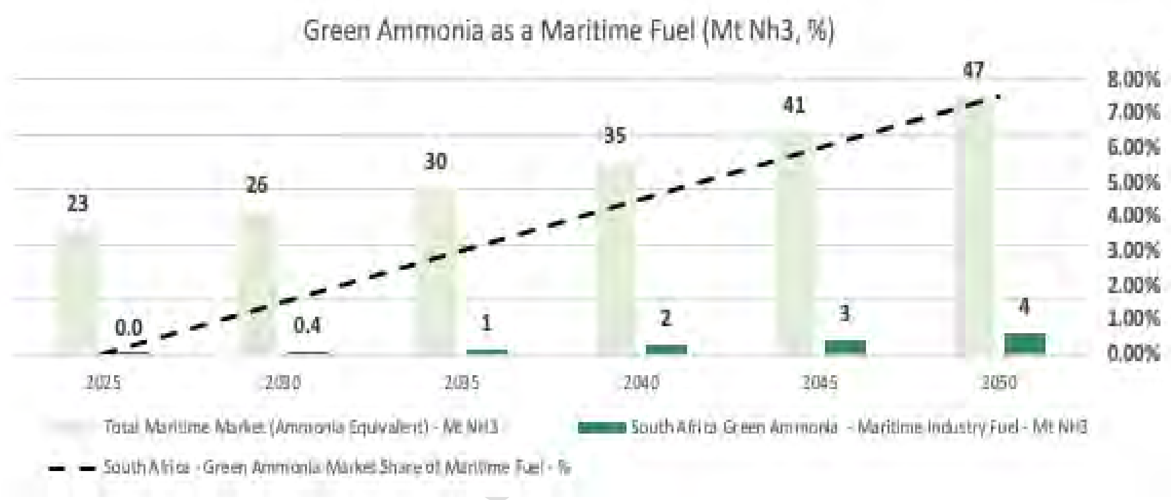


Figure 2.6: Green Ammonia as a Maritime Fuel, Global and South Africa Market Share

2.1.4 Sustainable Aviation Fuel

Aviation lags other decarbonisation efforts in the transportation sector and Sustainable Aviation Fuel (SAF) is deemed as the only viable large-scale solution for the aviation sector.

As a result, governments are considering blending mandates to introduce SAF into the jet fuel market. In 2017, International Air Travel Association (IATA) members unanimously agreed a resolution on the deployment of SAF, including for constructive government policies, and committed to only use fuels which conserve ecological balance and avoid depletion of natural resources. The attractiveness of the SAF opportunity is underpinned by decreasing renewable energy costs and green hydrogen production costs, with green hydrogen expected to decline below \$2/kg H_2 by 2030, from the current \$4,00-5,50/kg H_2 cost range.

The global SAF market, as percentage of the global aviation fuel market, is estimated to be ~10% by 2030 (~\$30bn of the \$314bn market) and is forecast to reach 47% by 2050 (~\$180bn of \$387bn), ranking it the largest by market share in the aviation fuel sector and offering an attractive market in a relatively short period of time.

Sasol's Fisher Tropsch process is positioned to produce a range of sustainable liquids and chemicals, and the Fisher Tropsch based Power-to-Liquid route to SAF is deemed to be very competitive in the long term.

2.1.5 Policies and Incentives

It is essential that the South African government pursue GH-supportive policies and create a regulatory framework that encourages cost competitiveness. To this end, government can undertake the following:

- Incentives – these could include subsidies, taxes and levies, as well as accelerated depreciation on capital equipment (both supply and demand side incentives could be used to drive cost reductions in the long term and enable a Just Transition, which will enable energy supply, sustainability and stability).
- Carbon subsidies – use carbon taxes to subsidise GH production.
- Preferential funding – undertake to provide low-cost funding through state-owned development finance institutions, incentivise private sector institutions to fund GH projects at preferential interest rates and seek preferential funding terms from global private sector and development finance institutions; and
- Government to government arrangements – import countries will be looking for energy security and export countries for market share, which could allow for preferential arrangements (e.g., long term supply agreements).

While these interventions will have a marginal effect individually on price competitiveness, collectively these could alter the terms of trade for GH, refer to Figures 2.5. These interventions, when combined with the geographic endowment of South Africa, which includes wind and solar resources and access to both the Indian and Atlantic oceans, could enable South Africa to significantly improve its competitiveness. These interventions will also provide clarity and enable investment in the sector. To supply 1.5 to 1.9 Mt of GH for the export market will require a total investment between US$44 to $61 billion (R0.6 to 0.9 trillion) to 2050 based on a declining cost curve, which reflects learning rates for capital equipment (US$49 to $69 billion or R0.7 to 1.0 trillion in 2021 money terms and costs). This will bring in revenue from GH of $3.4 to $4.4 billion, and support South Africa's balance of payments reducing the loss of export revenue from coal ($4 to $5 billion per year) as the global economy transitions away from coal.

2.2 Domestic demand drivers

The primary source of current domestic demand for hydrogen are the current uses of hydrogen in the mining, processing, chemical industries in South Africa. Based on the latest available data from Statistics South Africa, the total value of sold "Hydrogen, nitrogen, oxygen, carbon dioxide and rare gases; inorganic oxygen compounds of non-metals" was valued in 2017 at R5.5 billion (2014: R4.3 billion). At present, it is difficult to obtain data on the volume and value of hydrogen traded in the South African economy and as a result, it is recommended that in future Statistics South Africa create a separate reporting code for hydrogen and oxygen, which is a by-product of electrolysis.

South Africa is a significant energy consuming economy at approximately 5-6 exajoules of energy, ranking South Africa 20th in terms of energy consumption and on par with countries like Italy, Australia, Spain and Thailand. Most of this energy (95%) is fossil fuel based and represents a significant opportunity for decarbonisation and domestic GH demand growth.

Domestic demand drivers include decarbonisation based on country or company commitments and enforced through final product requirements; current consumption of grey hydrogen to be switched to GH; cost competitiveness of GH enabled through incentives and taxes versus its fossil alternatives; the availability and access to GH; and the maturity and acceptance of the application technology and access to support ecosystems.

GH production lifetime costs can be estimated as follows; cost of electricity (60-70% at current renewable energy prices) and cost of electrolyser and balance of plant equipment (30% to 40%). Based on current cost estimates, the production cost of GH is not cost competitive with other hydrocarbon-based fuels that it must displace over time. When considering fuel switching to GH, the effect of carbon taxes on fossil fuel energy serves to increase the price of these fossil fuels over time and thus accelerate market price parity. Although the combination of declining cost of GH production coupled with increasing carbon taxes is predicted to achieve GH price parity from 2025 to 2027, this doesn't account for the overall higher cost of energy to end-users or capital costs of transitioning energy assets. A more realistic or market view of achieving local price parity may therefore be closer to 2030

Noting the above considerations, and adopting the more aggressive demand view the key drivers of future South African demand – 2021 to 2050 are forecast to be (Figure 2.7):

- 2023-2025: Road transport, primarily Fuel Cell Vehicles (FCVs), of which a significant component will be Heavy Duty Vehicles (HDVs). Many projects are underway globally, including in South Africa with a hydrogen powered truck at Anglo Platinum's Mogalakwena PGMs mine, the Hydrogen Valley which is an 835km industrial and commercial corridor focused on mobility, and Sasol and Toyota South Africa Motor's partnership to commence exploration of the development of a GH mobility ecosystem. Mobility represents a significant opportunity for South Africa, but this will be sequenced based on economic viability, which will be dictated by volume and carbon emissions. Mining represents the best early adopter of hydrogen for mobility, followed by heavy duty logistics (trucks and buses) and later, when hydrogen refuelling stations are more widely available, fuel cell vehicles for mass transportation.
- 2023-2025: Refining and processing, which consumes significant amounts of hydrogen for the production of petroleum products and chemicals. Many refining and process plants that currently consume or produce grey or blue hydrogen have active projects to switch to GH. Sasol has initiated a Request for Proposal to consider GH in its industrial processes.
- 2025-2030: Chemical and Industry, notably the non-ferrous metals, green steel, and cement sectors, which will need to decarbonize to remain globally competitive. The world's first green steel pilot for fossil-free steel commenced operations in August 2021 as part of the HYBRIT project in Lulea, Sweden.
- 2028-2030: Green ammonia and methanol, which will replace current production from grey and blue hydrogen and add new production from new use cases. Ammonia is widely traded globally, and there are many pilot projects underway globally to evaluate ammonia as means to export hydrogen or as a direct fuel in many use cases, notably marine fuels.
- +2030: Power Storage and Balancing, which will see GH being used for long duration storage based on daily, monthly, and cross-seasonal balancing requirements. The round-trip efficiency of Power-to-Power is a limiting factor for uptake, however, with greater renewable energy penetration into the global energy system, the need for hydrogen as a

means to store curtailed/surplus renewable energy will increase, which will create a market for GH from this sector.

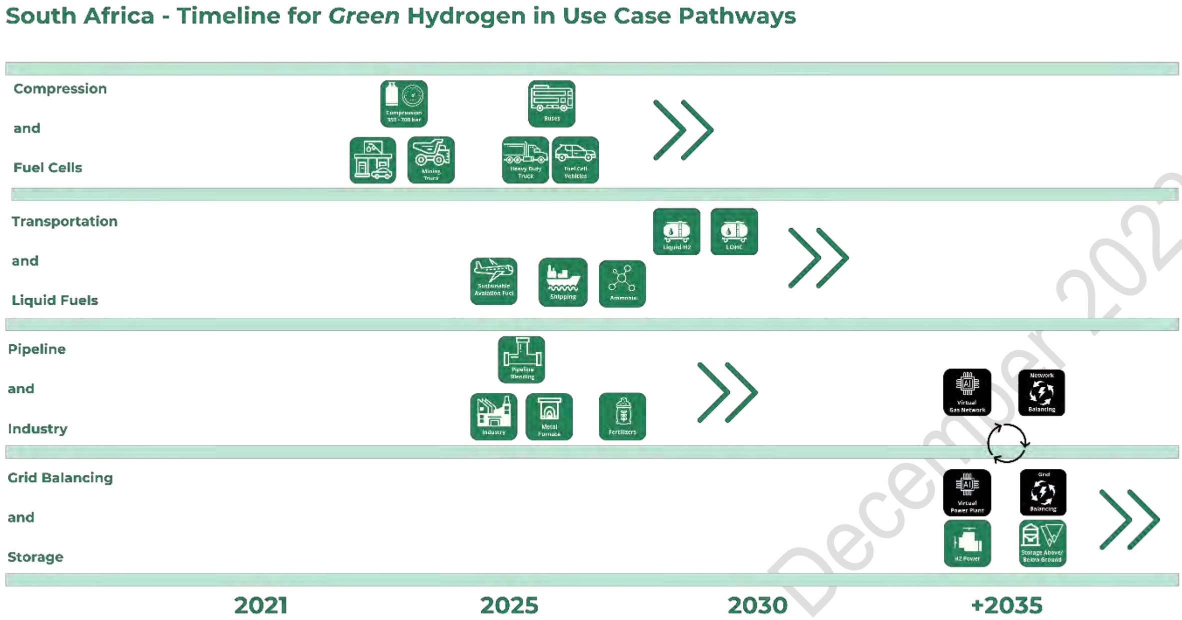


Figure 2.7: Indicative GH commercialisation roadmap and timeline (September 2021)

2.3 South Africa – developing a vibrant and sustainable domestic market

The studies referred to above under exports also assessed the size of the South African market for GH. These studies indicate significant variation in the quantum of domestic demand as shown in Figure 2.8. below

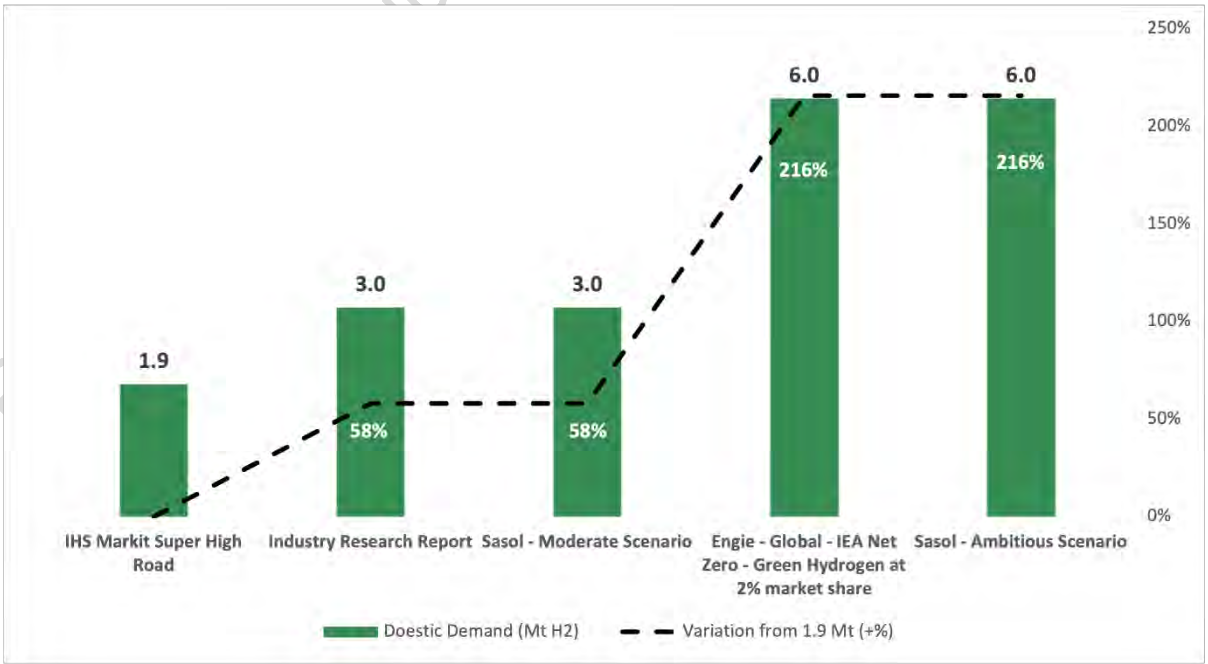


Figure 2.8: South Africa - Domestic Market Assessment

The initiatives that South Africa needs to undertake to spur demand for GH in the local economy and enable the domestic market to scale up consumption to the higher tonnages indicated in Figure 2.8 will require specific coordination and intervention between the public and private sector as discussed in Section 2.1.4.

From a demand summary perspective, it is considered that South Africa is more likely to realise the lower range of volumes presented above in figure 2.8 i.e., 2mtpa - 3mtpa range (including bunkering), whereas South Africa is likely to realise higher domestic volumes as shown above in figure 2.8 i.e., >3mtpa range with the supportive policies mentioned in the previous section and discussed in Section 2.1.4. Further detailed studies will be needed to consider the overall economic cost-benefit impact and value for money proposition of deeper government support and interventions to achieve more aggressive market demand.

GH represents a significant opportunity for South Africa to enable global decarbonisation through exports, allowing other countries to decarbonise, and domestic carbon reduction of its energy economy which consumes 5-6 exajoules of energy (ranked 20^{th} globally). In adopting this approach, South Africa will be seen as a key leader in the energy transition and could become a critical player in the new global energy economy providing an example for other emerging economies.

Accordingly, GH production will be driven by two distinct markets: export demand driven by the international trade of GH between countries and regions; and domestic demand, driven by fuel switching and new vectors for the use of GH for mobility, industrial processes and power.

Focusing on the hydrogen-supportive policies and creating a regulatory framework that encourages cost competitiveness will allow South Africa to play to win in the global GH landscape and spur the uptake of GH in the domestic economy.

3 Value Chain Analysis and identification of Hydrogen Hubs

3.1 Value Chain Definition

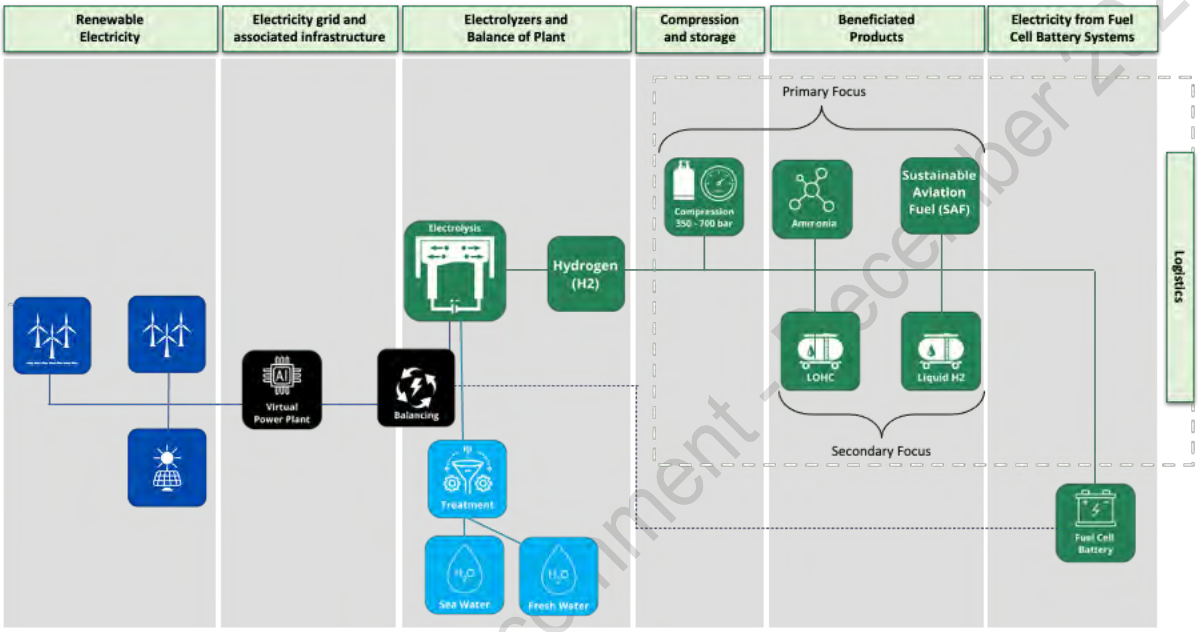


Figure 3.1: GH Value Chain

The key GH value chain components are: (refer to Figure 3.1)

- **Renewable electricity:** solar and wind, and other sources of renewable energy.
- **Electricity grid and associated infrastructure:** this includes transmission and distribution infrastructure as well as substations, inverters, battery storage and other associated (ancillary service) equipment, which has application to projects with dedicated renewable electricity supply or electricity wheeled from the grid.
- **Electrolysers and Balance of Plant:** this includes all necessary equipment for the electrolysis process, as well as associated equipment to enable hydrogen and oxygen separation and the production of hydrogen to the required specification at the designed flow rate of the plant (including desalination / RO treatment infrastructure).
- **Compression and storage:** if the end use is hydrogen, it needs to be stored. Compression from 30 bar, which is the typical exit pressure from the plant, to 300 or 700 bar for storage requires compression equipment and specialized storage equipment capable of handling pressurised hydrogen molecules.
- **Beneficiated products**: there are many pathways for beneficiated products, most notably green ammonia and methanol, which are traded globally. Sustainable aviation fuel offers an opportunity to decarbonise air travel. Liquid hydrogen and liquid organic hydrogen carriers (LOHC) are at an early stage of development and will develop over time as costs and technologies improve.

- **Electricity from Fuel Cell Battery Systems:** GH as a vector for long duration storage enables long duration storage based on daily, monthly and cross-seasonal balancing requirements, where the hydrogen is used in a fuel cell battery and converted back to electricity with only water as the by-product.
- **Logistics and supply chain**: key considerations for choosing the best logistics options are dependent on distance, and in the case of ammonia, liquid hydrogen or LOHC, the cost of conversion to ammonia, liquid hydrogen or LOHC and reconversion back to GH, if that is the end use.

Depending on the source of the electricity and the ultimate use case, there are many pathways along the value chain from green electrons to the electricity grid to GH to compression and storage, to beneficiated products (green ammonia, green methanol, liquid hydrogen, LOHC etc.) to logistics to re-conversion back to electricity, as applicable. The total cost to the end user of the GH is the sum of the component costs along the value chain pathway.

In order to develop GH production to supply the export and domestic market using a scenario of 1.9 Mt GH for export and 1.9 Mt GH for domestic consumption, significant investments in estimated installed capacity for renewable energy (solar 56 GW and wind 24 GW) and electrolysers (41 GW) are required, refer to Figure 3.2. GH represents a significant opportunity for South Africa to enable global decarbonisation through exports, allowing other countries to decarbonise, and domestic carbon reduction of its energy economy. In adopting this approach, South Africa will be seen as a key leader in the energy transition and could become a critical player in the new global energy economy providing an example for other emerging economies.

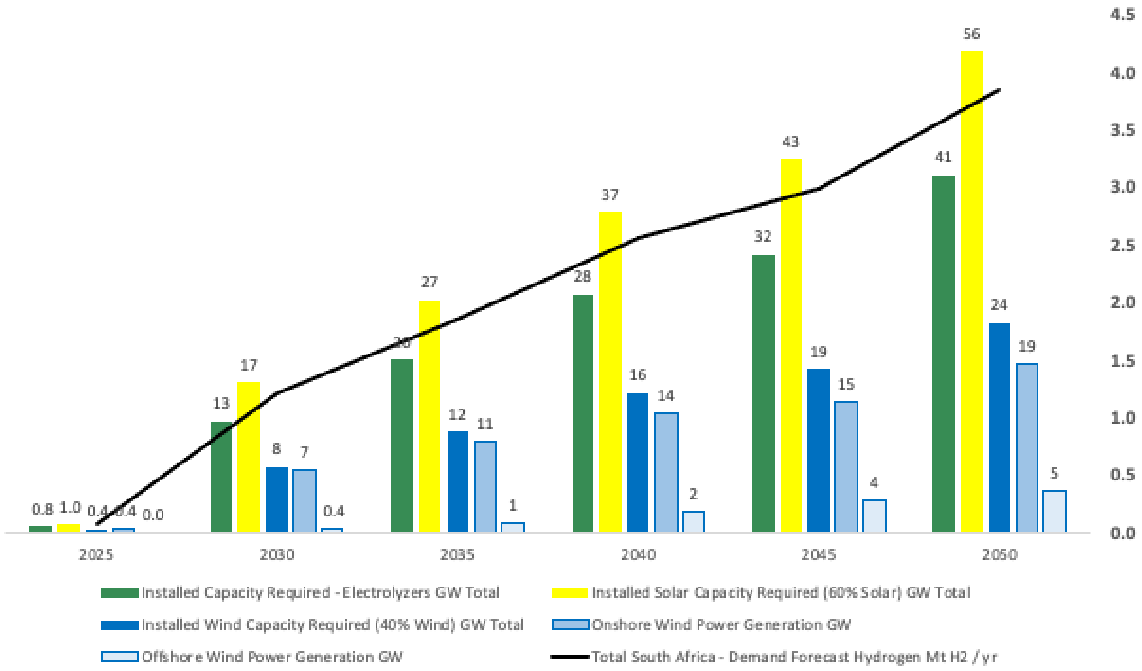


Figure 3.2: Total Installed Capacities in 5 Year Increments (GW) to Meet Demand (Collated from data sources, included in the literature review)

The key difference between the export and domestic market price for GH will be the need for the costs for ammonia conversion. For the export price, the costs of conversion for ammonia and transportation needs to be included, currently estimated at $0.5/kg GH.

3.2 Value Chain Dependencies

Table 3.1 provides details of South Africa's natural endowments (wind and solar energy, as well as its proximity to exports markets, Figure 3.3) and the GH production value chain mapped to elements that are within South Africa's control and those that are beyond South Africa's control. An assessment of the relevant finance, permitting and policy landscape is also undertaken, and the relevant state-owned entities and government departments responsible for managing this landscape are identified.

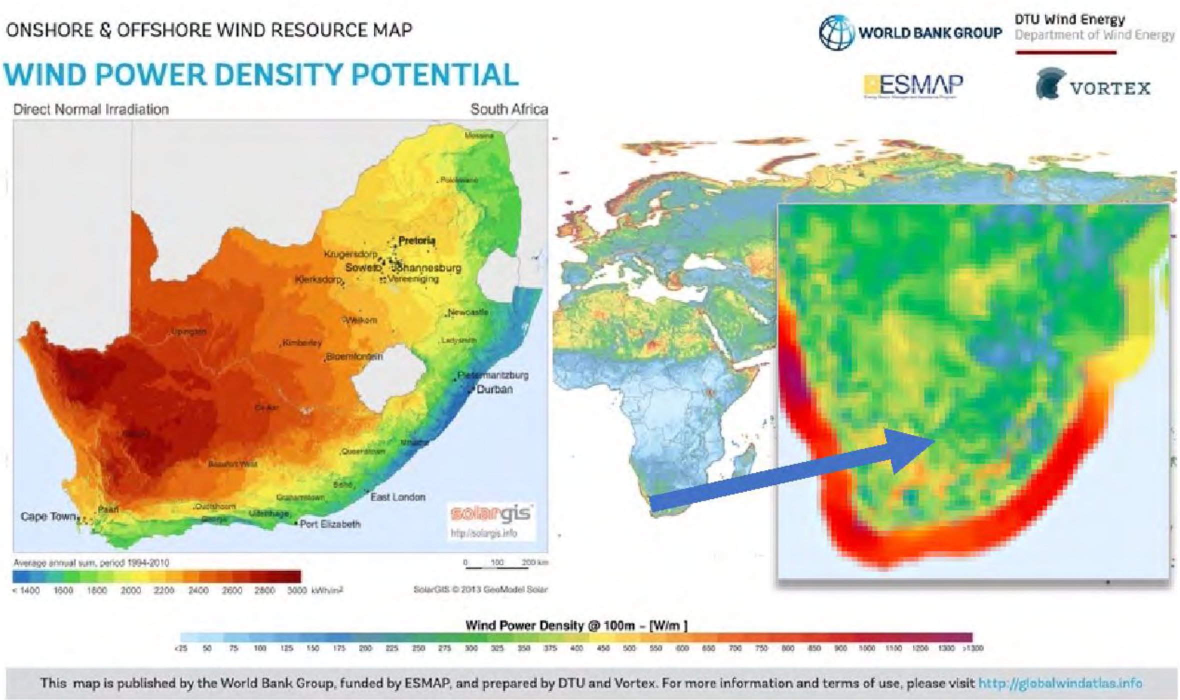


Figure 3.3: South Africa – Wind and Solar Resources (detailed maps in Appendix)

Table 3.1: GH Value Chain Dependencies, Optimization and Critical Role Players in South Africa

Element	Within South Africa’s Control (maximization strategy for optimal value chain)	Not Within South Africa’s Control (minimization strategy for optimal value chain)	Critical Role Players to enable the GH value chain (non-exhaustive)
Natural Endowment – Sea Water Resources and Freshwater Resources	South Africa has a large coastline from which it could tap into sea water, and while freshwater resources are a challenge, there are options to manage this optimally and supply some of this resource for GH production. Underground water resources from mining could also be used and could mitigate the Acid Mine Drainage problem facing mines in South Africa (optimise water allocations for GH considering all relevant factors)		water & sanitation, Department: Water and Sanitation, REPUBLIC OF SOUTH AFRICA agriculture, forestry & fisheries, Department: Agriculture, Forestry and Fisheries, REPUBLIC OF SOUTH AFRICA environmental affairs, Department: Environmental Affairs, REPUBLIC OF SOUTH AFRICA human settlements, Department: Human Settlements, REPUBLIC OF SOUTH AFRICA
Natural Endowment – Sun Hours	Solar hours are higher than global average (maximize use of solar resources by incentivizing investments in resource rich areas)		
Natural Endowment – Wind Hours	Wind hours both onshore and offshore offer a significant opportunity to supplement solar hours (maximize use of solar resources by incentivizing investments in resource rich areas)		

Element	Within South Africa's Control (maximization strategy for optimal value chain)	Not Within South Africa's Control (minimization strategy for optimal value chain)	Critical Role Players to enable the GH value chain (non-exhaustive)
Natural Endowment – Proximity to Atlantic and Indian Ocean	Proximity enables exports to the Western and Eastern hemispheres. (define a strategy to play in both European and Asian markets)		
Renewable Electricity – Solar and wind	Regulations, taxes, permitting and other operational items (maximize benefits to incentivize investment)	The installed costs of solar equipment, which is reliant on imports and subject to the exchange rate (evaluate local manufacturing options by OEMS).	the dtic Department: Trade, Industry and Competition REPUBLIC OF SOUTH AFRICA mineral resources & energy Department: Mineral Resources and Energy REPUBLIC OF SOUTH AFRICA national treasury Department: National Treasury REPUBLIC OF SOUTH AFRICA nersa NATIONAL ENERGY REGULATOR OF SOUTH AFRICA
Electrolysis and Balance of Plant	Regulations, taxes, permitting and other operational items (maximize benefits to incentivize investment)	The installed costs of electrolyser equipment, which is reliant on imports and subject to the exchange rate (evaluate local manufacturing options by OEMS and leverage the PGM supply chain to maximize local content)	
Fischer-Tropsch (ft) and catalysis IP	Sasol is one of the few companies with the capacity to produce industrial scale P2X product. In addition, the company has the potential to use the IP of its catalyst book and experience of building, licensing and operating		

Element	Within South Africa's Control (maximization strategy for optimal value chain)	Not Within South Africa's Control (minimization strategy for optimal value chain)	Critical Role Players to enable the GH value chain (non-exhaustive)
	large-scale FT plants to produce P2X products elsewhere in the world.		
GH and Ammonia Prices		In a regulated market sectors, price will be driven by cost of compliance until supply can meet demand. In a competitive market position, price of GH will be set by the lowest locational cost producer (use incentives, carbon subsidies and preferential funding to lower costs)	
Ammonia Plant	Regulations, taxes, permitting and other operational items (maximize benefits to incentivize investment)	The installed costs of ammonia equipment (e.g., air separation unit), which is reliant on imports and subject to the exchange rate (evaluate local manufacturing options by OEMs)	

Element	Within South Africa's Control (maximization strategy for optimal value chain)	Not Within South Africa's Control (minimization strategy for optimal value chain)	Critical Role Players to enable the GH value chain (non-exhaustive)
Export Infrastructure – Rail, Ports	Infrastructure availability, tariffs, regulations, taxes, permitting and other operational items		transport Department: Transport REPUBLIC OF SOUTH AFRICA; TRANSNET; PORTS REGULATOR OF SOUTH AFRICA
Import Infrastructure – Rail, Ports (in importing countries)		Competition for import terminal allocations and tariffs will be fierce (proactively develop relationships with importing countries (government to government relationships) and GH import hubs)	international relations & cooperation Department: International Relations and Cooperation REPUBLIC OF SOUTH AFRICA

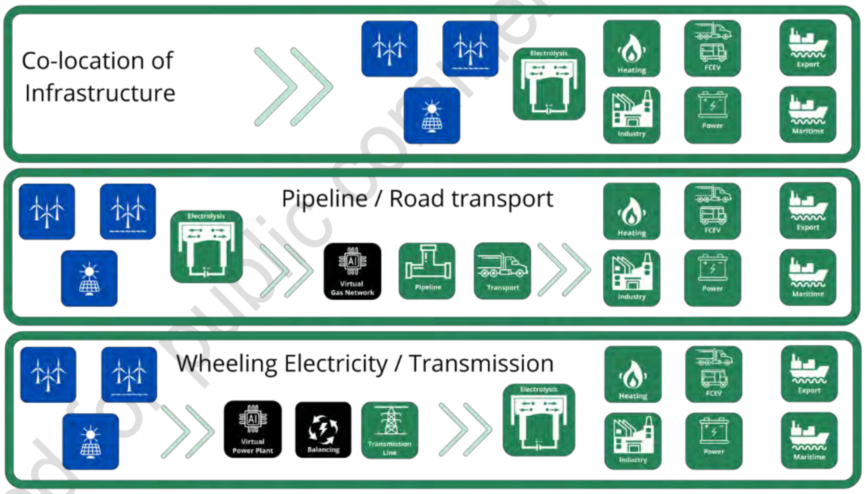
3.3 Requirements for Hydrogen Project Success

There are two types of projects that are under development globally, large scale GH projects for multiple GH customers, and isolated or co-located GH production for specific use case/s.

There are many examples of large-scale projects globally, notably the project by ACWA in NEOM, Saudi Arabia, which will produce 650 t per day of GH for export, reducing carbon emissions by 3 Mt CO_2 per year. This is the largest GH project globally and will consist of a 1 GW electrolyser powered by 4 GW of wind and solar electricity and a 1.2 Mt per year ammonia facility.

In the South African context, three supply archetypes for large scale projects will need to be considered:

- Co-locate renewable energy with demand, limited transportation and distribution infrastructure is required by users.
- Centralise renewable energy and the electrolyser to optimise natural resources and use pipeline or road transport to move the hydrogen molecules to areas of demand.
- Decentralise renewable energy to transport electrons and co-locate the electrolyser with areas of demand or production hubs.



There are many emerging examples of isolated in-house projects globally. The most notable projects are those of Amazon Inc. the retailer and cloud services company, which is the largest private procurer of renewable energy globally and has plans to be a significant participant in the GH value chain, notably for logistics and data centres and other use cases within its group of companies. Ultimately, it is these in-house projects that will result in the most GH usage over time as they will be driven by the need for GH solutions to solve in-house demand challenges and use carbon incentives for fuel switching to fund these projects from internal resources.

Figure 3.5: Global GH Projects

To get to GH production levels advocated by various forecasts to displace 15-20% of global primary energy by 2050, will require more than two million projects globally consisting of large scale and mostly smaller isolated/co-located GH projects. The NEOM project, another large GH global project, will displace just 15 000 barrels of oil per day, or 0.015% of daily global oil consumption. As of October 2021, just more than 400 GH projects have been announced (Figure 3.5), noting the sustainable aviation fuel project from Sasol and the mining truck / hydrogen valley project from Anglo American.

Irrespective of the size or type of project, all GH projects face the following key requirements to enable project success:

1. Renewable electricity at the lowest price:

   - The primary enabler of a GH economy is access to large allocations of cheap renewable energy – South Africa's endowment of renewable energy resources (solar and wind) gives an advantage in potentially producing cheap renewable energy.
   - Electricity infrastructure – Currently the best locations for cheap solar power are in the Northern Cape where the national grid is constrained in terms of potential to export electricity to the Gauteng (central load centre). Placement of electrolysers at the coast with the water source is limited by the national grid if the electricity is supplied from a significant distance.

2. Renewable electricity for the most hours (based on current renewable energy prices and electrolyser costs and efficiencies, GH projects are economic at 14 hours per day (at current renewable energy and electrolyser costs) or 5 000 hours per year, which means that solar power alone may not be sufficient to provide adequate returns or a competitive GH price and needs to be supplemented with wind, grid and/or other renewable energies – the Northern Cape has South Africa's highest peak sun hours at 2 600 to 3 000 hours per year, and when combined with wind will exceed 5 000 hours in certain locations.

3. Electrolyser and Balance of Plant at the lowest price.

    - including access to water - This should preferably not be fresh water and thus desalination or mine wastewater is preferred.

4. Maximum electrolyser efficiency vs price (e.g., Alkaline electrolysis has a lower efficiency but is cheaper than a PEM electrolyser which has a higher efficiency and is more expensive). Innovation in electrolyser equipment will see significant changes in years to come.

    - Efficiency can be improved through scale, operations optimisation, and investing in Research, Design and Development (RD&D).

5. Hydrogen price to enable project returns – standard IRRs for project finance related projects e.g., 8% yield for a European project and 18-20% yield for a project based in South Africa.

6. Off-take agreements for foreign programmes likely to be denominated in Euros or US Dollar which allow for the obtaining of cheap debt but will most likely exclude South African commercial banks participating.

7. A favourable debt-equity split, typical >60% - 70% debt with balance as equity will be very dependent on market off-take risk.

8. Favourable terms for debt, with typical periods of >7 years for debt payback commencing at the start of commercial operations.

9. Long term off-take agreements – typical projects require a 20-year term to enable cash flow certainty and bankability. This will be a challenge in light of national procurement programmes such as Germany H2Global only offering contracts to 10 years which will require project sponsors taking merchant risk at the tail.

To demonstrate the two project types outlined above i.e., a consumer driven project and an isolated/co-located project, two projects are considered in detail in Appendix 3 and various cross-sensitives to demonstrate the most important elements to enable project success are included.

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4 GH localisation and manufacturing opportunities

Six paths in which localisation can be established is listed in Table 4.1. Throughout this section different localisation opportunities are identified and require careful consideration to determine the topology mutually beneficial.

Table 4.1. Topologies for localisation

Manufacturing topology	Description	Intellectual property
Local subsidiary of foreign company	Can be an OEM or supplier to OEM	OEM / supplier
Local manufacturer: under toll or license	Set up equipment to manufacture	OEM / supplier
Local assembly plant	OEM combines imported and locally made components	OEM / supplier
Local partner manufacturer	OEM / supplier to OEM provides manufacturing support (e.g., tooling, expertise)	OEM / supplier
Local manufacturing partnership	Installs local production line in partner company	OEM / supplier
Local manufacture	Supplier to OEM / balance of plant	Local

4.1 Breakdown of Value Chain definition for local content analysis

A high-level assessment of localisation potential for the GH value chain is provided using a 3-level ranking system. Localisation opportunities in the supply chains are given priorities of high, medium, or low indicated by green, yellow, and blue background blocks respectively. The GH value chain is provided in Figure 3.1 and analysed in detail in Chapter 3. The areas of the GH value chain analysed in detail include GH production via PEM electrolysis and fuel cells including mobility end-use application. Certain GH value chain components will naturally see localisation as the export and domestic industries grow. These include an electricity grid and associated infrastructure, compression and storage, beneficiation products, and the logistics and supply chains.

4.1.1 South Africa's attractiveness in the global GH environment

The high-level attributes that make South Africa attractive for localisation includes:

- **Abundant local resources of PGMs.** Provides opportunity for SA to support PGM mining companies and local PGM beneficiation through policies and financial incentives to supply locally into local PGM beneficiation initiatives and attract international OEMs to establish local manufacturing facilities.
- **South Africa has an abundance of RE resources (wind and solar) to produce GH.** A sizable local market is anticipated by the international community, and this anticipated

market is attractive for international OEMs to establish local manufacturing facilities and supply into the domestic GH industry, with potential to export to other markets.

- **Large land availability served by a transmission grid that is the size of Europe.** Limitations on grid capacity in specific preferred resource locations where land is available, such as Northern Cape requires considerable grid expansion projects to optimally harness South Africa's full solar renewable potential to produce cost competitive GH.
- **Established manufacturing, engineering, and technical expertise.** South Africa has an established manufacturing sector that provides confidence to OEMs to establish manufacturing and penetration into the region. This also supports local BoP manufacturing, plant construction and operation and maintenance activities.

On their own each of these attributes do not necessarily provide sufficient motivation for localisation, but when considered collectively they contribute to the overall attractiveness for South Africa.

4.1.2 Value chain component - Renewable energy

This work does not include a detailed local content analysis on renewable energy sources, specifically wind and PV. Detailed analysis work is ongoing and obtained from the South African Renewable Energy Masterplan (SAREM). SAREM's focus is on the localisation potential of the renewable energy manufacturing value chain under different scenarios of renewable energy ambition. RE is a key component in the GH value chain and low cost RE and capacity factor (CF) are two key enablers for successful GH projects.

Key findings on the economies of scale required to attract investment and ensure sustainable development of localisation are outlined below:

- Wind: A local market of 400 MW/year/OEM for a minimum of 5 years is required for the local manufacture of blades.
- Wind: A local market of 1,000 MW/year is required for local nacelle assembly, and manufacturing of generators and converters.
- For solar PV a sustained demand of at least 1,000 MW/year is required for local module assembly. However, this will come at a 25-30% premium to imported panels.
- Production of components locally is an enabler for the growth of local raw material supply chains (Glass, steel, concrete, copper, and aluminium). Further detailed analysis is required to consider demand linkages, supply capability and breakeven volumes.
- Similarly, deployment of PV and wind locally will expand existing local manufacturing supply chains and services for Balance of Plant which now makes up 65% of the capex of a project. Further detailed techno-economic analysis is required to quantify the broader benefits.
- The ability of local manufacturers to prove and guarantee component and system quality and performance price competitively compared to imported modules is crucial

Based on demand projections outlined in Section 2, South Africa has sufficient GH production demand potential to justify the above localisation breakpoint estimates.

- Meeting SAs 2030 potential GH demand (refer to Figure 3.2) requires additional 17GW PV (3.4GW/year) and 8GW wind (1.6GW/year) deployment.
    - o Needs to be considered and included in the SAREM, the Integrated Energy Plan (IEP), the Integrated Resource Plan (IRP), and the Gas Utilisation Master Plan (GUMP).

- Huge transmission and distribution grid expansion will need to happen rapidly for both electricity security and GH ambitions by 2030.
    - Needs to be considered and included in the Transmission development plan (TDP).

4.1.3 Value chain component - Hydrogen production through electrolysis

Three main electrolyser technologies are available for GH production: Polymer Electrolyte Membrane Electrolysers (PEM) electrolysers, Alkaline Electrolysers and, Solid Oxide or High Temperature Electrolysers (SOEC or HTEL). These have similar supply chain components with distinct differences in the use of PGM catalysts present in PEM technology. Nickel and other non-PGM materials are used in Alkaline as well as SOECs. PEM electrolysers are emerging as the preferred technology for future GH production from intermittent renewable energy. South Africa's unique benefit in the global supply of PGMs and the preference shown for PEM technology in the future GH economy, is a good indication that South Africa should attempt to leverage its PGM resources to promote localisation of PEM electrolysis technology equipment and components. Equipment and components include electrolyser stacks, electrolyser systems, electrolyser catalyst coated membranes and membrane electrode assemblies (MEAs), as well as electrolyser Balance of Plant components. The main cost drivers for selecting PEM electrolysis as the technology of choice for future GH production are CAPEX and RE input costs.

Figure 4.1 shows the supply chain components of a PEM electrolyser and indicates the localisation priorities assigned. Figure 4.1 also lists local technology providers under each component. High and medium priority components are assessed in more detail in Table E.2.

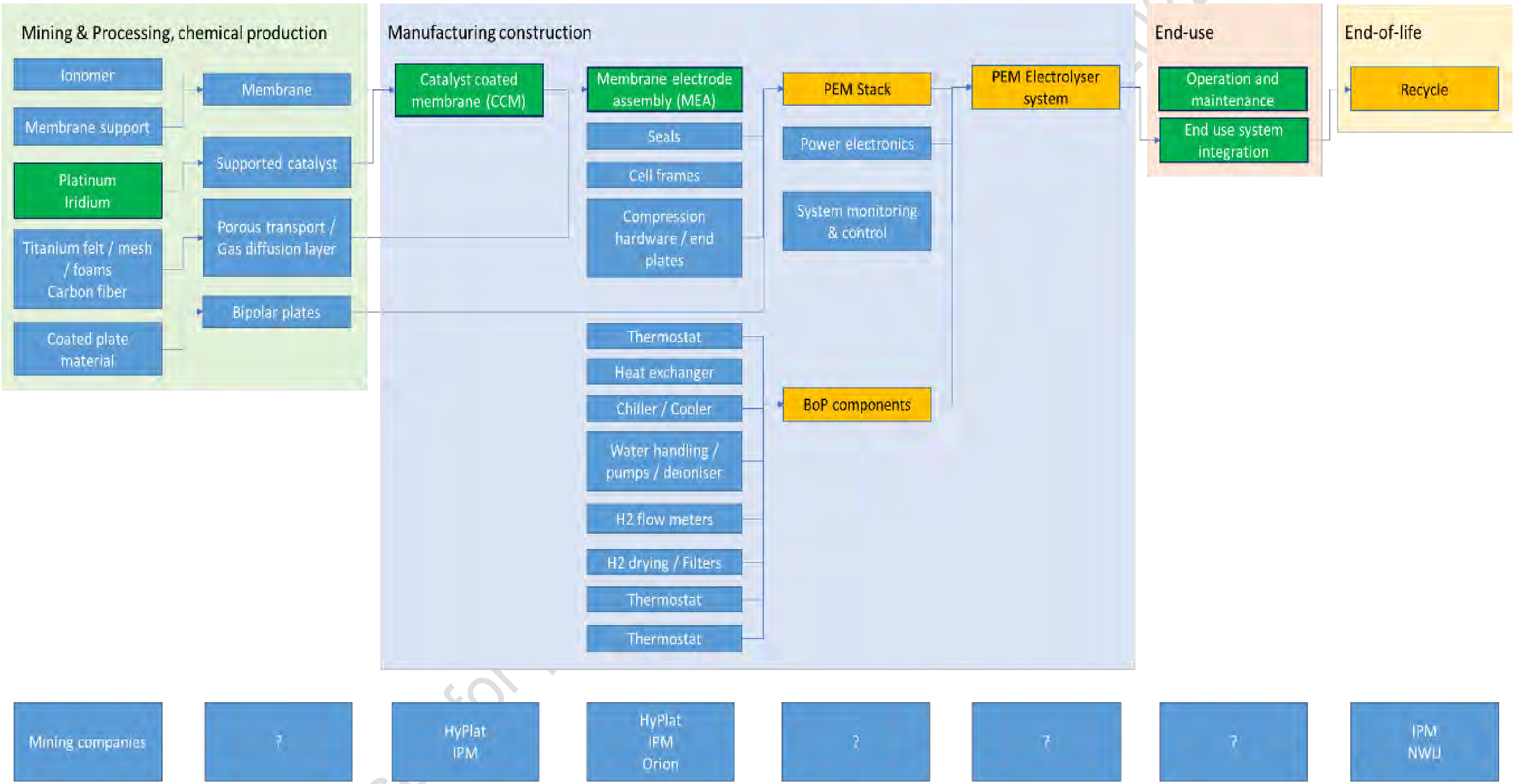


Figure 4.1. Localization potential for PEM electrolysis components.

High priority localisation opportunities identified in the short-term include:

- **PGM raw material mining and beneficiation:** SA is responsible for 72% of global PGM supply and considered the most important component in the hydrogen economy.
  - o PGMs currently contribute approx. 8% of the cost of a PEM electrolyser.
  - o PEM electrolysers current and future PGM loading requirements is given in Table E.4. Figure E.1. shows South Africa's potential demand for PGMs (Pt and Ir) for PEM electrolysers.
    - Iridium demand is expected to increase substantially.
- **CCM electrolyser components:** Beneficiation of locally mined PGMs into higher value components. The CCM contributes approx. 7.5% of the PEM electrolyser system costs.
  - o CCM requirements to meet anticipated global installed electrolysis (based on figures B.9 and B.10) will result in a substantial market for CCM revenues. Figure E.2 provides potential revenues based on optimistic assumptions.
- **System integration and O&M:** A domestic GH market will drive the need for local development. Skilled local talent is available and can be trained. Installation contributes 33% of installed system costs.

Medium priority localisation opportunities identified include:

- **Local electrolyser stack, systems and components:** The availability of PGM materials at competitive prices is a key enabler in developing local factories that are globally competitive businesses for the manufacture of such equipment and components.
  - o Localisation of electrolyser stack or systems can be achieved through one of the localisation topologies listed in Table 4.1.
  - o Localisation opportunities require agreements with international OEMs. A comprehensive list of OEMs is provided in Table E.5.
  - o Considered medium priority for now as it is a long-term consideration and dependent on the development of an off-take market, incentives, and policies to make localisation of facilities attractive for international OEMs.
- **Recycling:** Secondary PGM supplies because of recycling are expected to increase. Currently this route contributes approx. 25% to the platinum supplied.

4.1.4 Value chain component - Energy from fuel cell systems

Several fuel cell technologies are available on the market. The main technologies include Low Temperature PEM Fuel cells (LT PEM FC), Alkaline fuel cells (AFC), high temperature PEM fuel cells (HT PEM FC), phosphoric acid fuel cells (PAFC), and solid oxide or high temperature fuel cells (SOFC or HTFC). LT PEM FC is the current market leader with the biggest global market share (approx. 68%, 2019) and lowest cost. Majority of fuel cell OEMs globally (listed in Table E. 6) supply LT PEM FC technology. The LT PEM FC segment's high market share is primarily due to its commercial readiness and extensive use in stationary, transportation, and portable applications.

SOFCs and PAFCs are emerging with potential of a significant market share (8% and 12% respectively, 2019). These are favoured for stationary applications and have high efficiencies when operated in combined heat and power mode, however SOFC costs are still high. LT PEM FCs operate at low temperatures (approx. 80°C), giving it the advantage of faster start-up, load following capabilities, and reduced component stresses. With the renewed focus globally on decarbonisation causing the shift towards the hydrogen economy, it is expected that the demand for PEM FCs will increase.

The different fuel cells have similar construction and supply chain components with distinct differences in materials used for manufacture. The important difference being the use of PGM catalysts which is found in PEM and PAFC technologies. Nickel and other materials including low loadings of PGM and non-PGM materials mined locally are used in AFC and SOFC. South Africa's unique benefit in the global supply of PGMs and the potential for PEM technology in the future GH economy, is a good sign that South Africa can rely on its PGM resources to promote localisation of LT PEM FC and PAFC technologies' stacks, systems, components, and equipment. SOFC can also provide opportunity for localisation as is seen with Mitochondria's project Phoenix.

Fig 4.2 shows the supply chain components for LT PEM FCs. LT PEM FCs are the dominant fuel cell technology used in mobility applications. LT PEM FCs are expected to generate substantial PGM demand 2030+ as GH use becomes mainstream. Fig 4.2 also provides local technology providers under each component. High and medium priority components are assessed in more detail in Table E.3.

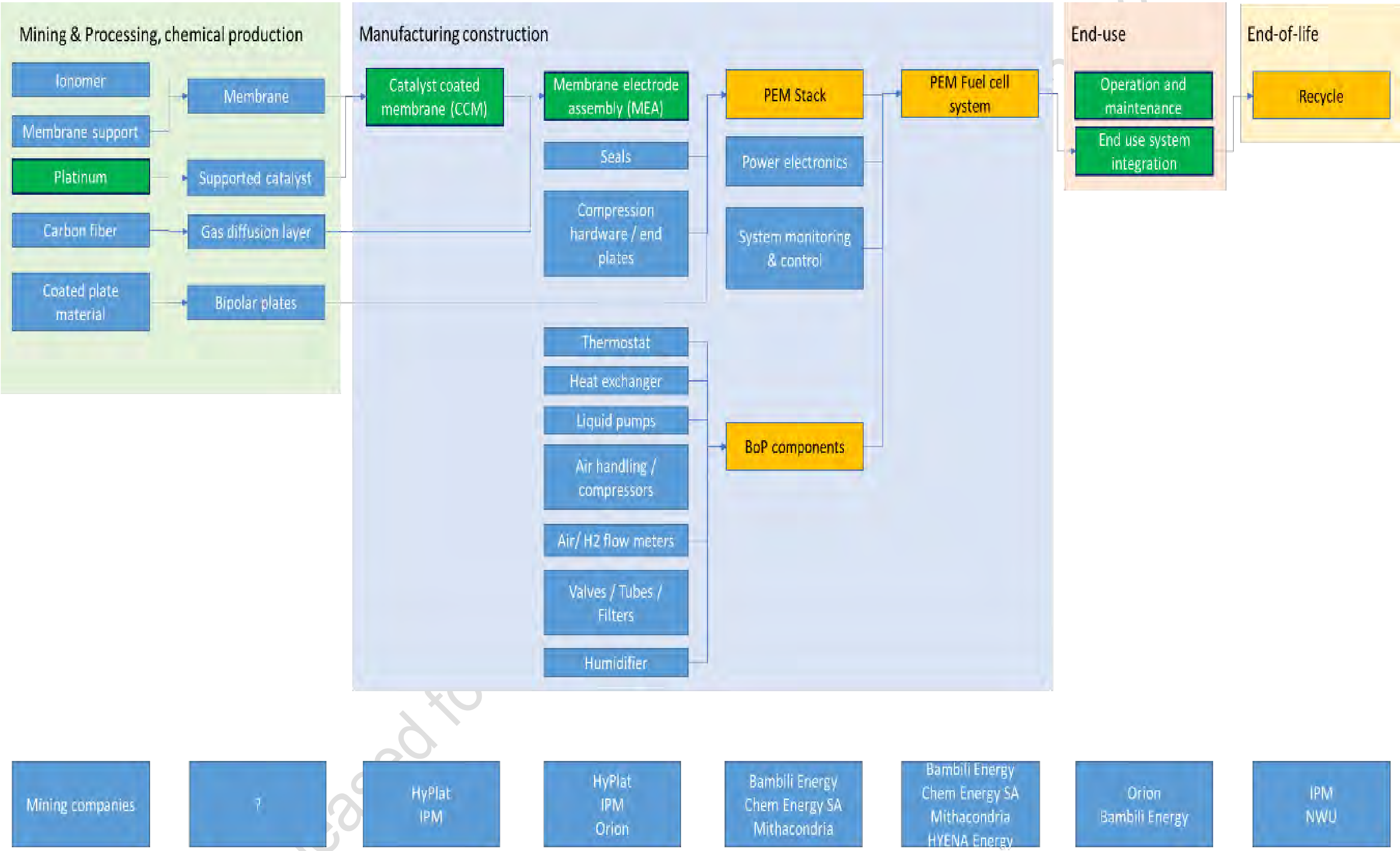


Figure 4.2. Localization opportunities for PEM fuel cells

High priority for localisation identified in the short-term include:

- **PGM raw material mining and processing:** SA is responsible for 72% of global PGM supply and PGMs are the most important component of the hydrogen economy.
    - PEM fuel cells potentially can create a demand for platinum that will become a substantial percentage of mined platinum. Figure E.1 shows the potential Pt demand required for PEM fuel cells in mobility applications based on optimistic expectations of FCEV deployment.
- **PGM Beneficiation:** Further beneficiation of locally mined PGMs into higher value components. MEAs contribute approx. 7% of a PEM fuel cell system cost.
    - Figure E.2 shows potential revenue from MEA supplies based on optimistic penetration for local manufacturing.
    - Policies and incentives (taxes, levies, etc.) around a local PGM market are required to support local beneficiation and attracting OEMs of stack, system, and component manufacturing.
    - Substantial local manufacturing can support additional potential for localisation of up-stream supply chain components (e.g., membranes).

Medium priority opportunities identified include:

- **Local fuel cell stack, systems and components:** The availability of PGM materials at competitive prices is a key enabler in developing local factories that are globally competitive businesses for the manufacture of equipment and components.
    - Technologies that will benefit from competitive PGM prices include PEM and PAFC.
    - This is considered medium priority as it is a long-term consideration and is dependent on the development of an off-take market, incentives, regulations, and policies to make localisation of facilities attractive for international OEMs.
- **Recycling:** Secondary supply because of recycling is expected to increase and contributes approx. 25% to the platinum supplied with the number expected to increase.
- **Automotive manufacturing:** Several major automotive OEMs are already present in South Africa.
    - The automotive industry is transitioning from ICE to BEV and FCEV.
    - BEV is expected to dominate the global passenger vehicle market with FCEV being more applicable to the heavy-duty mobility industry.
    - Several new FCEV OEM start-ups are emerging. The industry is still new, and OEMs have not yet established manufacturing contracts. The industry is not expected to be commercially available until 2025.

4.2 Phased plan and enablers required to localise

South Africa and Zimbabwe possesses close to 90% of the world's platinum reserves and will inherently benefit from GH through the PGM catalyst used in PEM electrolysis and several fuel cell technologies.

4.2.1. South Africa's attractiveness in the global GH environment

- **Abundant local resources of PGMs.** Provides opportunity for SA to incentivise international OEMs to establish local manufacturing facilities of components, stacks, or systems.
    - From the projects identified in the Engie Impact Hydrogen Valley report, the total amount of platinum required to fulfil the equipment (PEM electrolysers &

fuel cells) just in the H2 Valley, will increase the annual platinum production in South Africa by 1-2% in 2025.

        - The report gives 2030 GH demand for the three hubs analysed between 94 – 183 kt GH/year that results in the 1-2% Pt demand. This is less than 0.1% of the most conservative global demand of 300mT by 2050.
        - The PGM sector could see significant gains from the hydrogen economy, as platinum and other PGMs are a key catalyst material for both fuel cell and (PEM) electrolyser manufacturing.
        - Policies and incentives, both for PGM mining companies and OEMs to localise, are required to leverage the local PGM resources. This demand for platinum could generate up to $100 million US in revenue to the sector by 2030 (Figure E.3).
    - Figure E.2 shows the PGM demand that could result from the global GH electrolysis and fuel cell deployment.
    - Iridium demand for PEM electrolysis alone by 2050 requires 1/3 of current global Iridium demand. SA supplies 85% of global iridium.
    - Pt usage in PEM fuel cells, will result in a gradual increased demand for platinum in the medium to long term.

- **PGM beneficiation.** Beneficiation of PGM materials into higher value components provide South Africa with an opportunity to compete in the global GH value chain with value added PGM beneficiated components for PEM electrolysis and fuels cells.
    - As with PGMs raw materials, PGM beneficiation through CCM and MEA component manufacturing provides a considerable opportunity to supply these components into the global market.
    - Local technology developers already manufacturing and supply low volumes into the global market.
    - Easy access to PGM resources must benefit current local component manufacturers.
    - Figure E. 2. Shows the potential revenue from CCM and MEA supplies with optimistic assumptions of market penetration and global demand for PEM electrolysers (Figure 2.1) and PEM fuel cells.
- **South Africa has an abundance of RE resources (wind and solar) and land available to produce GH.** A sizable local market is anticipated by the international community, and this anticipated market is attractive for international OEMs to establish local manufacturing facilities.
- **Established manufacturing, engineering, and technical expertise.** SA has an established manufacturing industry and expertise along with a labour force that is completely trainable. Leveraging PGM resources is possible to motivate OEMs to localise manufacturing of components, stacks and systems and establish penetration into the Southern African region as well as export of components, stacks, and systems.

Major cost drivers and enablers for GH with potential to optimise cost:

- **Electricity price:** Electricity contributes the biggest cost component to the cost of GH.
- **Access to water:** This should preferably not be fresh water and thus desalination or mine wastewater is preferred.
- **Capacity factor:** Wind and solar are both constrained in terms of CF. Combining wind and solar power, and adding batteries, will give the highest utilisation (running hours) of electrolysers. Consideration must be given to CSP/PV hybrids to benefit from the storage available from CSP and the low-cost energy from PV.
- **Plant size:** (through scale of economies and improved efficiency by improved utilization of BoP).

- **Capital cost:** South Africa can be cost competitive in electrolyser manufacture when leveraging availability of local resources (RAW materials), a local market, as well as lower labour costs compared to developed countries.
    - Efficiency can be improved through scale, operation optimisation, and investing in RD&D.
- **Infrastructure and storage:** South Africa are at a disadvantage when considering hydrogen infrastructure and storage. Other countries have extensive existing gas infrastructure which can be retrofitted for hydrogen. These gas infrastructures provide considerable storage potential at a low initial cost for storage and transport. Locating and sizing GH production close to the hub (export, local use) is key.

4.2.2. Market and economic requirements for localisation

To make localisation attractive for international OEMs to establish local facilities, a wish list to establish local facilities have been identified. A detailed analysis is required to determine what makes sense for the country. The wish list identified through stakeholder engagement includes:

- South Africa needs to lead in the energy transition across Africa.
- Establish hydrogen hubs that focus on specific applications, e.g., hydrogen for maritime fuel, mining, solar to hydrogen, sustainable aviation fuel (SAF), etc
- Set the vision and targets for hydrogen penetration.
    - An explicit market for electrolyser target of 500MW/year to 1GW/year. A requirement of 2.5GW to 5GW by 2030.
    - Market demand must exist and be confirmed by project references.
        - To meet the most conservative model's 2050 demand (IHS = 1.9 Mt GH import and 1.9 Mt GH export) Figure 3.2 shows a 13 GW local electrolysis by 2030.
        - The 2025 local installed electrolysis according to Figure 3.2 is 0.8 GW.
        - In 2050 the total installed will have grown to 41GW.
- Local availability of main inputs and raw materials (e.g., steel, nickel), suppliers, distribution centres, and customers should be considered.
- Access to utilities and transportation (e.g., road, rail, air) with favourable costs.
- Design a heavy goods hydrogen refuelling plan to remove diesel
- Availability of current (and future) workforce with the required and/or upgradeable skills.
- Establish alternative fuels strategy: hydrogen, methanol, ammonia, SAF
- Facility and site should be able to physically accommodate future expansion and growth.
- Local advice and support to estimate project costs as precisely as possible.
- Suitability of location – climate, rainfall, extreme weather risks, etc.
- No significant deviations in the local codes and regulations compared to the home market.
- No significant objections or barriers from stakeholders to local manufacturing and site locations.
- In terms of funding support:
    - Incentives that bridge the gap on production costs given increased competition from India and China.
        - tax incentives ideally together with a local institution e.g., the IDC that provides guidance and assumes control over all applications and local bureaucracy processes.
    - Attractive loans
    - Grant funding for establishing manufacturing.
    - Grant funding for Feasibility and FEED studies.

- Annual CFD to incentivize GH for industry.
- Subsidy for GH transport fuel to drive demand.
- Expedited permitting
- Tax abatements and credits

4.2.3. Existing local technology providers

Beneficiation into high-value components, largely done abroad, is an immediate opportunity for localisation. Support for existing local content must be a high priority. Existing local developments of components and assembly of PEM electrolyser and fuel cells include:

- **Hydrox Holdings** - Hydrox Holdings is a South Africa company that has developed IP for a membrane-less Alkaline electrolyser. They have in the past received funding from Shell to develop a scaled-up demonstration system.
- **HyPlat** - HyPlat is a University of Cape Town/HySA spinoff company that manufactures fuel cell MEAs. HyPlat currently supplies low numbers and sizes of PEM fuel cell MEAs into the international market and are currently in the process of acquiring funding to scale up production to 1m units per year.
- **Chem Energy SA** - The Chem Group's head office is based out of Taiwan. They have established a local fuel cell system assembly company (Chem Energy SA) and plant in the Dube Trade-port near Durban. Their focus is on remote systems (telecom backup) and based on a methanol reformer. It is thus fuelled with methanol which is supposed to be more readily available and easily transported than compressed hydrogen. This solution is not CO_2 emission free.
- **HYENA Energy** - A University of Cape Town spinoff company that manufactures remote fuel cell-based power packs fuelled by LPG. They have developed a catalyst and reformer to produce hydrogen from LPG and water which is more readily available than compressed hydrogen, especially for remote areas away from the major centres. There is 15% less CO_2 emissions when compared with diesel generators.
- **Isondo Precious Metals (IPM)** - IPM have obtained equipment to localise MEA manufacturing under license. They have received funding from DTIC and are in the process of construction of their manufacturing facilities (Date announced: 16 July 2021).

4.2.4. Priorities for localisation

Localisation initiatives should consider supporting local industries that are already providing key components into the GH industry to expand, and develop an environment (market, policies, incentives, etc.) to attract international OEMs. Priorities are:

- Analyse the potential for support to expansion of one or more existing local technology providers.
  - Beneficiation of PGM materials by supporting and investing in a local manufacture of CCM/MEA components for the global PEM electrolyser and fuel cell markets could create a substantial export market revenue.
- Provide an environment to attract equipment, component, and system manufacturing for:
  - Electrolysers (Comprehensive list provided in Table E.5)
  - Fuel cells (Comprehensive list provided in Table E.6)
  - Fuel cell vehicles – Several major automotive OEMs are already present in South Africa. The automotive industry is transitioning from ICE to BEV and FCEV. Majority transitions will be to BEV which will have an unwanted effect on the local automotive manufacturing industry, with most OEMs likely to move manufacturing and assembly of BEV and FCEV back to their countries. This opportunity does not

appear to be attractive for localisation and is considered a risk of automotive OEMs exiting the country as they transition to BEV.

4.2.5. Key linkages to other economic sectors

Table 4.2 highlights links between the GH value chain and services and inputs provided by the economic sectors in South Africa.

Table 4.2. Linkages to other economic sectors.

GH value chain / Economic sectors	Water resources	Renewable energy	Electricity grid and associated	Electrolyser and BoP	Compression, storage and	GH and beneficiated	Electricity from Fuel cell & Battery
Agriculture	X	X					
Electricity	X	X	X	X		X	X
Construction	X	X	X	X	X	X	X
Personal services							
Resource extraction, Mining	X	X		X	X	X	X
Transportation & communication					X	X	
Manufacturing	X	X	X	X	X	X	X
Trade		X	X	X	X	X	X
Government	X	X	X	X	X	X	X
Finance	X	X	X	X	X	X	X

Economic sectors that will benefit across most of the GH value chain components are:

- **Government and finance:** These are seen as a first requirement across the entire GH value chain and important for both policies and regulations to fast-track GH implementation and establishing G2G relationships for export market and establishing infrastructure.
- **Electricity:** Electricity and CF of RE inputs are major cost drivers for the GH value chain. Currently South Africa's grid is constrained in certain RE resource dominant corridors (e.g., Northern Cape). Availability of infrastructure (overhead power lines or pipelines) to link RE to GH hubs and local demand centres is crucial infrastructure that takes several years to develop.
    - Requires integration with SAREM
    - Requires integration with Integrated Energy Plan (IEP) and IRP
    - Requires integration with TDP
- **Resource extraction, mining:** RAW material is identified as a high priority for localisation of both PEM electrolysers and PEM fuel cells equipment, components and/or systems.
- **Manufacturing:** PGM beneficiation, steel and other metals industry, machinery and equipment through local equipment and component manufacture for electrolyser and fuel cell stacks, integrated systems, and end use applications (FCEV).

- **Construction:** The construction sector will inherently benefit from the development of new hydrogen hubs, ports, electrical and gas infrastructure, renewable energy plants and is likely to be the sector to contribute most to terms employment.

5. Supply chain and GH Hub development

5.2. Identification of GH Hub and Supply chain analysis

When considering the technical Value Chain definition outlined above, it is evident that GH supply chains can be designed on 2 models as follows:

1. Co-locating renewable energy and production equipment (electrolysis process) and evacuation of the product or GH molecules by transport or pipeline if economies of scale can be achieved; or
2. Locating production (electrolysis process) near the demand node and evacuate renewable energy via wheeling on the national grid or dedicated grids if economies of scale can be achieved.

Based on analysis and industry engagement, the following hubs have been identified as preferred locations for GH development for exports and domestic consumption, shown by Figure 5.1:

- Inland Hubs:
    - The Vaal/Johannesburg Hub (extension to Rustenburg, Tshwane, and Mogalakwena; incorporating the whole Bushveld Igneous complex).
    - Limpopo/Mogalakwena Hub.
- Coastal Hubs:
    - eThekwini/Richards bay hub.
    - Port of Ngqura/Coega SEZ.
    - Atlantis SEZ (greentech focus) Hub.
    - Port of Saldanha bay and Saldanha bay SEZ.
    - Boegoe bay port/Namakwa SEZ.

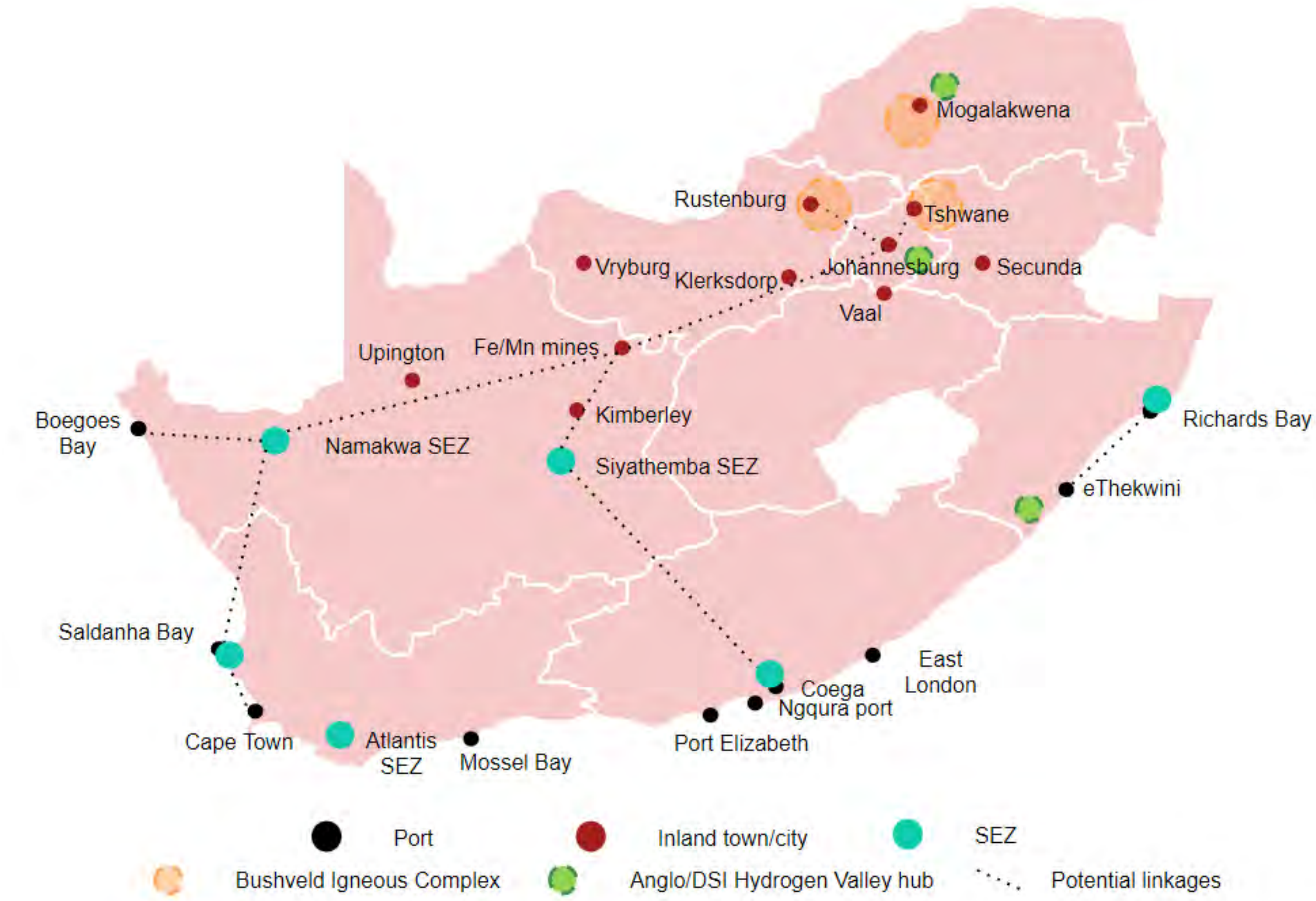


Figure 5.1: Geographic location of potential GH Hubs

5.1.1. Overview of key options:

A potential hydrogen hub on the West coast, will link to the Northern Cape solar resource and will be an optimal export opportunity to EU and potential American markets. Two options of Saldanha bay and Boegoe bay are considered but these have very different dynamics due to Saldanha Bay being a well-established port with an IDZ, local demand potential and logistics infrastructure, whereas Boegoe Bay will be a green-field port development. However, the pre-feasibility study for the Boegoe Bay development is nearing completion.

Similarly, a hydrogen hub in the Eastern Cape will optimally link to Eastern Cape wind resource. The port facilities of Ngqura, by Coega, is a well-established port and IDZ and will give access to trading routes both East and West of South Africa.

Further up the East coast Port of Durban (eThekwini) is a well-established trading port, but the port and surrounds are highly congested. The Port Authority's strategic planning is focused on container traffic with the aim to relocate the energy cluster at Island View to Richards Bay. Richards Bay also has a well-established trading port, as well as industrial activity to potentially diversify the local use of hydrogen. Richards bay's offshore wind resource is amongst the best in South Africa.

Inland, the Vaal triangle is an attractive location due to the concentrated industrial manufacturing activity developed over the years, including Sasol's Sasolburg plant, ArcelorMittal's (AMSA) steelworks, and Safripol's polymer processing. The Vaal would specifically focus on domestic uptake of hydrogen (Sedibeng District Municipality, 2012).

These locations have been assessed according to the technical requirements of a hydrogen hub:

- Access to a renewable energy resource.
- Availability of renewable energy development zones (REDZ).
- Market positioning of the hydrogen hub; export, domestic, or both.
- Existing infrastructure including logistics networks, transmission corridors, and port access.
- Existing industries which could serve as anchors for the local deployment of hydrogen i.e., demand proximity.
- Access to resources, including human capital, components, and equipment.
- Purpose of the hydrogen hub, which could either be:
    a. To serve an export market.
    b. To develop a domestic market alongside the export infrastructure.
    c. To anchor local hydrogen deployment in the PGM industry.

Figure 5.2 shows the assessment framework and the rating of each location.

Although all locations have above average renewable energy resources, Boegoe bay, Saldanha, and the Vaal have the best solar resource while Coega and Richards Bay have the best wind resource. Boegoe bay, the Vaal, and Coega have the closest proximity to a REDZ which could incentivise the financing and construction of solar and wind farms. The closest REDZ to Durban and Richards Bay is over 600 km away, indicating a lack of renewable energy financing schemes to leverage off.

Durban is not seen as an optimal location due to port congestion and constrained land. Richard's bay has an added attraction of already being proposed for large scale marine bunkering and has a bigger industrial footprint closer to its port. Foskor's fertiliser processing and Rio Tinto's titanium mining operations could expand the scope of local adoption of hydrogen.

The above locations have a connected logistics network which will make access to resources (human capital, components, equipment) simpler and cheaper.

The Vaal is strongly domestic oriented and can fulfil the domestic deployment of hydrogen due to its industrial footprint, well established infrastructure, and its inland location. The Vaal triangle could also serve the purpose of anchoring hydrogen in the PGM industry; the existing pipeline infrastructure could be used to transport hydrogen across the North West, Gauteng, Limpopo, and Mpumalanga where most PGM activity occurs.

Coega's market outlook is both export and domestic, however its focus should be on export. It is a viable location for export due to its immediate port access and central location along South Africa's coastline. Coega is home to a sizeable industrial footprint, including FMCG and pharmaceutical companies, and provides an option for local deployment of hydrogen as part of domestic demand growth.

Saldanha bay has strong existing port and industrial infrastructure; local demand through opportunities like Saldanha Steel, Namaqua Sands and other industries further provide attractive domestic demand. Saldanha bay also has well established logistics and an IDZ. This will give Saldanha an opportunity to move quicker at lower cost and lower risk as an export hub for green ammonia.

The Boegoebaai green hydrogen hub in the Northern Cape can be a strategic project to open Southern Africa's full green energy potential. The location places it relatively close in proximity to rich mining and agriculture sectors compared to other existing ports. The Boegoebaai Port will provide an enabling platform for the province to achieve the key frontiers proposed in the 2021 Sustainable Infrastructure Development Symposium South Africa (SIDSSA). **Supporting the efforts by the Northern Cape Economic Development Agency in the development of the Boegoebaai programme needs to be given top priority.**

Figure 5.3 shows the hydrogen hub locations, and provides an overview of each location's relative advantages, risks and purpose. Figure 5.4 shows the visual representation of the GH hub locations, as well as the demarcated REDZ, existing infrastructure, and industrial activity.

	West Coast		Central (Inland)	Southeast coast		
	Boegoes Bay	**Saldanha Bay**	**Vaal**	**Coega**	**eThekwini**	**Richards Bay**
Renewable energy resource*	**Solar - 2,100 kWh/m²** Wind - 6.3 m/s	**Solar - 2,100 kWh/m²** Wind - 7.7 m/s	**Solar - 2,100 kWh/m²** Wind - 4.4 m/s	Solar - 1,800 kWh/m² **Wind - 8.0 m/s**	Solar - 1,700 kWh/m² Wind - 6.7 m/s	Solar - 1,700 kWh/m² **Wind - 7.9 m/s**
REDZ	*REDZ8 - Springbok 1.5 Mha available 200 km away*	*REDZ1 - Overberg REDZ2 - Komsberg 0.53 Mha & 0.88 Mha available 290 km & 360 km away*	*REDZ9 - Emalahleni REDZ10 - Klerksdorp - 200 km & 130 km away*	*REDZ3 - Cookhouse 0.74 Mha available 150 km away*	*REDZ4 - Stormberg 1.2 Mha available 640 km away*	*REDZ4 - Stormberg 1.2 Mha available 810 km away*
Market outlook	*Domestic (hydrogen) Export*	*Domestic (ammonia, hydrogen) Export*	*Domestic (various)*	*Domestic (hydrogen) Export*	*Export*	*Domestic (ammonia, hydrogen) Export*
Existing infrastructure*	*N1 road corridor Northern tx corridor Kimberley Airport (830 km) - -*	*N1 road corridor Western and Central tx corridor Cape Town Int'l Airport (150 km) Port - 21 m depth Storage facilities - 8 km from port*	*N3 road corridor Central tx corridor OR Tambo Int'l Airport (85 km) - -*	*N2 road corridor Eastern tx corridor Port Elizabeth Int'l Airport Port - 18 m depth Future storage - 790,000 m³*	*N2 and N3 road corridors Eastern tx corridor King Shaka Int'l Airport Port - 12 m depth -*	*N3 corridor - Richards Bay Airport Port - 12.5 m depth -*
Existing industries	*Agriculture Mining (iron, manganese) Manufacturing (cement, steel)*	*Agriculture Mining (zircon, rutile, ilmenite) Manufacturing (steel)*	*Manufacturing (agri-processing, (petro)chemicals, plastics, steel) Tourism*	*Manufacturing (automotive, FMCG, pharmaceuticals) Property development Tourism*	*Mining (coal, quarry) Manufacturing (automotive, cement, chemicals, paper, steel)*	*Mining (titanium) Manufacturing (fertiliser)*

*Figure 5.2. GH hub assessment framework (Solargis, 2021; Vortex, 2021; Transnet National Port Authority, 2021) **

* Best renewable energy resource in South Africa: Solar - 2,400 kWh/m2 and Wind - 10.6 m/s
tx - transmission
All locations have a sustainable water source

	West Coast		Central (Inland)	Southeast coast		
	Boegoes Bay	**Saldanha Bay**	**Vaal**	**Coega**	**eThekwini**	**Richards Bay**
Advantages	• *Potential R13bn investment into iron ore/manganese export port infrastructure* • *Access to the Americas and Europe market* • *Option to upscale freely for future production* • *Incentivised renewable energy production* • *Possibility to anchor local hydrogen uptake through the mining industry*	• *Best quality renewable energy resource* • *Access to the Americas and Europe market* • *Option to upscale freely for future production* • *Possibility to anchor local hydrogen uptake through industrial activity* • *Easy access to resources* • *Can fulfill short-term export trading requirements*	• *Incentivised renewable energy production* • *Possibility to anchor local hydrogen uptake through the PGM and manufacturing industry* • *Well established existing infrastructure* • *Very easy access to resources*	• *Access to the East and West markets without incurring additional costs* • *Option to upscale for future production freely* • *Incentivised renewable energy production* • *Possibility to anchor local hydrogen uptake through the manufacturing industry* • *Very easy access to resources*	• *Access to the East market* • *Possibility to anchor local hydrogen uptake through the mining industry* • *Very easy access to resources*	• *Access to the East market* • *Possibility to anchor local hydrogen uptake through ammonia production* • *Easy access to resources*

Figure 5.3. Potential GH hub locations

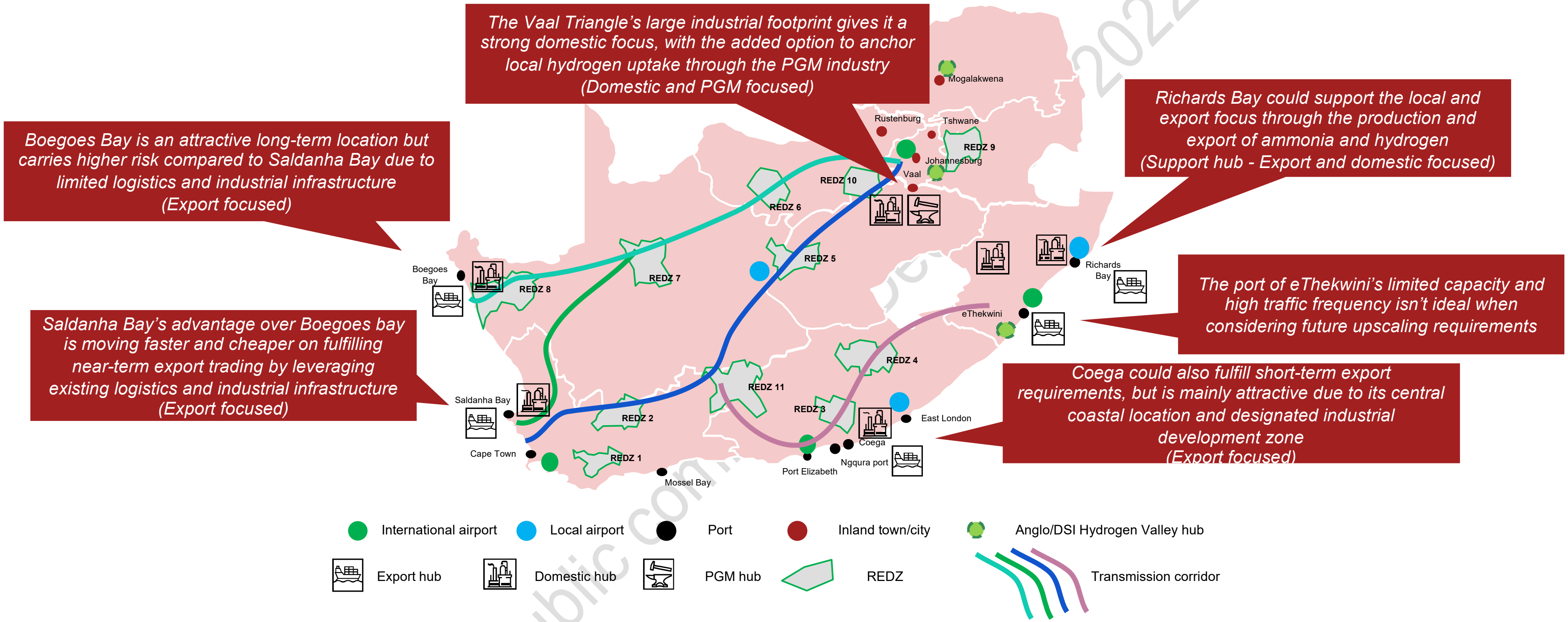


Figure 5.4. Visual representation of potential GH hub locations

5.2. Summary of findings

It is important to create focus and prioritisation in the blueprint design. This has also been identified by international OEM's as well as in the literature review as global best practice. It is therefore proposed that the identified locations be promoted for longer term development as the GH sector develops in South Africa.

5.3. Summary of current GH activities in SA

Figure 5.5 shows a visual summary while Table 5.2 shows a detailed summary of the prioritised GH projects across South Africa. A full GH project list is shown in Appendix E. Figure 5.6 shows the investment support needed for the GH production projects, including skills training centres and a GH hub enabling investment for Coega and Vaal. Figure 5.7 also shows the investment required to bring forward South Africa's 3.8 mtpa GH production scale from 2050 to 2040, and the additional demand uplift that can be unlocked through further funding' ~$133 bn in further funding.

Figure 5.5 shows a visual summary while Table 5.2 shows a detailed summary of the prioritised GH projects across South Africa. A full GH project list is shown in Appendix F. Figure 5.6 shows the investment support needed for the GH production projects, including skills training centres and a GH hub enabling investment for Coega and Vaal.

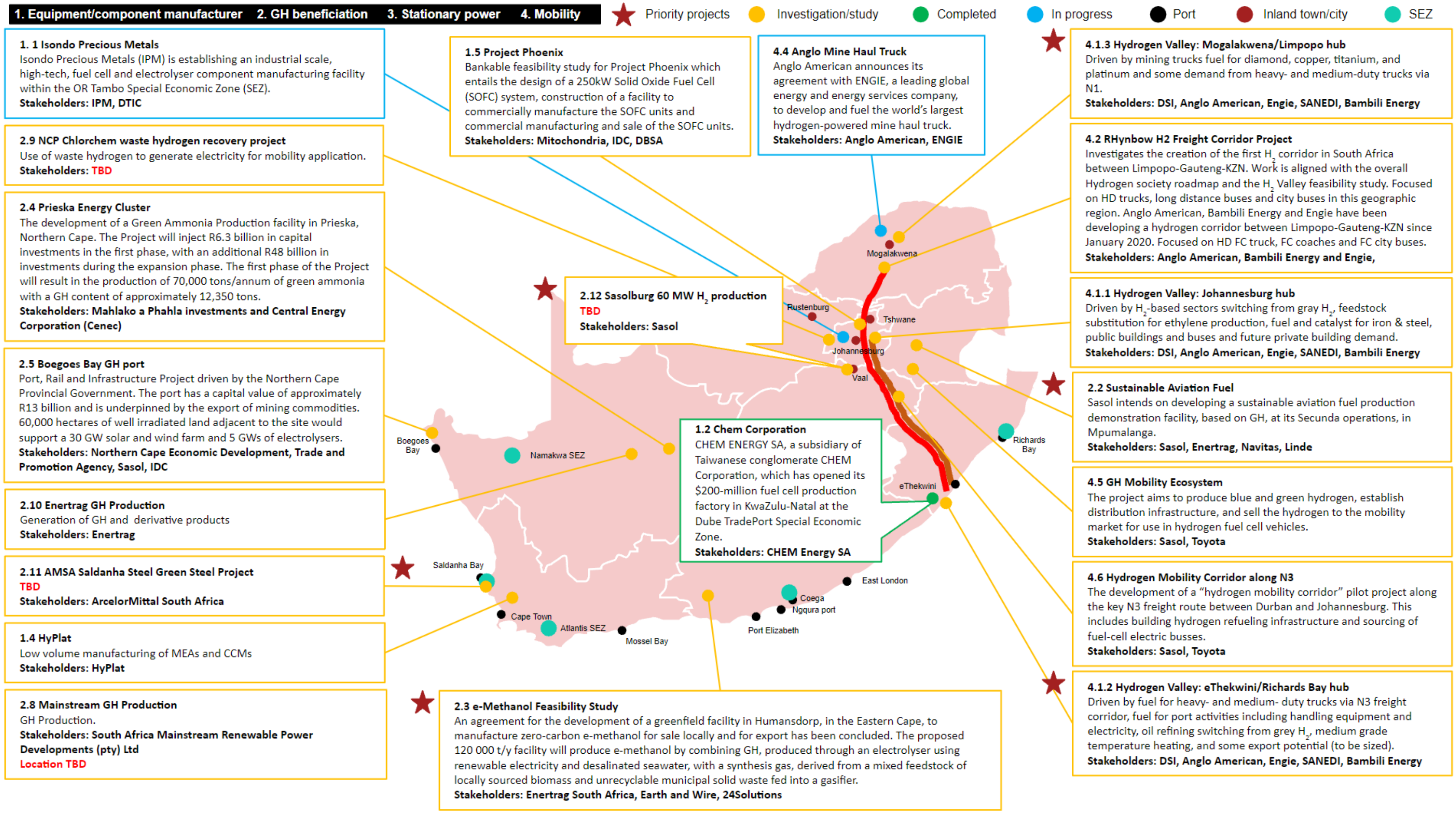


Figure 5.5. Prioritised summary of local GH activities

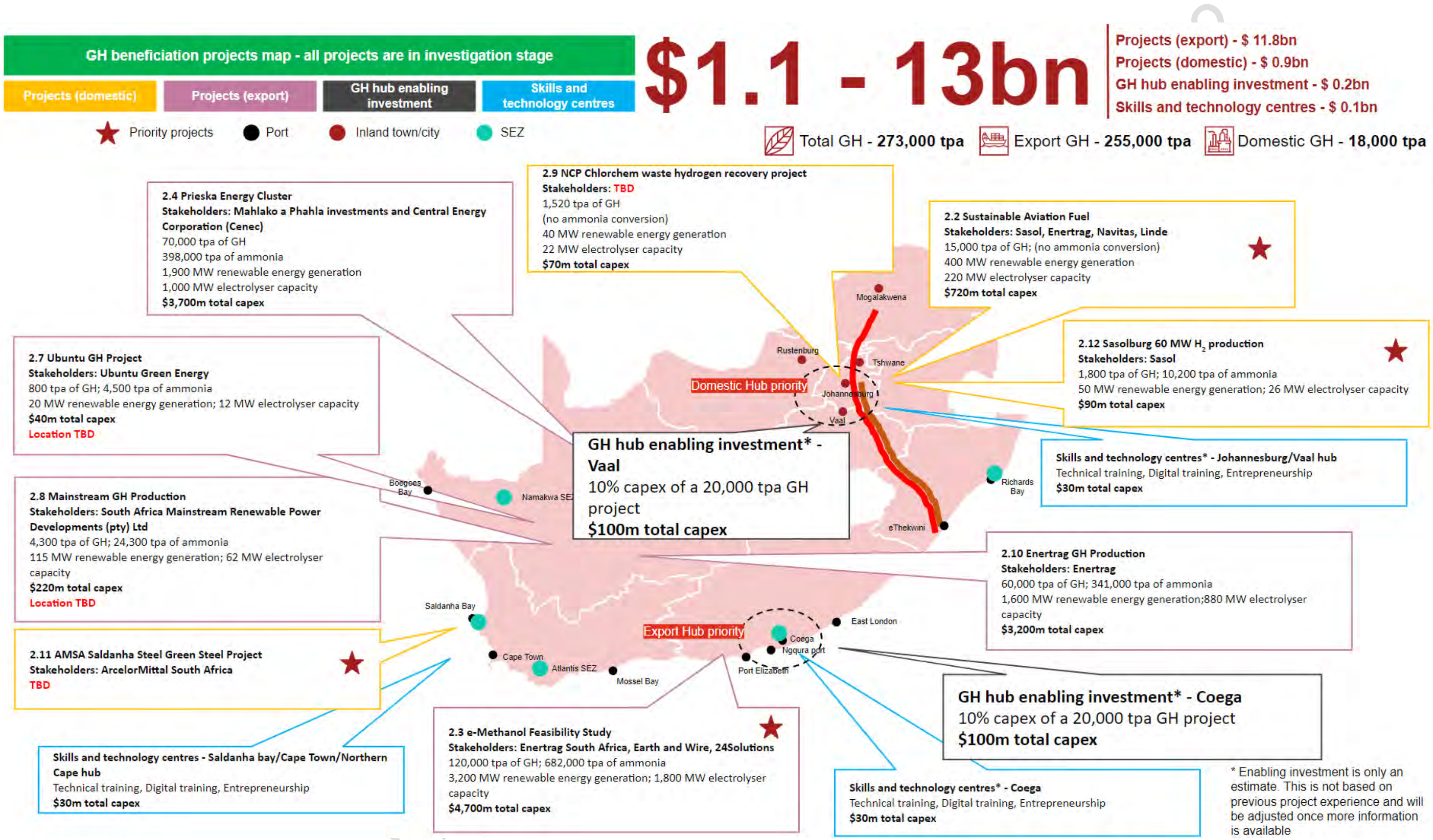


Figure 5.6. Capital invest support needed for GH production projects to be commissioned in 2025

Key insights

- South Africa requires an **initial seed capital of $1bn to expedite GH export of 20 ktpa**.
- Within three to five years, several GH projects, both export and local, will come online **increasing GH scale to 270 ktpa**, requiring **capital of $13bn, displacing** carbon emissions by **21 Mtons of CO_2**.
- **The target of 3.8 mtpa** is originally set for 2050, however, a **scaling up investment of $31bn** between 2030 and 2040 will enable South Africa to expedite this baseline production **displacing 294 Mtons of CO_2**.
- Between 2040 and 2050, South Africa can aggressively pursue deeper decarbonisation by seeking a **GH demand uplift to 7 mtpa**. This will displace **541 Mtons** of CO_2 and requires **$133bn in investment support**.
- Emissions calculated from the investment date to the end of the decade, assuming 3 years of development and 7 years of operations from the date of investment to the end of the decade. **Annual emissions reduction from 7 mtpa GH equals 76.8 Mtons CO_2, or between 18 to 20 % of South Africa's annual carbon emissions.**

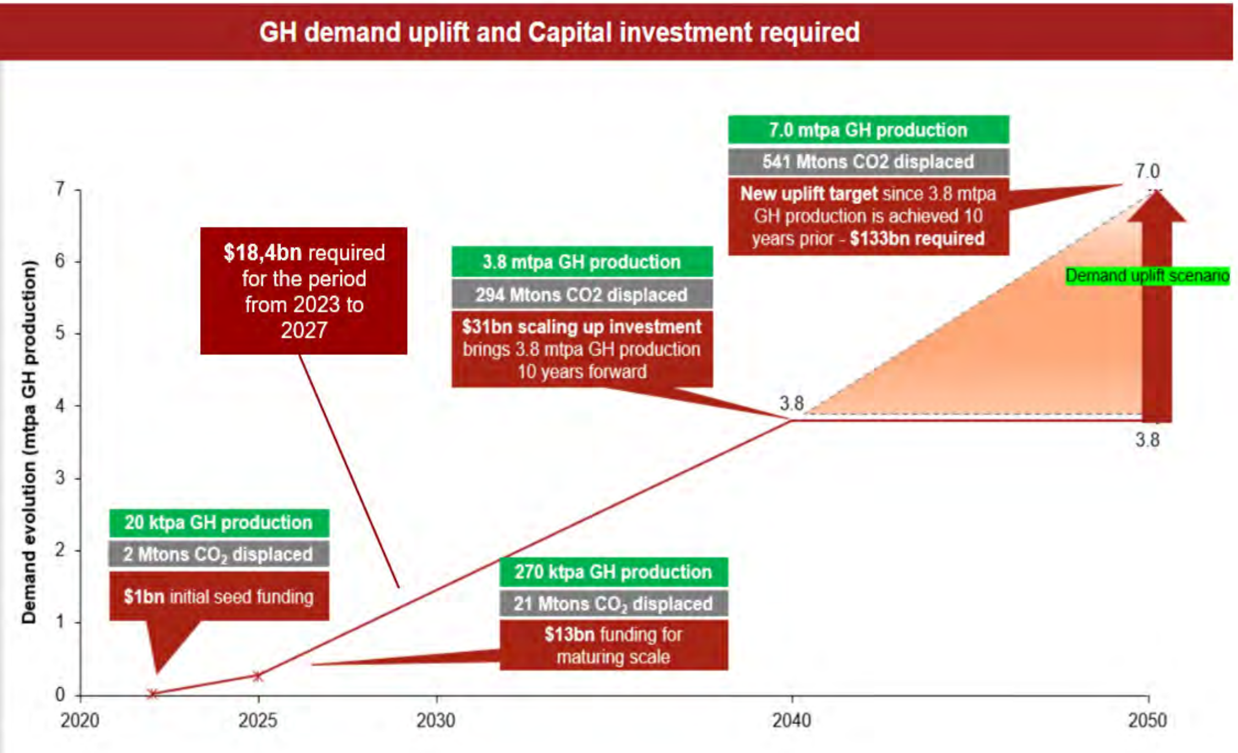


Figure 5.7. GH demand uplift and Capital investment required to scale up South Africa's GH production scale to 3.8 mtpa by 2040.

Table 5.2: Prioritised GH related initiatives in South Africa

* Minor, medium, major rating of Project Scale based on size of hydrogen/ammonia capacity, investment, electricity generation, or equipment used

#	Project Scale*	Location	Project	Status	Description	Stakeholders
Local component manufacture/IP development						
1.1	Major	Gauteng, Johannesburg	Isondo Precious Metals	Facilities in construction phase	Isondo Precious Metals (IPM) is establishing an industrial scale, high-tech, fuel cell and electrolyser component manufacturing facility within the OR Tambo Special Economic Zone (SEZ)	IPM. DTIC
1.2	Major	Kwa-Zulu Natal, Durban	Chem Corporation	Facilities construction completed	CHEM ENERGY SA, a subsidiary of Taiwanese conglomerate CHEM Corporation, which has opened its $200-million fuel cell production factory in KwaZulu-Natal at the Dube TradePort Special Economic Zone.	CHEM Energy SA
1.4	Major	Western Cape, Cape Town	HyPlat	Operating	Low volume manufacturing of MEAs and CCMs	Hyplat
1.5	Minor		Project Phoenix	Feasibility study	Bankable feasibility study for Project Phoenix which entails the design of a 250kW Solid Oxide Fuel Cell (SOFC) system, construction of a facility to commercially manufacture the SOFC units and commercial manufacturing and sale of the SOFC units.	Mitochondria, IDC, DBSA

#	Project Scale*	Location	Project	Status	Description	Stakeholders
			GH beneficiation			
2.2	Medium	Mpumalanga, Secunda	Sustainable Aviation Fuel	Cooperation agreement announced	SASOL intends on developing a sustainable aviation fuel production demonstration facility, based on GH, at its Secunda operations, in Mpumalanga to be bid in the first round of the H2Global auction programme.	Sasol, Enertrag, Navitas, Linde
2.3	Major	Eastern Cape, Humansdorp	e-methanol feasibility study	Feasibility study (requires more detail)	An agreement for the development of a greenfield facility in Humansdorp, in the Eastern Cape, to manufacture zero-carbon e-methanol for sale locally and for export has been concluded by a consortium comprising Earth and Wire, ENERTRAG South Africa and 24Solutions. The proposed 120 000 t/y facility will produce e-methanol by combining GH, produced through an electrolyser using renewable electricity and desalinated seawater, with a synthesis gas, derived from a mixed feedstock of locally sourced biomass and unrecyclable municipal solid waste fed into a gasifier.	Enertrag South Africa, Earth and Wire, 24Solutions
2.4	Major	Northern Cape, Prieska	Prieska Energy Cluster	Feasibility study and scoping (2025 commission date)	The project entails the development of Green Ammonia Production facility in Prieska, Northern Cape. The Project will inject R6.3 billion in capital investments in the first phase, with an additional R48 billion in investments during the	Mahlako a Phahla investments and Central Energy Corporation (Cenec).

#	Project Scale*	Location	Project	Status	Description	Stakeholders
					expansion phase. The first phase of the Project, which will be located 10km outside Prieska in the Northern Cape, South Africa, will result in the production of 70,000 tons/annum of green ammonia with a GH content of approximately 12,350 tons.	
2.5	Major	Northern Cape, Boegoe Bay	Boegoe Bay GH Port	Feasibility study (memorandum of agreement signed)	Port, Rail and Infrastructure Project driven by the Northern Cape Provincial Government. The port has a capital value of approximately R13 billion and is underpinned by the export of mining commodities. 60,000 hectares of well irradiated land adjacent to the site would support a 30 GW solar and wind farm (6 times SA's current installed renewable energy capacity) and support 5 GWs of electrolysers	Northern Cape Economic Development, Trade and Promotion Agency, Sasol, IDC
Mobility demonstration						
4.1.1	Major	Gauteng	Hydrogen Valley Feasibility Investigation - Johannesburg Hub	Feasibility study started	Driven by H2-based sectors switching from grey H2, feedstock substitution for ethylene production, fuel and catalyst for iron & steel, public buildings and buses and future private building demand.	DSI, Anglo American, Engie, SANEDI, Bambili Energy

#	Project Scale*	Location	Project	Status	Description	Stakeholders
4.1.2	Major	Kwa-Zulu Natal	Hydrogen Valley Feasibility Investigation - eThekwini/Richards Bay Hub	Feasibility study started	Driven by fuel for heavy- and medium-duty trucks via N3 freight corridor, fuel for port activities including handling equipment and electricity, oil refining switching from grey H2, medium grade temperature heating, and some export potential (to be sized).	DSI, Anglo American, Engie, SANEDI, Bambili Energy
4.1.3	Major	Limpopo	Hydrogen Valley Feasibility Investigation - Mogalakwena/Limpopo Hub	Feasibility study started	Driven by mining trucks fuel for diamond, copper, titanium, and platinum and some demand from heavy- and medium-duty trucks via N1.	DSI, Anglo American, Engie, SANEDI, Bambili Energy
4.2	Major	Gauteng, Kwa-Zulu Natal, Limpopo	Rhynbow H2 freight corridor project	Feasibility study in progress	Investigates the creation of the first H2 corridor in South Africa between Limpopo-Gauteng-KZN. Work is aligned with the overall Hydrogen society roadmap and the H2 Valley feasibility study. Focused on HD trucks, long distance buses and city buses in this geographic region. Anglo American, Bambili Energy and Engie have been developing a GH corridor between Limpopo-Gauteng-KZN since January 2020. Focused on HD FC trucks, FC coaches and FC city buses.	Anglo American, Bambili Energy and Engie

#	Project Scale*	Location	Project	Status	Description	Stakeholders
4.4	Minor	Limpopo, Mogalakwena	Anglo Platinum	Implementation	Anglo American announces its agreement with ENGIE, a leading global energy and energy services company, to develop and fuel the world's largest hydrogen-powered mine haul truck.	Anglo American, ENGIE
4.5	Major	Kwa-Zulu Natal	GH Mobility Ecosystem	Concept phase	The project aims to produce blue and GH, establish distribution infrastructure, and sell the hydrogen to the mobility market for use in hydrogen fuel cell vehicles	Sasol, Toyota
4.6	Major	Gauteng, Kwa-Zulu Natal	Hydrogen Mobility Corridor along N3	Concept phase	The development of a "hydrogen mobility corridor" pilot project along the key N3 freight route between Durban and Johannesburg. This includes building hydrogen refuelling infrastructure and sourcing of fuel-cell electric busses.	Sasol, Toyota
Funding programs						
6.1	Major	International	BMU	In progress	Germany's National Hydrogen Strategy provides 600 million euros which the BMU will use to fund the PtX Pathways project developing the PtX market in Morocco, Argentina and South Africa	Germany

#	Project Scale*	Location	Project	Status	Description	Stakeholders
6.2	Major	International	BMWi	In progress	Funding the 200-million-euro concessional financing for hydrogen projects in South Africa by KfW	Germany
6.3	–	International	BMBF	In progress	Funding the Hydrogen Atlas for sub-Saharan Africa	Germany, SADC, ECOWAS
6.4	–	International	BMZ	In progress	Funding H2Global, which subsidises the import of green H2 into Germany	Germany

5.4. Integration with Current and Planned Pipeline Routes:

5.4.1. Current Pipeline Routes:

South Africa's natural gas pipeline system is composed of two networks: the Mozambique to Secunda Pipeline (MSP), Figure 5.8, and the Transnet Gas Pipeline Network (TGPN), Figure 5.9.

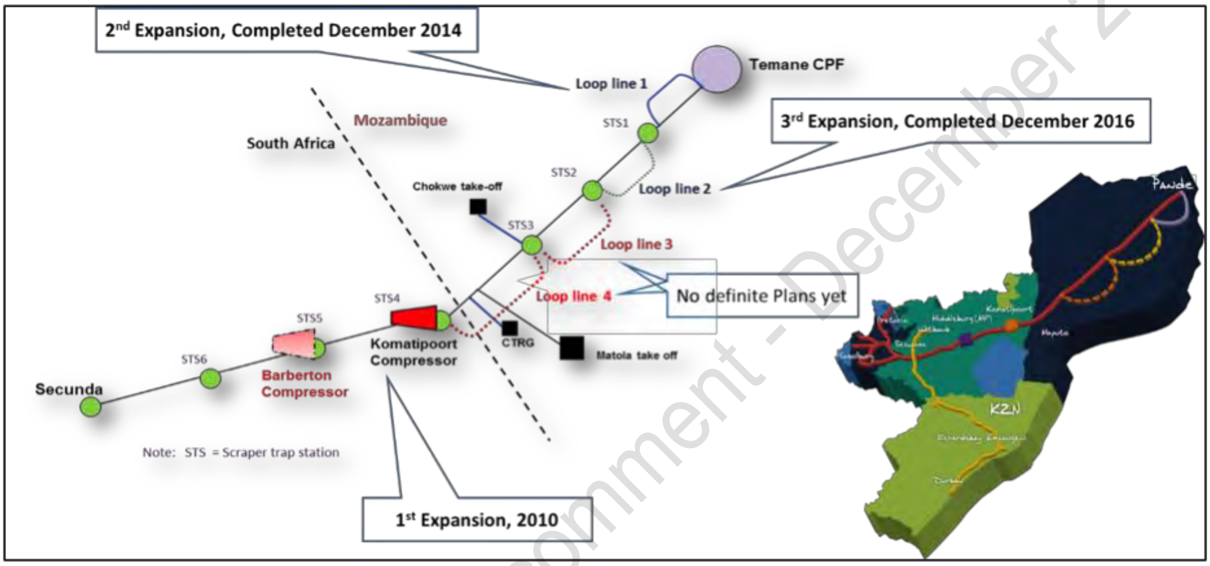


Figure 5.8: ROMPCO pipeline route

The MSP is a 26" diameter, 865 km long gas transmission pipeline from the Central Processing Facility at the Temane gas field near Vilanculos in Mozambique to Secunda in South Africa and was commissioned in 2004. The first expansion project on the MSP to increase throughput capacity to South Africa was the compressor station at Komatiepoort. The project was initiated in 2008 and the compressor station was commissioned in December 2010. In 2012, the second expansion on the MSP to increase throughput capacity to Mozambique was approved. This is a 26" diameter 127 km long gas transmission pipeline running parallel to the original MSP from the CPF to the first Scraper Trap Station (STS), STS1. Loop Line 1 was commissioned in December 2014. The third expansion on the MSP is also a 26" diameter 127 km long gas transmission pipeline running parallel to the original MSP but from the first to the second STS, i.e., STS1 to STS2. The pipeline was commissioned in December 2016.

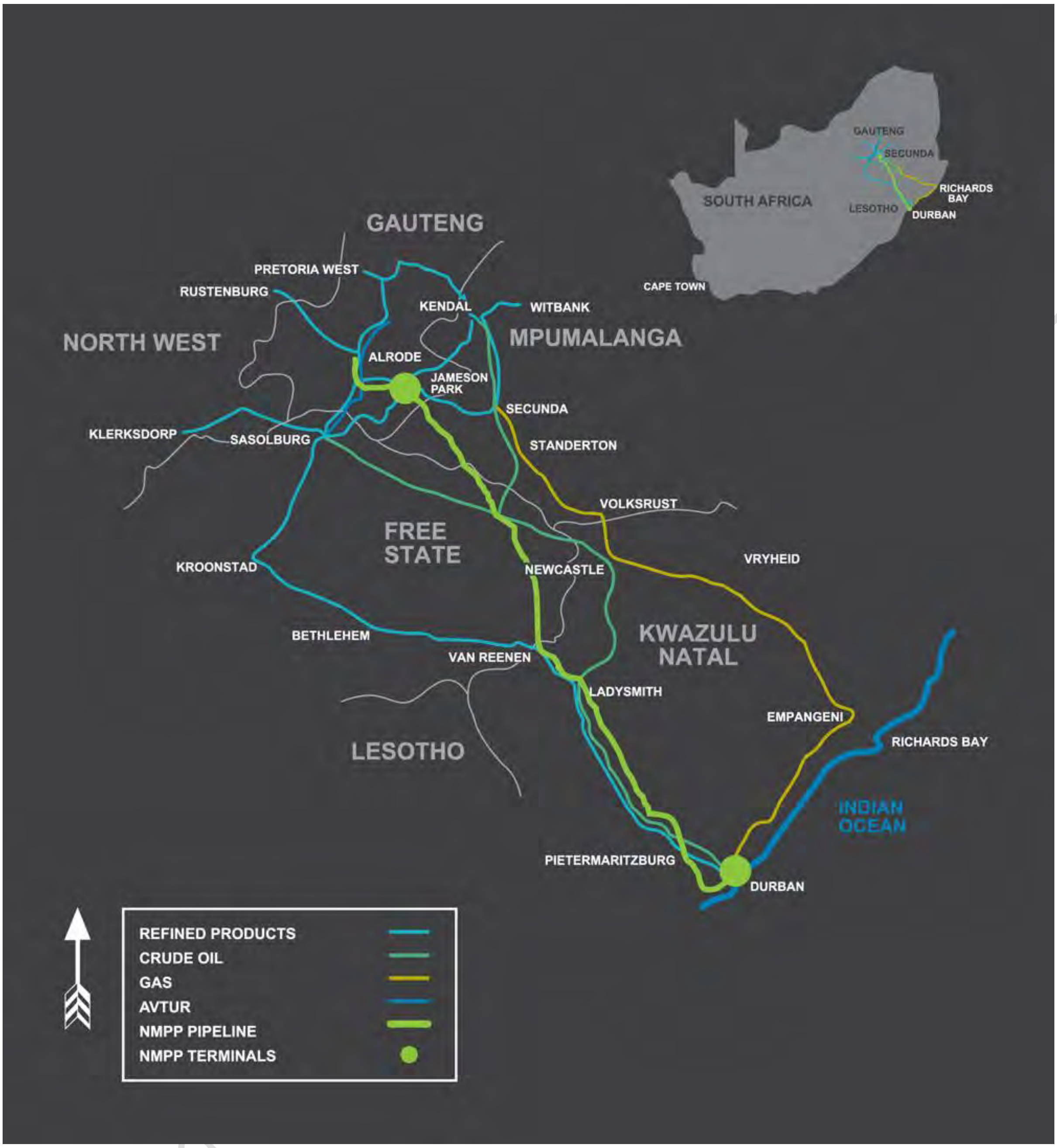


Figure 5.9: Transnet gas pipeline route (oranje line in above image)

The TGPN (a converted line previously used for liquids) runs from Secunda to Durban via Empangeni. It has take-off points at Newcastle and Richards Bay as well as along the route between Empangeni and Durban. The pipeline transports 450 million cubic metres of gases.

Converting natural gas pipelines to carry a blend of natural gas and hydrogen (up to about 15-20% hydrogen) may require only modest modifications to the pipeline. If the hydrogen in the existing pipeline network (MSP and extension and TGPN) is above 15-20%, this will require new pipelines to be laid. Rather than a repurposing of existing pipelines, this will require repurposing of the pipeline network on the pipeline route.

5.4.2. Planned Pipeline Routes:

SA has limited natural gas pipeline network infrastructure. However, the potential to exists to extend existing hydrogen pipelines (SBG Springs) and to optimise renewable energy infrastructure, grid infrastructure and pipeline infrastructure. Figure 5.10 provides an overview of the Phased Gas Pipeline Network (PGPN), which emanated from the Operation Phakisa Oceans Lab, with South Africa's Renewable Energy Development Zones (REDZs).

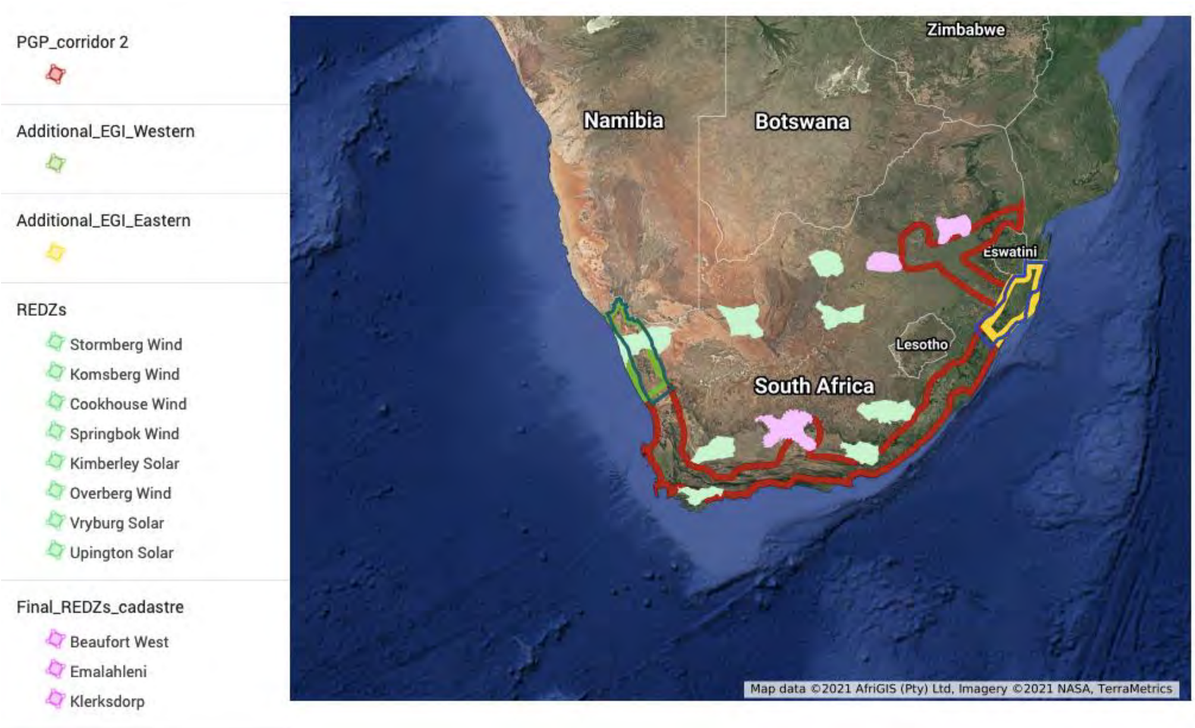


Figure 5.10: Phased Gas Pipeline Network overlayed Renewable Energy Development Zones

For the new pipeline system, it is likely that these pipelines will require additional detailed study on the best option to ensure the pipelines can be used for both natural gas and hydrogen service, and the options for the best material for the pipeline construction will be done at the time of final investment decision based on relevant engineering studies.

6. Designing an enabling ecosystem

The success of a South African GH industry lies in a holistic and investor friendly ecosystem with clear and focused government support. Strong collaboration models between public and private sector will be required with much stronger leveraging of private sector capacity, capability and finance than has typically been seen in the South African economy. Such an ecosystem should recognise the need for speed with clear and bold policies if South Africa is to be a competitive global player. Key enablers that help create such an ecosystem have been outlined below under Skills, Regulation and Finance. In addition to these essential requirements of skills, supportive policy/regulations and access to preferential financing it is essential that mechanisms be set in place to facilitate the interaction between the state and the private sector to assist with engaging across multiple ministries and to coordinate interactions at government-government level, i.e., effectively a "One Stop" shop for engaging with government to secure the delivery of GH projects (as opposed to coordinating strategy).

6.1. Ensuring skills development for a successful GH economy

South Africa's major industries such as chemicals, mining, and manufacturing have created local talent and developed IP to grow the industrial manufacturing base since the 1950s (Sasol, 2021). South Africa's tertiary and technical institutions continue to stay relevant on the global stage by adapting skills curriculums, developing world class research material, and attracting top talent from across the globe to increase the pool of talent available to South Africa's industries (Study Portals Masters, 2021). South Africa's foundational skills are shown at the bottom of Table 6.1.

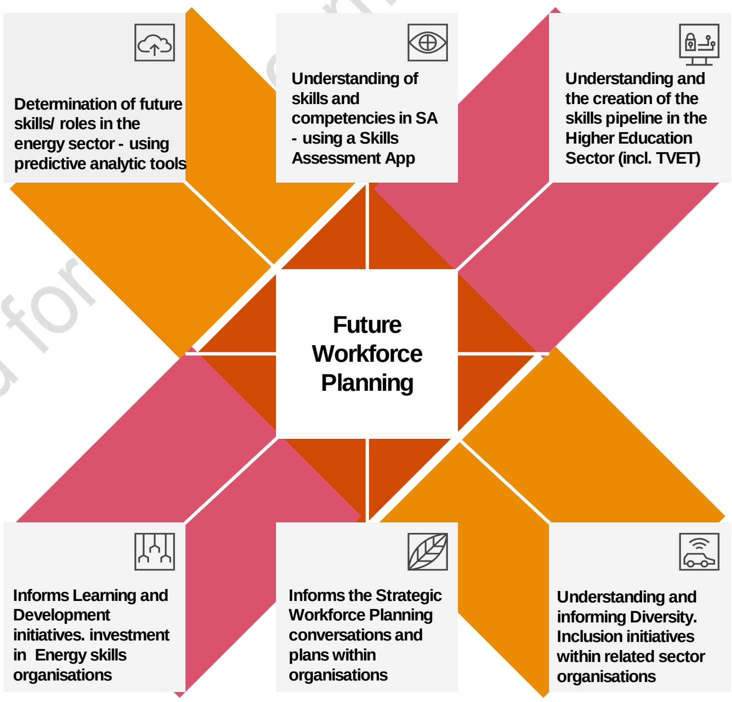
Climate change has profound links between the environmental challenge that South Africa faces and the social and economic stability of the country. Renewable energy and GH challenges the way in which South Africa have been dealing with environmental and social issues in the past, as it encourages a transition away from fossil fuels that has been the energy lifeblood of the South African economy and the employment source for thousands of South Africans for many decades. Potential job losses and social impacts of decarbonising South Africa's economy can therefore only be addressed through skills development in the renewable energy and GH sectors. South Africa's updated NDC states that the government is currently in the process of finalising a Just Transition Plan which will define pathways compatible with pursuing efforts to limit temperature increase to 1.5 °C. As part of this plan, the upskilling of workers to enable a functioning GH sector will be key.

A 2019 study by the Council for Scientific and Industrial Research and the Germany-based Institute for Advanced Sustainability Studies estimates that up to 1.6 million jobs can be created in South Africa through energy sector transformation by 2050. Sectoral job opportunities in the future GH economy for skilled graduates are expected to range from operations, maintenance, management of PGM mining, refining and beneficiation, transportation, construction, to industrial manufacturing. A sectoral alignment with industry-specific requirements will also facilitate a just labour transition, where potential job losses in the traditional coal mining industry, for example, are mitigated through the upskilling, retraining and onboarding of workers in the green economy. A key aspect that would need to be developed by the government is a GH jobs pipeline that will enable industry to plan and collaborate with educational institutions to create jobs and train the labour force needed for a GH economy.

Future GH workforce skills will not only focus on servicing a GH economy but will also be flexible to service adjacent industries in a holistic manner related to climate mitigation and circular economies thereby aiding South Africa's just transition. These new skills include:

- **Green career pathways** - assessing the main opportunities for green careers in the local context, while investing in reskilling and upskilling initiatives to meet the current and future green skills gap.
- **Natural capital skills** - protecting and monitoring the earth's natural resources including environmentalists, hydrologists, and biochemists.
- **Green engineering and tech skills** - design and maintenance of solar panels, wind turbines, electrolysers, and other green technologies.
- **Green architecture and future cities planning skills** - constructing and integrating green buildings and green spaces into future cities.
- **Sustainable agriculture skills** - implementing digital solutions in agriculture such as organic farming, urban farming, and precision agriculture; all enabled through data, drone, and DNA technology.
- **Environmental justice skills** - managing the intersection of human rights and environmental rights to ensure that a just transition is possible, and diversity, equity, and inclusion forms a strong foundation for participation in the green economy for all.
- **Circular economy skills** - building processes and industries that fit into circular economy principles to support development of a green transition.
- **Operation management and system integration skills** - integrating the nodes of green economic development to be aligned and think as "one" (World Economic Forum, 2021; United Nations Industrial Development Organisation, 2021).

A holistic skills development approach should include the steps set out in the figure below:



The localisation opportunities identified across the value chain, the available local skills and green skills needed to service the GH localisation opportunities are ranked in Table 6.1 according to South Africa's local capability.

All skills training should have reskilling or upskilling initiatives to build and grow local capacity; these initiatives can be incentivised through SETA funding with a long-term view to support upskilling in tertiary institutions. Government will also have to balance the need to outsource GH value chain expertise to expedite GH project development and local skills proliferation against local capacity building. A more detailed analysis of the potential job creation associated with the GH sector is encouraged as part of the Commercialisation Roadmap.
The additional interventions identified in Table 6.1 will support the uptake of green skills and green technology locally.

The identified skills action plan needs to be driven by working closely with the Department of Science and Innovation and Department of Higher Education and Training .

The Department of Science and Innovation will be critical to support the following :

- Drive innovation, R&D and skills development;
- Support commercialisation, together with dtic, of innovative products, processes and services that will reduce costs and enhance competitiveness of SA component production;
- Assist with management of patents and licences, both local and foreign;
- Co-ordinate research on critical mineral value chains and
- Research and insights into chemical value chains to support sustainability and global competitiveness

The Department of Higher Education and Training will be responsible for the following :

- Align to the identified skills and action plan in this commercialisation strategy;
- Co-create technical training courses to develop future skills requirement to support GH and associated value chains;
- Focus on systems and design thinking to under-pin inter-related nature of GH development;
- Co-ordinate funding and support for university-programmes;
- Support and coordinate skills development in industry;
- Bring SETA funding at industry level and
- Funding support for GH PhD projects, programmes and scholarships.

Table 6.1: Localisation opportunities and skills prioritisation framework

Value chain	Localisation opportunity (Priority)	Skills required	Skills sourcing	Government can build local skills capacity by...
Renewable Energy generation	Hydrogen and renewable energy specialists **(High)**	Circular economy skills	Outsource	• **Incentivising the private sector to support local capacity** as they outsource for missing and limited skills. • **Support educational institutions** with development and funding of training programmes focused on the GH industry. • **Creating financial incentives for the private sector** to roll out upskilling initiatives.
		Green architecture and future cities planning skills	Outsource	
		Green engineering and tech skills	Local, but limited	
		Natural capital skills	Outsource	
		Sustainable agriculture skills	Local, but limited	
Electrolysers and Balance of Plant	PGM beneficiation **(High)**	Technical engineering (renewable, marine)	Local, but limited	**Incentivising the private sector to support local capacity** as they outsource for technical engineering expertise specific to electrolyser manufacturing
	Recycling of used PGM products **(Medium)**	Circular economy skills	Local, and growing	**Supporting the roll out of upskilling initiatives** through funding and financial incentives to encourage quicker uptake by the private sector

	CCM* and MEA* electrolyser component manufacture **(High)**	Circular economy skills	Local, but limited	● **Incentivising the private sector to support local capacity** as they outsource for technical engineering expertise specific to **CCM and MEA component manufacturing**, **green engineering**, and **circular economy integration**. ● **Support educational institutions** with development and funding of training programmes focused on the GH industry.
		Green engineering and tech skills	Outsource	
		Manufacturing and Assembly	Local, but limited	
Beneficiated Products	Fuel cell stack and systems manufacture **(Medium)**	Circular economy skills	Outsource	● **Incentivising the private sector to support local capacity** as they outsource for technical engineering expertise specific to **fuel cell stack manufacturing**, **green engineering**, and **circular economy integration**. ● **Support educational institutions** with development and funding of training
		Green engineering and tech skills	Local, but limited	

		Manufacturing and Assembly	Local, but limited	programmes focused on the GH industry.
	Automotive manufacture **(Medium)**	Manufacturing and Assembly	Local, and mature	–
All	Systems Integration and Operations and maintenance **(High)**	Circular economy skills	Local, but limited	• **Incentivising the private sector to support local capacity** as they outsource for missing and limited skills. • **Incentivising the private sector to roll out upskilling initiatives** to develop growing skills, through funding models and financial incentives. • **Developing ecosystem and research partnerships** to diversify mature skills into other segments of the GH value chain and other industries.
		Environmental justice skills	Local, and growing	
		Green career pathways	Outsource	
		Green architecture and future cities planning skills	Outsource	
		Operation management and system integration skills	Local, and mature	

Foundational skills South Africa has developed strong expertise in
Ancillary and support services/ Architecture and Engineering design services/ Business and Management services/ Construction/ Finance and Legal services/ Information and Communications Technology/ Insurance and Healthcare services/ Logistics and transport/ Manufacturing and Assembly/ Risk Management/ Skilled labourers/ Technical engineering

* CCM (catalyst coated membrane) and MEA (membrane electrode assembly)

6.2. Providing a clear and focused regulatory environment

Clear and stable regulation pertaining to hydrogen is essential in order to deliver certainty to developers and investors so projects and applications can be implemented with reduced risk. A clear and supporting regulatory framework that supports hydrogen development in South Africa will also foster investor confidence and financing, thereby reducing the financial support that government would have to provide to support the development of the industry. However, South Africa's current regulatory framework does not support the development of a hydrogen industry. Given the potential scale and scope of a fully developed hydrogen economy in South Africa, it will be a significant body of work to develop a regulatory framework that:

a) Considers and addresses the many areas of law and policy that a fully developed GH economy may potentially affect.
b) Ensures the safety of the community and industry at all times.
c) Enables South Africa to follow a just transition pathway.
d) Removes investment barriers and supports the investment in South Africa's GH economy.
e) Contemplates and allows for the breadth and complexity of the activities that a GH industry will undertake.
f) Can respond to new technologies and commercial approaches as they develop, and the industry matures.

The purpose of this section is to:

a) Provide a summary of the current law and policy potentially relevant to the development of a GH industry in South Africa.
b) Provide initial recommendations on regulatory incentives that could be introduced to support the development of the hydrogen economy in South Africa.
c) To summarise the next steps to develop the law and policy required to facilitate a GH industry in South Africa.

6.3. South Africa's existing regulatory framework

South Africa does not currently have an explicit regulatory framework related to the development of a hydrogen economy; however, some new policy instruments are under development, e.g., National hydrogen policy/strategy, National hydrogen masterplan. Thus far, pilot projects have been implemented within the confines of South Africa's existing regulatory frameworks. Ultimately, in order for hydrogen to play a role in South Africa's just transition, the hydrogen value chain would have to operate within three broad spheres of law, including Energy and Infrastructure, Environmental regulation, and Health and Safety provisions.[1] The integration across these areas is critical to support the development of a robust and coherent policy and regulatory framework including the masterplans currently under development by the Department of Trade and Industry and the Public Private Growth Initiative.

[1] This report focussed on core energy and environmental laws in relation to GH. There are additional policies such as the Green Transport Strategy 2018 and the National Transport Master Plan 2016 that also implicitly support the uptake of GH. These policies must be assessed as part of the regulatory and policy assessment work package.

6.3.1. Energy law and policy

The hydrogen industry will need to access new and existing energy infrastructure - including electricity networks, gas networks, ports, roads and rail. Currently, South Africa's energy laws do not explicitly address the production of GH but can be argued to implicitly support the uptake of GH when considering certain sustainability provisions found in South Africa's primary energy law and policy.

The Department of Mineral Resources and Energy has indicated that under current legislation, renewable energy deployment related to GH production will be exempted from both electricity policy planning (IRP) and regulation (licensing) as long as it is "islanded" from the grid. To date, no formal notice has been published in this regard. This will have an impact on GH production economics in that there is a typical overbuild of wind and solar to ensure that optimal electrolyser load factors are achieved. Unless an alternative economic use for the excess renewable energy production can be found, plants will need to be curtailed during certain hours of the day.

Table 6.2: Energy law and policy relevant to GH

Law/Policy	Relevance to GH development
National Energy Act 34 of 2008	The National Energy Act is South Africa's overarching piece of legislation for the energy sector. Section 5 of the National Energy Act imposes a duty on the Minister of Energy to promote access to affordable, sustainable, and environmentally suitable energy and energy services to all people. The Act requires the Minister in consultation with the Minister of Trade and Industry, the Minister of Labour and the Minister of Environmental Affairs, to *"adopt measures not contemplated in any other legislation, to minimise the negative safety, health and environmental impacts of energy carriers."* Section 19(1) of the National Energy Act provides a legal mechanism to introduce a set of regulations specifically aimed at regulating GH: *"The Minister may, after consultation with those Cabinet Ministers whose areas of responsibility will be affected by the proposed regulations, without derogating from his or her general regulatory powers, by notice in the Gazette **made regulations** regarding…* *(d) minimum contributions to national energy supply from renewable energy sources.* *(e) the nature of the sources that may be used for renewable energy contributions to the national energy supply.* *(f) measures and incentives designed to promote the production, consumption, investment, research and development of renewable energy;"* Considering the provisions above and the opportunities that GH presents, the government could consider introducing a set of regulations specifically aimed at promoting South Africa's GH economy. To date, government has not made use of these

Law/Policy	Relevance to GH development
	provisions and regulations to this effect have not been published.
Electricity Regulation Act 4 of 2006	Although the promotion of renewable energy and hydrogen is not explicitly mentioned in the objects of the Act, there are implicit references that can support the argument for increased renewables in the country's energy mix. This is evident when considering the references to sustainability and the acknowledgement that the interests of future electricity customers must be considered.
Integrated Resources Plan of 2019	The IRP does not currently provide renewable energy capacity specifically allocated for the development of GH. As the demand for GH grows, the IRP must be reviewed in order to allocate specific renewable energy to electrolysers located in GH hubs.
Integrated Energy Plan 2016	The IEP aims to guide future energy infrastructure investments, identify and recommend policy development to shape the future energy landscape of the country. The National Energy Act requires the IEP to have a planning horizon of no less than 20 years – the last adopted version was in 2003 with a revision in 2016 that commenced however was not completed. It is an overarching plan that informs the development of future energy sector roadmaps, i.e., for security of supply (liquid fuels and electricity) and for diversity of supply (coal, gas and renewable energy. Eight key objectives were identified: ensure the security of supply, minimise the cost of energy, increase access to energy, diversify supply sources and primary sources of energy, minimise emissions from the energy sector, promote energy efficiency in the economy, promote localisation and technology transfer and the creation of jobs and promote the conservation of water. Hydrogen is mentioned in the existing version within the context of an alternative energy source and as an energy carrier "*The hydrogen economy is undergoing serious consideration in South Africa, in an effort to develop safe, clean and reliable alternative energy sources to fossil fuels.*" The revision of the IEP remains outstanding and updating to capture the evolving energy policy landscape is required.

6.3.2. Environmental law and policy

Stringent air and water pollution control laws can determine the cost-effectiveness of using renewable sources of energy over fossil fuels. Similarly, land use planning and Environmental Impact Assessment laws can demonstrate the sustainability of wind and solar energy. However, the environmental regime in South Africa beginning with the environmental right in section 24 of the Constitutional to sector legislation is an underutilised driver of renewable energy and more specifically, GH. The table below outlines how South Africa's environmental laws can implicitly be applied to support the uptake of GH in South Africa.

Table 6.3: Environmental law and policy relevant to GH

Law/Policy	Relevance to GH development
National Environmental Management Act 107 of 1998	The principle of environmental management in section 2 of the NEMA has the potential, not only to discourage the use of fossil fuels, but crucially to promote renewable energy and the development of the GH industry. NEMA promotes and provides a normative framework that points towards a sustainable energy system in South Africa. This is evident when considering the sustainable development provisions set out in Section 2(4) of the Act that provide that: *"(v) that the use and exploitation of non-renewable natural resources is responsible and equitable and considers the consequences of the depletion of the resource. (vi) that the development, use and exploitation of renewable resources and the ecosystems of which they are part do not exceed the level beyond which their integrity is jeopardised."*
Draft Climate Change Bill	South Africa's Draft Climate Change Bill makes no reference to the phase out of fossil fuels or the decarbonisation of South Africa's energy sector. However, as part of the sectoral emissions target mechanism outlined in the Bill, GH could be introduced as a mitigation measure to achieve the sectoral emissions target that would have to be set by the Minister of Mineral Resources and Energy.
Environmental Impact Assessment Regulations, 2014	An area of planning that best illustrates how environmental planning can be used to promote the necessary renewable energy infrastructure for the production of GH is the EIA Regulations. As far as energy activities are concerned, the major issues have been the dilatory impact of the EIA process on energy projects.
Mineral and Petroleum Resources Development Act, 28 of 2002 (MPRDA)	The MPRDA is among the environmental legislation contemplated by s 24(b) of the Constitution of South Africa – to the extent that it is aimed at promoting sustainable development in the mining industry. Although not directly linked to the development of the hydrogen economy, the sustainable development provisions provided for in the act will be a key implicit driver to utilize South Africa's PGM resources.

6.3.3. Health and Safety law and policy

Particular attention and priority should be given to develop technical safety standards in respect of hydrogen and the hydrogen industry - with a likely focus initially on interactions with the gas network and key gas industry stakeholders, hydrogen safety requirements related to storage, handling and transport, and adoption of hydrogen fuel cell technology (heavy vehicles and stationary applications).

By prioritising and developing technical standards in advance of regulatory responses being developed, the technical standards can be 'built into' law and policy in respect of the hydrogen industry. This will mean that safety compliance requirements will be consistent across the industry improving investor confidence in South Africa's ability to produce and trade with GH in a safe manner.

6.4. Regulatory incentives

GH faces barriers that prevent its full contribution to South Africa's energy transformation. Amongst others, barriers include those that apply to all shades of hydrogen, such as the lack of dedicated infrastructure, high production costs, energy losses, and credibility of the origin of GH. All of these barriers can however be addressed by means of introducing key regulatory incentives that would support the development of South Africa's domestic and well as the export markets for GH. Some of the key incentives have been outlined below.[2]

6.4.1. Domestic market incentives

Carbon pricing is a useful tool to guide investment decisions, especially those that will have long-term impacts on future emissions and can complement stimulus packages focusing on the increased uptake of GH. A progressively increasing carbon price alongside stimulus packages provided by the government will provide essential confidence for investment in long-lived, low-carbon infrastructure and research, development and demonstration of GH technologies. Carbon pricing mechanisms coupled with effective revenue recycling mechanisms that support investment in clean energy options will be a key enabler to drive GH production forward.

6.4.1.1. **Carbon pricing**

Many countries have included carbon pricing mechanisms as key strategic drivers in their respective GH strategies. These policies are aimed at equalising the cost competitiveness of GH in comparison with fossil fuel-based sources. In many cases, countries have introduced either explicit carbon pricing mechanisms such as emission trading schemes or carbon taxes or have introduced implicit carbon pricing mechanisms such as fuel subsidy removals. In some cases, countries have implemented both explicit as well as implicit measures. The application of these mechanisms within the South African context are discussed below.

Explicit carbon pricing mechanisms:

GH will bring major GHG emission reductions when used to replace fossil fuels for many ends uses. Reflecting environmental and climate costs in energy prices will be critical in order to support the uptake of GH. By increasing the costs associated with the externalities of GHG emissions, energy generators and consumers will be required to pivot to low-carbon energy sources such as GH in order to remain competitive.

In South Africa, the government introduced the Carbon Tax Act (Act 15 of 2019) as South Africa's primary explicit carbon pricing mechanism. An initial headline tax rate of R120 per ton carbon dioxide equivalent (CO_2e) was introduced in 2019, however, various tax-free allowances result in an effective tax rate that varies between R6.00 (US$0.4) and R48.00 (US$4.22) per ton of CO_2e. The World Bank reported that carbon prices of at least US$40–

[2] The regulatory discussion is not aimed at outlining a comprehensive regulatory framework for South Africa, but rather outlines high-level regulatory support mechanisms that can support South Africa's GH economy. A detailed regulatory assessment would need to be undertaken as part of a separate Work Package.

80/tCO2 by 2020 and US$50–100/tCO2 by 2030 are required to cost-effectively reduce emissions in line with the temperature goals of the Paris Agreement.[3] Based on the aforementioned rates, it is evident that South Africa's carbon tax rate is significantly lower compared to the carbon price required to reach the climate change commitment target set out in the Paris Agreement. Although the government introduced the carbon tax at a low rate in order to maintain South Africa's competitiveness, based on international developments, the government would need to increase South Africa's carbon tax rate in order to signal its decarbonisation efforts to investors. An increased carbon tax rate will however only be viable if appropriate carbon tax revenue recycling mechanisms are put in place in order to foster investor confidence in the government's ability to inject carbon tax revenue back into the GH value chain.

When considering the mobility sector, the carbon tax associated with the use of petrol and diesel is currently charged in terms of Schedule 1 of the Customs and Excise Act. The carbon fuel levy associated with the use of petrol is currently set at 8 cents per litre and 9 cents per litre for diesel. Possible mechanisms to discourage the use of the aforementioned products will be to increase the carbon fuel levies of these fuel sources and stipulate that the use of GH will have a carbon fuel levy of nil, as is the case with biodiesel.

Although South Africa has implemented the Carbon Tax, the increase of carbon tax rates specifically aimed at developing the GH sector, or the removal of fuel subsidies may have detrimental effects on the economy and socio-economic circumstances. As such, the implementation of more stringent carbon pricing mechanisms must be carefully considered and subject to an extensive socio-economic and economic impact analysis.

Implicit carbon pricing mechanisms:

Apart from explicit carbon pricing mechanisms, such as the carbon tax mentioned above, implicit forms of carbon pricing can also be considered by the South African government in order to support the development of the GH economy. Fossil fuel subsidies are responsible for various fiscal, social and environmental problems. These problems include harmful impacts on energy markets and greater fiscal burdens on governments, as well as environmental impacts. Once fossil-fuel support measures have been identified and quantified as much as possible, measures for reform need to be prioritised.[4] Fossil fuel subsidy reform will help policy makers to close the economic gap with GH, while reducing market distortions and making the real price of fossil fuels clearer.

In a recent report published by the International Institute for Sustainable Development (IISD), South Africa was ranked as the second worst performer of the G20 non-OECD member countries, behind Saudi Arabia, for its lack of transparency and continued support for fossil production through fossil fuel subsidies.[5] However, the scale and allocation of fossil fuel subsidies in South Africa is not well known and as such, it is difficult to recommend where fossil fuel subsidies can be removed in order to implicitly support the uptake of GH. The transition to a low-carbon, climate resilient economy that is sustainable and inclusive means altering the structure of the economy and the flows of support that maintain the carbon intensive, energy intensive economy that we have today. Current fossil fuel subsidies therefore

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[3] World Bank. "State and Trends of Carbon Pricing 2020" (May), *World Bank, Washington, DC. Doi: 10.1596/978-1-4648-1586-7*.

[4] Little is known on fossil fuel subsidies in South Africa, and extensive research would need to be undertaken to establish to what extent fossil fuel subsidies exist and whether they can be reformed to support the GH sector.

[5] The report stated that South Africa spends R93-billion a year on direct support for fossil fuel use through subsidies to its predominantly coal-based electricity system - see IISD, Doubling Back and Doubling down: G20 scorecard on fossil fuel funding (November 2020).

need to be assessed within the aforementioned context and redirected towards supporting the GH economy in South Africa, subject to the relevant economic and socio-economic impact assessments being done. Within the South African context, energy subsidies should be used to assist energy-vulnerable populations to access low carbon energy sources and to guarantee competitiveness of companies that aim to introduce low carbon energy solutions.

6.4.1.2. Tax incentives

The cost of GH production could be lowered by reducing the taxes and fees within the GH value chain. Lowering corporate, business and sales taxes on GH could also improve revenues and the rate of return on projects. The introduction of clean energy tax incentives has historically been provided for in section 12 of the Income Tax Act and has resulted in increased renewable energy uptake and numerous energy efficiency measures. The regulatory measures provided for in the Income Tax Act and their possible application to the GH sector are set out in the table below:

Table 6.4: Income Tax Act incentives relevant to GH

Description	Details	Section	Application to GH
Accelerated depreciation allowance (RE)	In respect of assets brought into use for the first time and solely for the production of renewable electricity. The allowance is based on the cost of the assets and 50%, 30% and 20% is granted in each of the first three years of use, respectively.	12B(1)(h)	Can be amended to also include assets brought in for the production of GH.
Energy savings allowance (EE)	National allowance for taxpayers that carry on a trade and that implement EE projects that successfully achieve energy savings. The allowance is calculated as 95 cents per kilowatt hour (kWh), or equivalent, of energy savings achieved during the year of assessment, made against a baseline measured at the beginning of the year. Independent, registered and accredited professionals need to measure and verify the value of the energy savings and the allowance is not granted if a concurrent EE savings benefit is received from government or a semi-government agency	12L	Applying similar provisions to Hydrogen would be difficult given the fact that hydrogen consumption is not considered an energy efficiency project.
Industrial policy project (IPP) allowance (EE)	Industrial policy projects that use improved EE and cleaner production technology, inter alia, are entitled to an allowance of 35% – 100% of the cost of new and unused manufacturing assets used in the project.	12I	GH projects could be classified as Industrial policy projects in order to receive the additional investment and training allowance

Description	Details	Section	Application to GH
			set out in section 12I
Exemption of proceeds (RE/EE)	When certified emission reductions from approved clean development mechanism (CDM) projects, registered before 31 December 2020, are disposed of, the proceeds are exempt. CDM projects could include RE or EE projects.[6]	12K	Similar provisions can be reintroduced for GOs in order to incentivise the trading of GH.
R&D allowance (RE/EE)	A 150% allowance in respect of expenditure incurred directly and solely on approved R&D activities undertaken in South Africa. The expenditure must be incurred in the production of income, in carrying on any trade. The allowance also extends to pre-trade expenditure incurred in respect of approved R&D activities.	11D; 11A	In order to encourage pilot projects, sections 11D and 11A could be extended to include GH R&D.
Accelerated depreciation allowance for R&D (RE/EE)	In respect of new and unused R&D machinery or a plant brought into use for the first time. The allowance is based on the cost of the assets and 50%, 30% and 20% is granted in each of the first three years of use, respectively.	12C(1)(gA)	Such provisions could apply to existing assets to be retrofitted for GH storage.
Depreciation allowance for R&D buildings (RE/EE)	The cost of a building used for R&D is allowed in equal portions over a period of 20 years	13(1)(b)	These provisions could apply to buildings that would be needed as part of R&D GH projects.

6.4.1.3. Import duties

As discussed in previous sections, the costs of manufacturing electrolysers in South Africa are significantly more when compared to the manufacturing costs that other countries have achieved. In order for GH to be a viable option, GH production companies would need to import electrolyser equipment in order to produce GH at a cost competitive rate. However, customs duties (import duties) are imposed in terms of the Customs and Excise Act 91 of 1964 on imported goods and technologies. They are levied on imported goods with the aim of raising revenue and protecting the local market.

In order to reduce the costs associated with the production of GH, the government should consider reducing or exempting the import duties and VAT which will be payable on imported GH technologies in terms of the Customs and Excise Act. For example, a reduction or rebate

[6] With the introduction of the Carbon Tax Act 15 of 2019, this provision was repealed.

of import duties can be applied to the importation of electrolysers. In such a case, importers of GH manufacturing equipment must be required to apply to the International Trade Administration Commission of South Africa (ITAC) for a certificate that qualifies them to import without being subject to burdensome import duties. The rebate could be introduced on a temporary basis and be phased out as soon as electrolyser manufacturing costs have reached a cost competitive level.

Government recently published a Draft Schedule 7 of the Customs and Excise Duties Act outlining the extent to which certain goods and products are exempted from import duties. Based on the relief items set out in Schedule 7, there exists an opportunity to include a relief item focussed on the importation of goods and technologies related to the production of GH. For example, Relief Item 498.02 provides a full import tax exemption to "goods of any description imported by a registered SEZ operator for use in the construction and maintenance of the infrastructure of a CCA in an SEZ." Based on the fact that GH production would be focussed on certain hydrogen hubs, similar provisions could be included in Schedule 7 to provide GH production companies with an incentive to import electrolysers with the necessary capacity to produce GH at a cost competitive price.

6.4.1.4. Permitting, licencing and authorisation

Stakeholders involved in the development of South Africa's GH economy have repeatedly highlighted the fact that South Africa's licencing and authorisation processes are too timeous and delays the implementation of projects. Renewable energy companies have reported difficulties with land use and rezoning approvals among a host of other authorisations. This multi-approval process for development remains fragmented in the energy planning sector and is one of the barriers to expeditious approval of renewable energy projects needed for the production of GH. The problem is also compounded by the existence of provincial planning laws that may not always speak to national planning, environmental and energy legislation.

Some of the licenses and authorisations that would be applicable to GH includes water use licenses, environmental authorisations comprising various impact assessments in terms of the Environmental Impact Assessment Regulations, as well as electricity generation licenses. The Department of Forestry, Fisheries and Environment, amended NEMA in 2019 to allow for Strategic Environmental Assessments (SEA) within defined Renewable Energy Development Zones (REDZs), which are intended to expedite environmental permissions. Assessment of other activities related to the deployment of GH project which could be excluded under NEMA should be considered.

The applicable authorizations are managed by different entities including the Department of Forestry Fisheries and Environment, NERSA, and the Department of Mineral Resources and Energy. In order to expedite the authorisation and licensing processes, the need exists to introduce a single "one-stop" mechanism to facilitate all the licensing and authorisation processes required as part of implementing a GH project. This would enable South Africa to move fast and take advantage of the opportunities that the hydrogen economy presents within a timely fashion.

6.4.1.5. Standards for the GH mobility sector

GH has been recognized as an alternative fuel for the mobility sector in the EU. In South Africa, hydrogen powered vehicles, in particular buses and heavy-duty vehicles, might play a significant role in climate change mitigation within the transport sector and the development of the GH economy. Due to the lack of economies of scale and the dominance of electric vehicles in South Africa, Fuel Cell Electric Vehicles (FCEVs) are not a viable option for South Africa in the near future. In addition to the high purchase price, the lacking GH refuelling infrastructure can be regarded as one the main economic barriers for the deployment of the fuel cell vehicles.

In order to accelerate the market penetration of heavy-duty fuel cell vehicles, a supportive national framework and financial incentives are needed. Various financial and non-financial incentives from direct purchase grants to tax and registration fee exemptions and zero VAT can push the deployment of these vehicles. The implementation of zero-emission vehicles targets could also create the initial demand for GH refuelling stations which are pre-conditions for making heavy duty fuel cell vehicles a viable option for mining and logistics companies.

To help local officials deal with proposals for GH fuelling stations, GH codes and standards would need to be developed. The applicant looking to build a GH refuelling station should show compliance with all requirements set out in the standards. The standards should at a minimum, outline the following:

- General Fire Safety Requirements
- General Storage requirements
- GH dispensing technology requirements
- Hydrogen Fuel Quality standards for Fuel Cell Vehicles

In order to develop the above-mentioned standards, the following international standards can be used to inform the design of the standards:

- ISO 19880-1:2020 - Gaseous hydrogen
- SAE International standards (SAE J2601/2, “Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles,” and SAE-J2601, “Fuelling Protocols for Light Duty Gaseous)

6.4.2. Export market incentives

6.4.2.1. Special Economic Zone incentives

As highlighted in the sections above, the development and location of GH SEZs will be a key enabler to support South Africa’s GH economy. The regulatory basis for the development of SEZs is the Special Economic Zones Act 16 of 2014. In terms of section 21(1) of the Act the Minister of Trade and Industry may determine and implement support measures, including incentive schemes, for operators and businesses operating within Special Economic Zones. This provision can be used as a basis to provide tailored support mechanisms for GH SEZs. Some of the key incentive mechanisms that have been introduced include the following:

- The main tax benefit available to a qualifying company within a special economic zone is the reduced corporate tax rate from 28% (the standard corporate tax rate) to 15%.[7]
- Qualifying businesses operating within SEZs are also eligible for an accelerated depreciation allowance of 10% for buildings.
- VAT and Customs Relief – Businesses within customer-controlled areas will qualify for VAT and customs relief.
- Employment Tax Incentive – Employers that hire low-salaried staff (below R60 000 per annum) in any SEZ will be entitled to this incentive.

New as well as existing incentive mechanisms outlined above can be introduced in GH SEZs or applied to REDZs. Ultimately, the Act aims to boost private investment (domestic and foreign) in labour-intensive areas in order to stimulate job creation, competitiveness, skills and technology transfer as well as increasing exports of beneficiated products. The provisions of the Act therefore also act as a basis to support South Africa’s just transition.

[7] The Taxation Laws Amendment Act 23 of 2020 extended the tax incentives provided to SEZs until 31 December 2030.

6.4.2.2. **Guarantees of Origin (GO)**

As a response to the global commitment to reduce emissions in accordance with the Paris Agreement, many countries have introduced regulatory measures which encourage the increased uptake of renewable energy technologies by means of Guarantees of Origin (GO) systems. Where these systems have been properly implemented and enforced, they have been known to create a market for the environmental attributes associated with the renewable energy technologies and have resulted in increased renewable energy penetration rates. One way to prove the renewable origin of GH is by means of a GO system, creating a credit-based chain of custody that provides hydrogen consumers with certainty pertaining to the green nature of the hydrogen.

The use of GOs was introduced in regional EU policy in the form of the EU Renewable Energy Directive. The Renewable Energy Directive mandates levels of renewable energy use within the European Union.[8]

The European Parliament recently proposed amendments to the Directive specifically aimed at improving the certification system associated with low-carbon fuels such as GH and proposed that in order to strengthen the guarantees of origin system in the EU, certification of low-carbon fuels should be addressed in a separate legislative proposal such as the Hydrogen and Decarbonised Gas Market Package. This is an important development and signals the fact that guarantees of origin associated with hydrogen should potentially be handled separately from GOs emanating from renewable energy generation only.

However, certain requirements would have to be met in order for such a system to be functional. Some of these principles include the following:

- **Traceability** - The listing and retirement system should allow the environmental attribute to be tracked from the point of production to the point of consumption. One of the main criticisms of a credit-based chain of custody system is that it disassociates the GOs claim from the physical product. This means that an electricity producer using fossil fuels can still purchase GOs and then claim that the energy they sell is renewable. For example, a plant producing hydrogen from fossil fuel (grey hydrogen) can purchase GOs from a site of GH production that uses solar panels, and on this basis claim that the energy produced is renewable. This problem could be solved if GOs associated with hydrogen were only to be traded within a specific closed system and linked to specific GH offtake agreements.
- **Tradability** - GOs should comply with internationally recognised standards in order to be tradeable in the jurisdictional area it was built for, creating a liquid market whereby the environmental attributes of the GH can be traded as part of the GH itself.
- **Transparency** - GOs should accurately demonstrate to final customers the renewable energy sources linked to the GH. The system needs to avoid false or misleading claims and ensure that additionality is proven. For instance, limiting GH GOs to generation capacity specifically allocated for GH production and to plants that do not form part of existing grid connected systems such as REIPPP.

[8] Article 55 of the Directive states that: "Guarantees have the sole function of showing to a final customer that a given share or quantity of energy was produced from renewable sources. A guarantee of origin can be transferred, independently of the energy to which it relates, from one holder to another. However, with a view to ensuring that a unit of renewable energy is disclosed to a customer only once, double counting and double disclosure of guarantees of origin should be avoided. Energy from renewable sources in relation to which the accompanying guarantee of origin has been sold separately by the producer should not be disclosed or sold to the final customer as energy from renewable sources. It is important to distinguish between green certificates used for support schemes and guarantees of origin."

- **Trustworthiness** - Once the above principles are implemented, final consumers will actively use GOs as a market instrument building GH consumption and decarbonising economic activities.

GO schemes should be designed to allow the international trading of GH, helping to create a global market. Criteria to be considered in certification design:

- CO_2 threshold limit to be considered green,
- Technology agnostic or specify,
- End use sectors – all or specific applications (could impact the baseline reference)

In South Africa, the concept of trading with GOs (known as Renewable Energy Certificates/RECs) has been introduced but is still in its nascent phase of development. zaRECs (Pty) Ltd administers the REC market in South Africa in accordance with the principles of the European Energy Certificate System (EECS) on behalf of members of the REC South Africa market participant's association (RECSA). The system in South Africa is therefore similar to that of other REC systems as the system follows international protocol but has only been implemented on a small voluntary scale to date. The system is also limited to guaranteeing renewable power generation and does not extend to the GH value chain.

In order for South Africa's GH export market to be competitive, the country would have to ensure that a GO System aligns with what import countries, such as Germany requires from a GO system. The system would also need to comply with the requirements of the EECS (European Energy Certificate System) in order to satisfy European GH investors. The EECS (European Energy Certificate System) is a standardization system for the European GOs. Aligning a possible South African GH GO system with the requirements of foreign registry systems will ensure that South Africa is able to compete in the export market.

6.4.3. Summary of key regulatory recommendations:

1. **Prepare a Regulatory Development Timeline:**
    - **a.** The timeline must, where practicable and relevant, detail the timing of the review of the relevant law and/or including the expected date for the promulgation of new law and policy based on actions outlined in the commercialisation roadmap.
    - **b.** Outline timed regulatory responses for the hydrogen industry in alignment with anticipated technological and commercial developments.
2. **Develop regulatory objectives for how the GH industry should be regulated.**
    - **a.** Agreeing on regulatory objectives would simplify coordination of regulatory responses across government departments given the overarching objective would be consistently across all sectors and departments.
    - **b.** A key element in this regard would be to ensure that integrated stakeholder management and advocacy processes are in place in order to align public and private sector opinions and inputs.
    - **c.** Conduct feasibility studies to establish the financial impact of possible GH regulatory incentives.
3. **Develop a set of regulations specifically aimed at creating enabling environment for GH**
    - **a.** Utilise section 19(1) of the National Energy Act to introduce regulations that regulate and support South Africa's GH economy and includes measures and

incentives designed to promote the production, consumption, investment, research and development of GH.

b. Consider other existing laws and policies that could support the uptake of GH.

c. Develop GH standards and specifications related to production, storage, transportation and end-use applications based on international standards and best practice.

4. **Introduce regulatory measures to support South Africa's GH export market**
    a. Introduce measures for SEZs to produce and export hydrogen at a cost competitive price.
    b. Design and introduce a GO system to install investor confidence in key import nodes.
5. **Introduce regulatory measures to support South Africa's domestic GH market**
    a. Introduce explicit and implicit carbon pricing mechanisms coupled with GH revenue recycling mechanisms
    b. Build on existing regulatory tax incentives to support the GH value chain.
    c. Introduce a single institutional body to expedite licensing processes and facilitate the development of the GH sector.
    d. Introduce standards and codes to develop South Africa's GH mobility sector, including emission reduction targets in the transport sector and GH refuelling station standards.

6.5. Securing availability and low-cost finance

Although there is a movement amongst financiers globally away from funding carbon-based projects in favour of greener initiatives, given the size and complexity of the value chain and the anticipated scale of the GH economy in South Africa, financing GH projects will still require innovative financing structures sourced from multiple stakeholders. Ensuring that the financing landscape incentivises investment both from local and international sources is also critical.

The broad principles of traditional project finance are likely to still be applied, necessitating collaboration by government, international development finance institutions, multilateral financing agencies, local commercial lenders and private sector investors. Given the anticipated involvement of international OEMs, export credit agencies are another key stakeholder group in the funding universe. In addition to national government funding, it will be necessary for strong relationships to be developed with the governments of developed countries who have programmes in place to support developing countries in their climate change pursuits.

Globally, various forms of funding mechanisms are being applied to enhance the financing landscape, including:

a) direct public funding.
b) public-private partnerships.
c) leveraging funding from developed markets specifically set aside to support the green transition in developing/carbon intensive countries.
d) leveraging funding from export credit agencies.
e) green/project bond financing; and
f) blended finance mechanisms.

The above forms of funding, together with more traditional project financing approaches, can be categorised into three broad categories, as follows:

a) Government on-balance sheet finance.
b) Private finance; and
c) Development finance.

6.5.1. Government on-balance sheet finance

Direct public funding

Direct public funding includes an allocation of taxation revenue, budget surplus', borrowings globally etc. as a means of supplementing the financing requirements for a project to reduce the overall cost of financing. Some examples internationally include:

a) Asian and European governments have pledged direct public funding to 2030 for development of national hydrogen industries and economy.
b) Japan has committed some $1.5 billion to support zero-emission hydrogen production locally and overseas and to develop distribution infrastructure.
c) France plans to invest €7 billion by 2030 targeting industrial decarbonization, heavy duty transport, and R&D.
d) Germany has adopted a "package for the future" with €7 billion to speed up the market rollout of hydrogen technologies nationally, complemented by €2 billion to foster international partnerships.
e) the UK government is providing funding worth $238 million to support engineering and design studies for net-zero hubs, including blue and GH infrastructure projects, as part of their carbon removal strategy.

Globally, funds are also being directed from existing budgets to support energy transitions or innovation. For instance, the EU is using its Important Projects of Common European Interest (IPCEIs) support mechanism for R&D projects involving more than one Member State. Some national strategies are also including hydrogen within their post-COVID recovery plans to secure extra funds.

Green/project bond financing

Financing instruments linked to green initiatives have become more and more popular in recent years as the world transitions to a net zero economy. Green financing is an effective means of encouraging the development of infrastructure focussed on reducing carbon emissions and provides a form of de-risking by providing long-term grant and concessionary funding to an investment. While not yet as widely seen as PPPs within the hydrogen space (more a theme of general renewable energy), Europe is leading the way in sovereign green bond issuance and attracting international investment. The private sector is also raising green financing in the form of bonds as a means of financing private projects.

Internationally, green financing is often associated with pension funds, insurance agencies, government instruments, endowments and foundations. Public capital can be used to provide credit enhancements (by government-owned development finance institutions) that will attract private capital. DFIs or green banks can advance the minimum financing required to make the investment viable, with the remainder of the financing requirement contributed by private capital.

a) In 2012, South Africa established the green fund managed by the DBSA. The DBSA also announced the launch of its first green bond earlier this year. The €200m bond was issued through a private placement with the French development finance institution, the Agence Française de Développement (AFD).

b) The UK government's £500 million innovation fund will be used to support five hydrogen production projects.
c) Air Liquide has launched a specific green bond for hydrogen projects.
d) Germany issued a green bond to develop hydrogen capabilities and was 5x oversubscribed.
e) French car parts maker Faurecia issues green bond to fund hydrogen fuel cell capabilities.
f) The UK's Northern Gas has issued a green bond to support its transition to hydrogen.
g) Plug Power Inc – a private space hydrogen player in the US, has issued a green bond to raise financing for project capabilities.

6.5.2. Private finance

In addition to traditional sources of private finance such as direct equity investments, lending by commercial banks etc., private funding can be stimulated by developing, for example, public-private partnerships.

Public-private partnerships

The public-private partnership model is already well understood in South Africa. Combining public and private sector involvement by partnering government with key private stakeholders, including infrastructure developers, renewable energy companies, research institutions, vehicle manufacturers, and infrastructure focussed private equity funds, are key themes in this space globally.

Some examples include:

Fukushima10 Hydrogen Energy Research Field, is funded by the Japanese government and three private project developers—Tohoku Electric, Toshiba, and Itwatani.

a) Fukushima10 Hydrogen Energy Research Field, is funded by the Japanese government and three private project developers—Tohoku Electric, Toshiba, and Itwatani;
b) In China, there exists the Chinese Hydrogen Alliance, and is supported by China Energy Corporation and 18 other sponsors, including companies, universities, and research institutes, invests globally in research and development of fuel cell technology;
c) Germany has H2Mobility, the Scandinavia Hydrogen Highway Partnership and the California Fuel Cell Partnership.
d) The Dutch government aims to invest up to €338 million in GH projects in addition to planned investments of €9 billion of which most are private.
e) Australia's Asian Renewable Energy Hub14 project, which is being developed by a consortium of developers and investors - Intercontinental Energy, CWP Renewables, Vestas, and Pathways Investments - plans to invest $36 billion to develop renewable power, storage, and transport infrastructure for hydrogen production.
f) Toshiba, Kawasaki, and Mitsubishi, and automakers like Toyota, Nissan, and Honda anchor hydrogen associations and groups that invest alongside government in the development of fuel cell technology in Japan; and

g) The EU has created the European Clean Hydrogen Alliance to help build up a clear and robust pipeline of viable investment projects, which aims to coordinate investments and policies along the hydrogen value chain and promote cooperation across private and public stakeholders.

6.5.3. Development finance

Leveraging funding from developed markets

A number of larger, developed countries have set aside or have committed to setting aside funding specifically to support the decarbonisation initiatives of developing countries. Taking advantage of those additional pockets of funding will support the development of larger scale projects locally, which will enhance efficiencies and ultimately reduce pricing.

a) The United Kingdom has several initiatives to support developing country decarbonisation:
   - UK Government Investment into Africa:
     i. Invested £50 million in African renewable energy projects.
     ii. These projects are based on winners of the energy catalyst competition and include Solar farms in Kenya, Geothermal power stations in Ethiopia, energy storage in SSA.
     iii. The UK government will assist them with funding and attracting further investment for wind and solar farms.
   - The UK's Ayrton Fund
     i. £1 billion Ayrton Fund announced by PM Boris Johnson to help developing nations reduce fossil fuel emissions.
     ii. The Fund will focus on research, development, and demonstration into clean energy for low/middle income earning developing nations and will run for 5 years from April 2021.
     iii. The Fund will further be supported by the UKs International Climate Finance (ICF) increasing the funding to £11.6bn
     iv. The UK investment to help phase out coal in developing countries
   - The UK plans to use COP26 to drive the phasing out coal and help developing countries adopt renewable energy:
     i. £72.3 billion of funding to be used in this regard

b) IRENA/Abu Dhabi Fund for Development (ADFD):
   - Jointly collaborated to support and fund renewable energy in developing countries for a combined total of $630 million for 21 renewable energy projects.
   - To date ADFD has held 7 funding cycles raising $214 million.
   - The $420 million comes from government funding sources, the private sector and development funds.
   - Current project countries include Cuba, Cabo Verde, Mauritania, Mali, Niger, Iran, Solomon Islands, Antigua and Barbuda, Senegal, Samoa, Argentina, Rwanda, Burkina Faso, Maldives, Seychelles.

c) European Union
   - The EU (ex UK) and the European Investment Bank have availed funds of €21.9 billion to support climate action in developing countries.

- The investment currently focuses on Argentina, Canada, Chile, China, India Kenya and Morocco.
- Likewise, in 2019 the European commission provided €2.5 billion to developing countries for climate adaptation activities.
- The European Investment Bank provided €3.1billion for developing countries focused on projects in Africa and other regions.
- Global Climate Change Alliance+:
  i. The main channel for EU support targeting climate action in developing countries
  ii. Backed by grant funding up to the value of 420 million
- EU Green climate Fund:
  i. Set up in 2010 to help developing countries reduce greenhouse gas emissions.
  ii. Funding sat at $9.78bn in 2019 and to be used until 2024.

The South African government should seek to position itself strongly with key representatives from the UK and the European Union, setting out a clear vision of decarbonising one of the world's largest carbon emitters, to encourage a portion of these funds to be directed towards initiatives locally.

Leveraging funding from export credit agencies

Export credit financing is often used to fund infrastructure projects (especially those in the developing world) in conjunction with, or as an alternative to, more traditional project financing. It enables project companies to obtain more flexible (and often cheaper) financing arrangements. In addition to financing, export credit financiers may also provide insurance, particularly political risk insurance that is either unobtainable or prohibitively expensive in the commercial marketplace, which incentivises investment by international financiers.

Given the anticipated involvement of international OEMs, obtaining export credit financing from financiers in the home countries of those OEMs is a compelling source of financing and/or insurance in the context of an emerging industry in South Africa.

Blended finance mechanisms

a) On-lending structures: public financiers like DFIs use their high credit rating to access funding at lower rates to allow projects requiring significant infrastructure investment to be more cost-competitive.
b) Subordinated debt can be issued by multilateral development banks or DFIs and can help attract and insulate senior debt investors, such as institutional investors, from certain risks inherent in renewable projects.
c) The DBSA's Infrastructure Fund has specifically been set up to arrange, coordinate, structure and engage with financial institutions and the markets to develop financial instruments that will enable investments in large-scale infrastructure projects, by:
   - contributing fixed capital.
   - improving bankability by addressing market failures/shortcomings; and
   - maximise participation by the private sector, institutional investors, development finance institutions and multilateral development banks.

6.5.4. Recommendations

Government particularly has a strong role to play in unlocking the financing of GH projects, not necessarily through majority contribution but rather by mitigating specific investor risks by, for example:

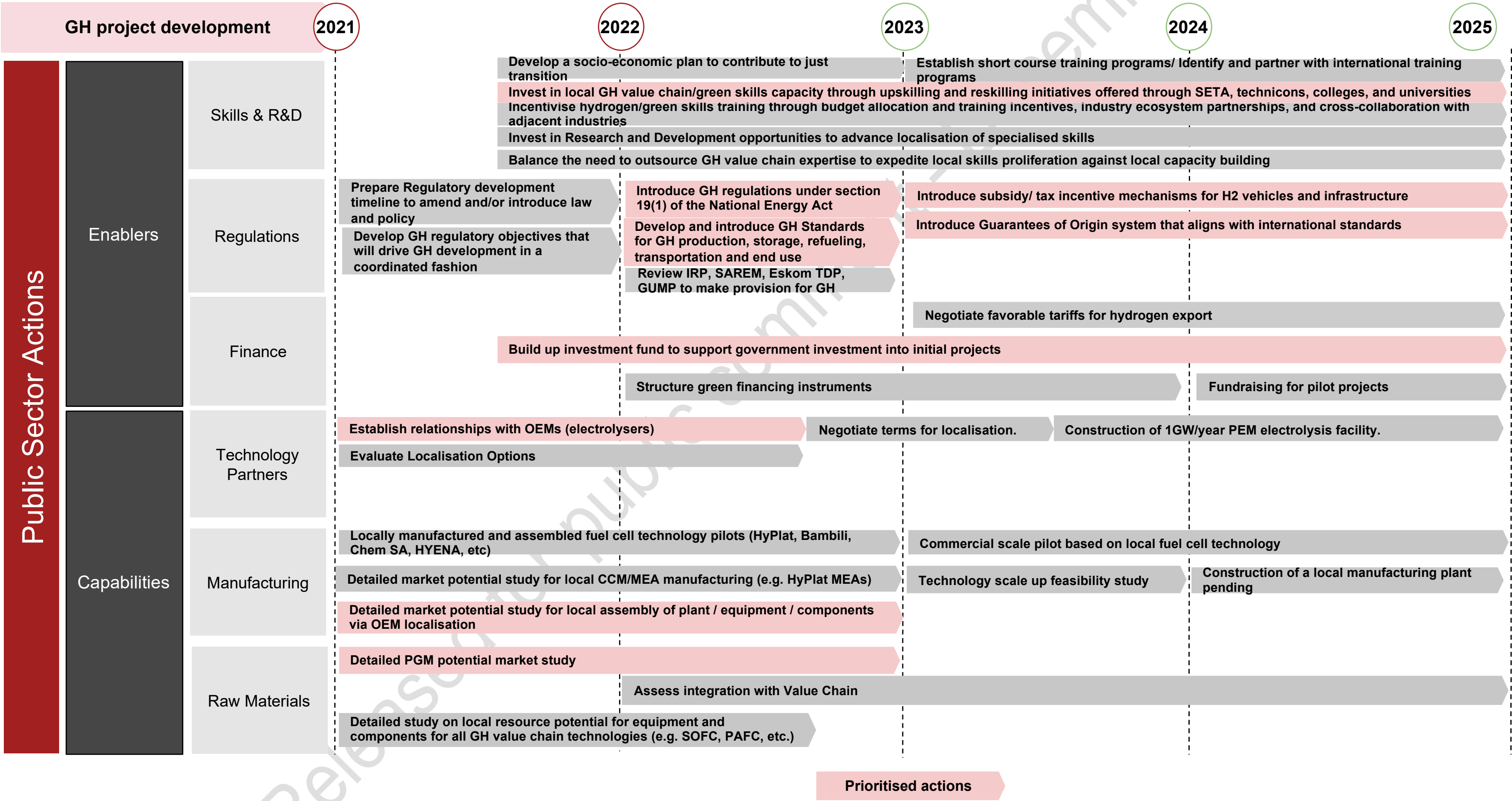
a) developing strong relationships with the governments of developed countries (specifically the UK and members of the European Union) who have programmes in place to support developing countries in their climate change pursuits.
b) providing partial guarantees.
c) providing blended concessional finance; and/or
d) providing grants and/or subsidies to pilot projects.

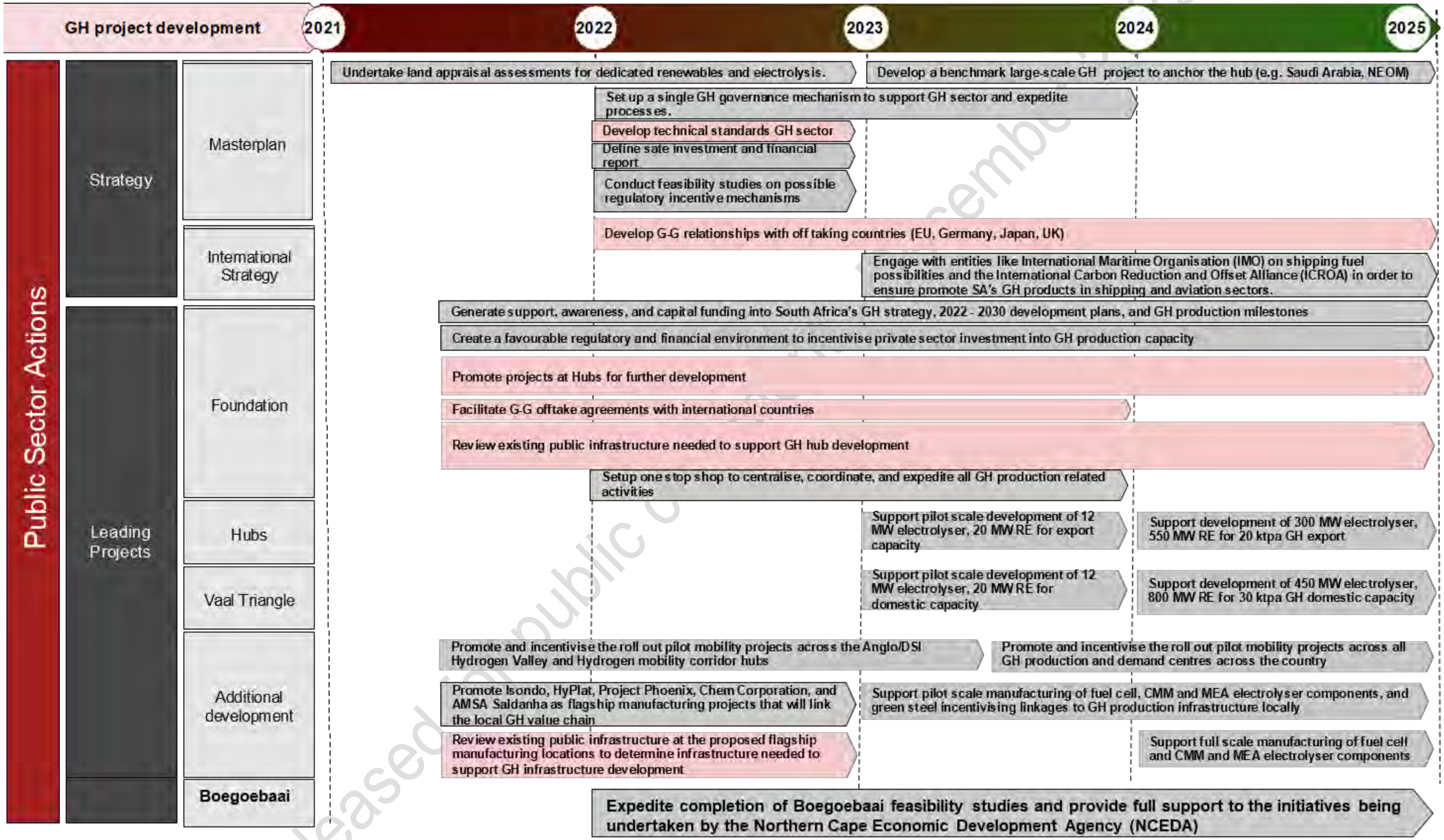
Possible innovative sources of funding for government to support the above objectives include:

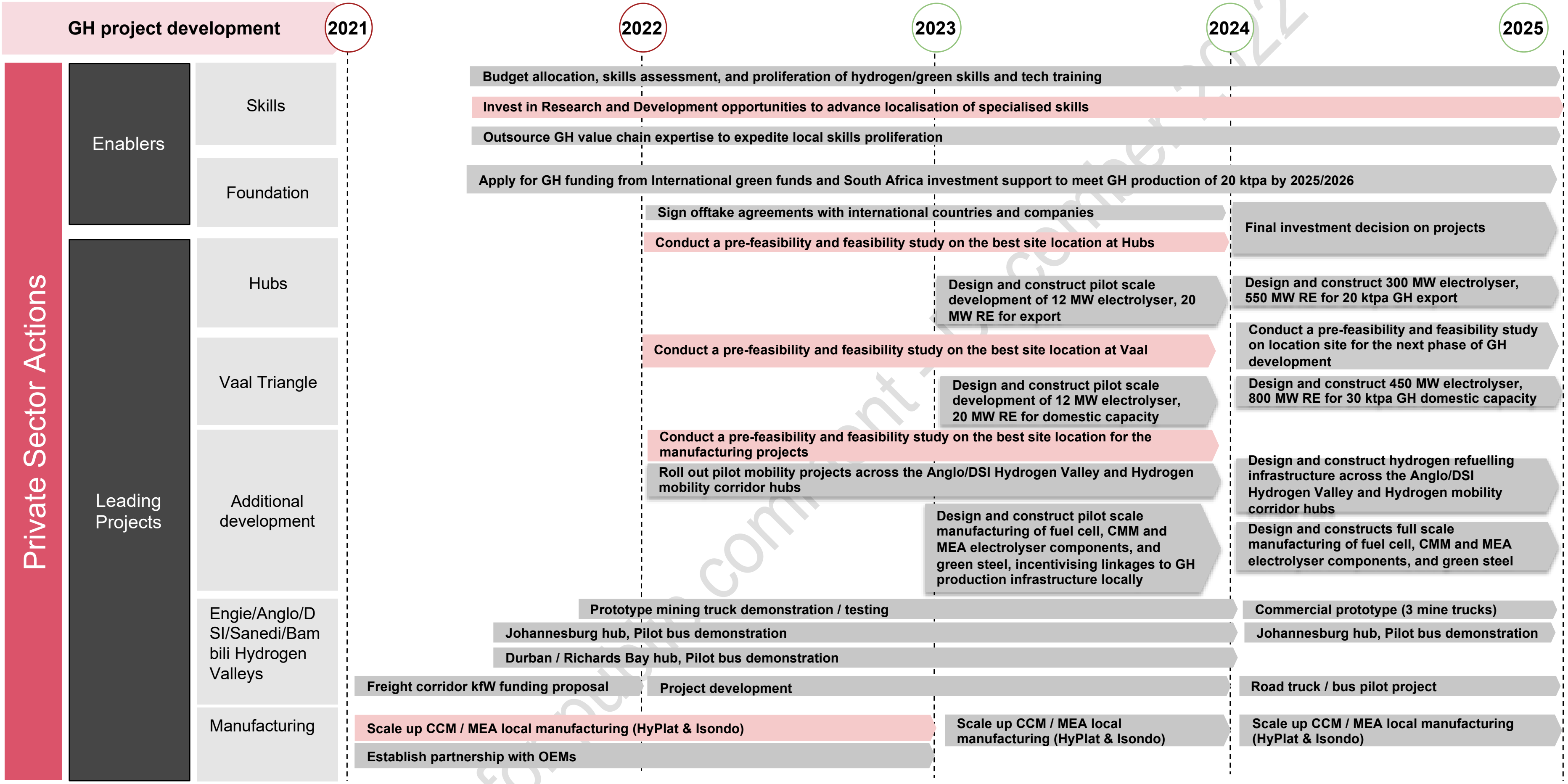
a) issuing a government-backed green bond.
b) introducing special, marginal levies on existing carbon fuel consumption (e.g., additional levy on fuel at the pumps) which could generate a pool of funding which could be applied to the country's movement towards greener fuels; and
c) redirecting income from carbon taxes towards green initiatives

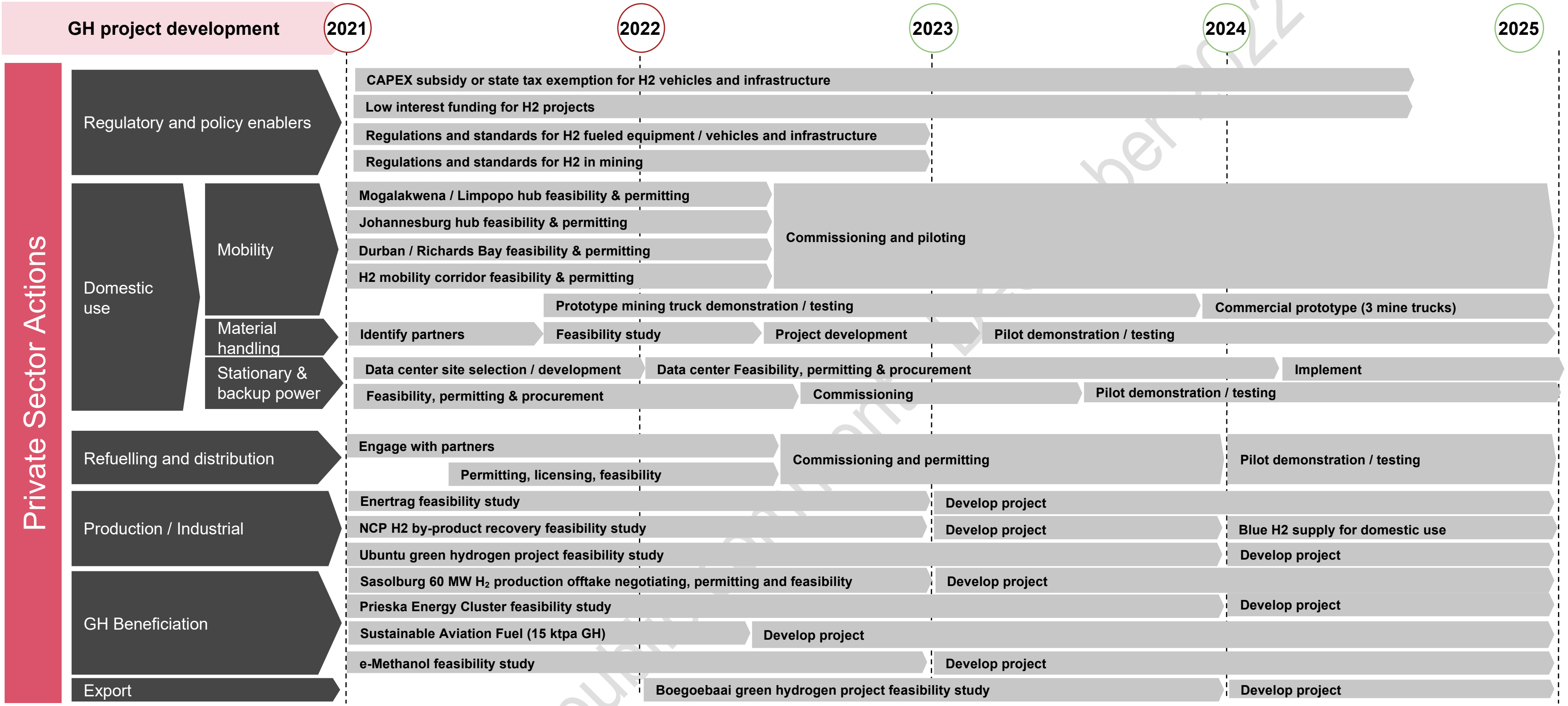
7. GH Commercialisation Roadmap and Funding Plan

7.1. Short-term Roadmap (2023-2027)




GH project development
2021
2022
2023
2024
2025
Public Sector Actions
Strategy
Masterplan
International Strategy
Leading Projects
Foundation
Hubs
Vaal Triangle
Additional development
Boegoebaai
Undertake land appraisal assessments for dedicated renewables and electrolysis.
Develop a benchmark large-scale GH project to anchor the hub (e.g. Saudi Arabia, NEOM)
Set up a single GH governance mechanism to support GH sector and expedite processes.
Develop technical standards GH sector
Define safe investment and financial report
Conduct feasibility studies on possible regulatory incentive mechanisms
Develop G-G relationships with off taking countries (EU, Germany, Japan, UK)
Engage with entities like International Maritime Organisation (IMO) on shipping fuel possibilities and the International Carbon Reduction and Offset Alliance (ICROA) in order to ensure promote SA's GH products in shipping and aviation sectors.
Generate support, awareness, and capital funding into South Africa's GH strategy, 2022 - 2030 development plans, and GH production milestones
Create a favourable regulatory and financial environment to incentivise private sector investment into GH production capacity
Promote projects at Hubs for further development
Facilitate G-G offtake agreements with international countries
Review existing public infrastructure needed to support GH hub development
Setup one stop shop to centralise, coordinate, and expedite all GH production related activities
Support pilot scale development of 12 MW electrolyser, 20 MW RE for export capacity
Support development of 300 MW electrolyser, 550 MW RE for 20 ktpa GH export
Support pilot scale development of 12 MW electrolyser, 20 MW RE for domestic capacity
Support development of 450 MW electrolyser, 800 MW RE for 30 ktpa GH domestic capacity
Promote and incentivise the roll out pilot mobility projects across the Anglo/DSI Hydrogen Valley and Hydrogen mobility corridor hubs
Promote and incentivise the roll out pilot mobility projects across all GH production and demand centres across the country
Promote Isondo, HyPlat, Project Phoenix, Chem Corporation, and AMSA Saldanha as flagship manufacturing projects that will link the local GH value chain
Support pilot scale manufacturing of fuel cell, CMM and MEA electrolyser components, and green steel incentivising linkages to GH production infrastructure locally
Review existing public infrastructure at the proposed flagship manufacturing locations to determine infrastructure needed to support GH infrastructure development
Support full scale manufacturing of fuel cell and CMM and MEA electrolyser components
Expedite completion of Boegoebaai feasibility studies and provide full support to the initiatives being undertaken by the Northern Cape Economic Development Agency (NCEDA)


GH project development
2021
2022
2023
2024
2025
Private Sector Actions
Enablers
Skills
Foundation
Leading Projects
Hubs
Vaal Triangle
Additional development
Engie/Anglo/DSI/Sanedi/Bambili Hydrogen Valleys
Manufacturing
Budget allocation, skills assessment, and proliferation of hydrogen/green skills and tech training
Invest in Research and Development opportunities to advance localisation of specialised skills
Outsource GH value chain expertise to expedite local skills proliferation
Apply for GH funding from International green funds and South Africa investment support to meet GH production of 20 ktpa by 2025/2026
Sign offtake agreements with international countries and companies
Final investment decision on projects
Conduct a pre-feasibility and feasibility study on the best site location at Hubs
Design and construct pilot scale development of 12 MW electrolyser, 20 MW RE for export
Design and construct 300 MW electrolyser, 550 MW RE for 20 ktpa GH export
Conduct a pre-feasibility and feasibility study on the best site location at Vaal
Conduct a pre-feasibility and feasibility study on location site for the next phase of GH development
Design and construct pilot scale development of 12 MW electrolyser, 20 MW RE for domestic capacity
Design and construct 450 MW electrolyser, 800 MW RE for 30 ktpa GH domestic capacity
Conduct a pre-feasibility and feasibility study on the best site location for the manufacturing projects
Roll out pilot mobility projects across the Anglo/DSI Hydrogen Valley and Hydrogen mobility corridor hubs
Design and construct hydrogen refuelling infrastructure across the Anglo/DSI Hydrogen Valley and Hydrogen mobility corridor hubs
Design and construct pilot scale manufacturing of fuel cell, CMM and MEA electrolyser components, and green steel, incentivising linkages to GH production infrastructure locally
Design and constructs full scale manufacturing of fuel cell, CMM and MEA electrolyser components, and green steel
Prototype mining truck demonstration / testing
Commercial prototype (3 mine trucks)
Johannesburg hub, Pilot bus demonstration
Johannesburg hub, Pilot bus demonstration
Durban / Richards Bay hub, Pilot bus demonstration
Freight corridor kfW funding proposal
Project development
Road truck / bus pilot project
Scale up CCM / MEA local manufacturing (HyPlat & Isondo)
Scale up CCM / MEA local manufacturing (HyPlat & Isondo)
Scale up CCM / MEA local manufacturing (HyPlat & Isondo)
Establish partnership with OEMs



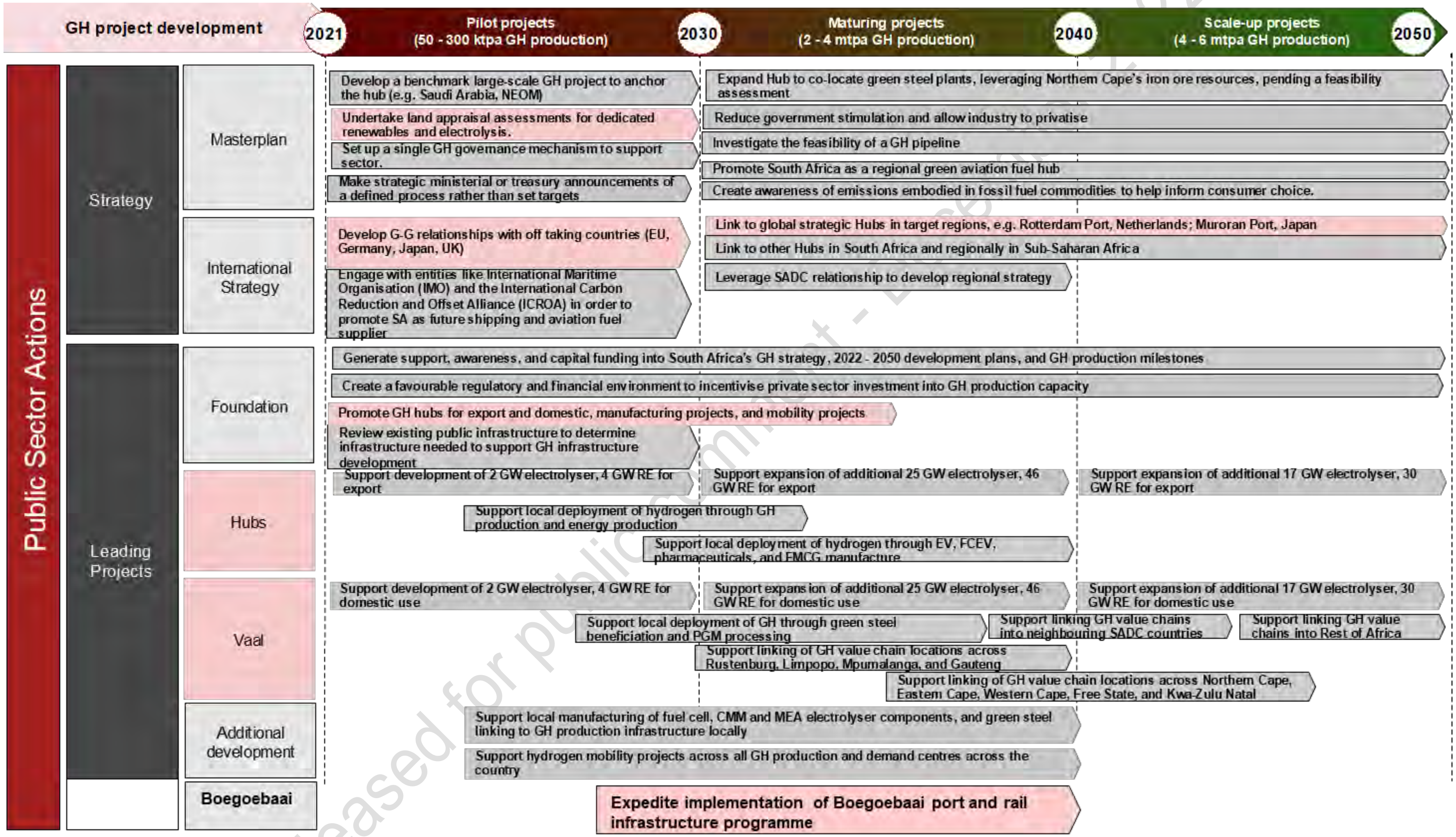
GH project development
2021
2022
2023
2024
2025
Private Sector Actions
Regulatory and policy enablers
CAPEX subsidy or state tax exemption for H2 vehicles and infrastructure
Low interest funding for H2 projects
Regulations and standards for H2 fueled equipment / vehicles and infrastructure
Regulations and standards for H2 in mining
Domestic use
Mobility
Mogalakwena / Limpopo hub feasibility & permitting
Johannesburg hub feasibility & permitting
Durban / Richards Bay feasibility & permitting
H2 mobility corridor feasibility & permitting
Commissioning and piloting
Prototype mining truck demonstration / testing
Commercial prototype (3 mine trucks)
Material handling
Identify partners
Feasibility study
Project development
Pilot demonstration / testing
Stationary & backup power
Data center site selection / development
Data center Feasibility, permitting & procurement
Implement
Feasibility, permitting & procurement
Commissioning
Pilot demonstration / testing
Refuelling and distribution
Engage with partners
Permitting, licensing, feasibility
Commissioning and permitting
Pilot demonstration / testing
Production / Industrial
Enertrag feasibility study
Develop project
NCP H2 by-product recovery feasibility study
Develop project
Blue H2 supply for domestic use
Ubuntu green hydrogen project feasibility study
Develop project
GH Beneficiation
Sasolburg 60 MW H₂ production offtake negotiating, permitting and feasibility
Develop project
Prieska Energy Cluster feasibility study
Develop project
Sustainable Aviation Fuel (15 ktpa GH)
Develop project
e-Methanol feasibility study
Develop project
Export
Boegoebaai green hydrogen project feasibility study
Develop project

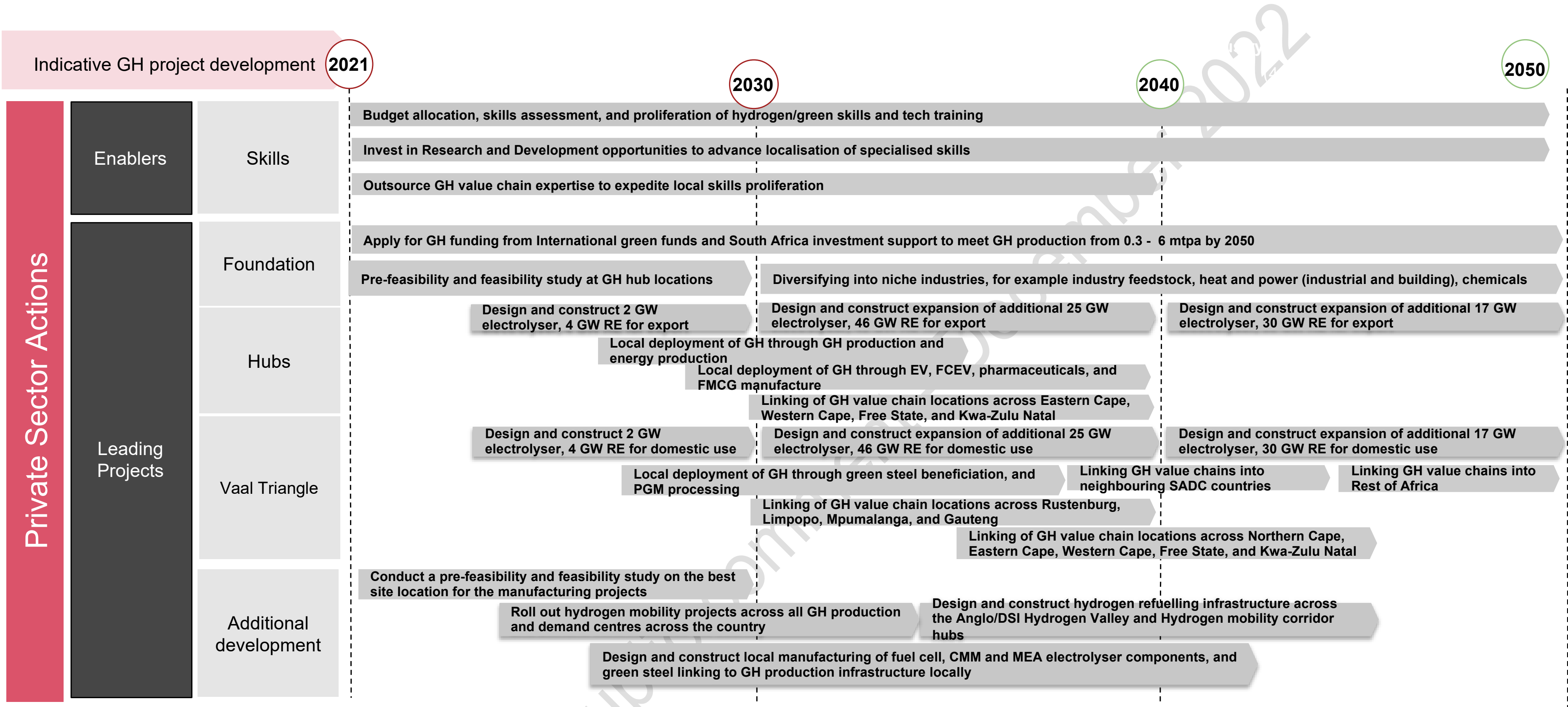
7.2. Long-term Roadmap (2023-2050)

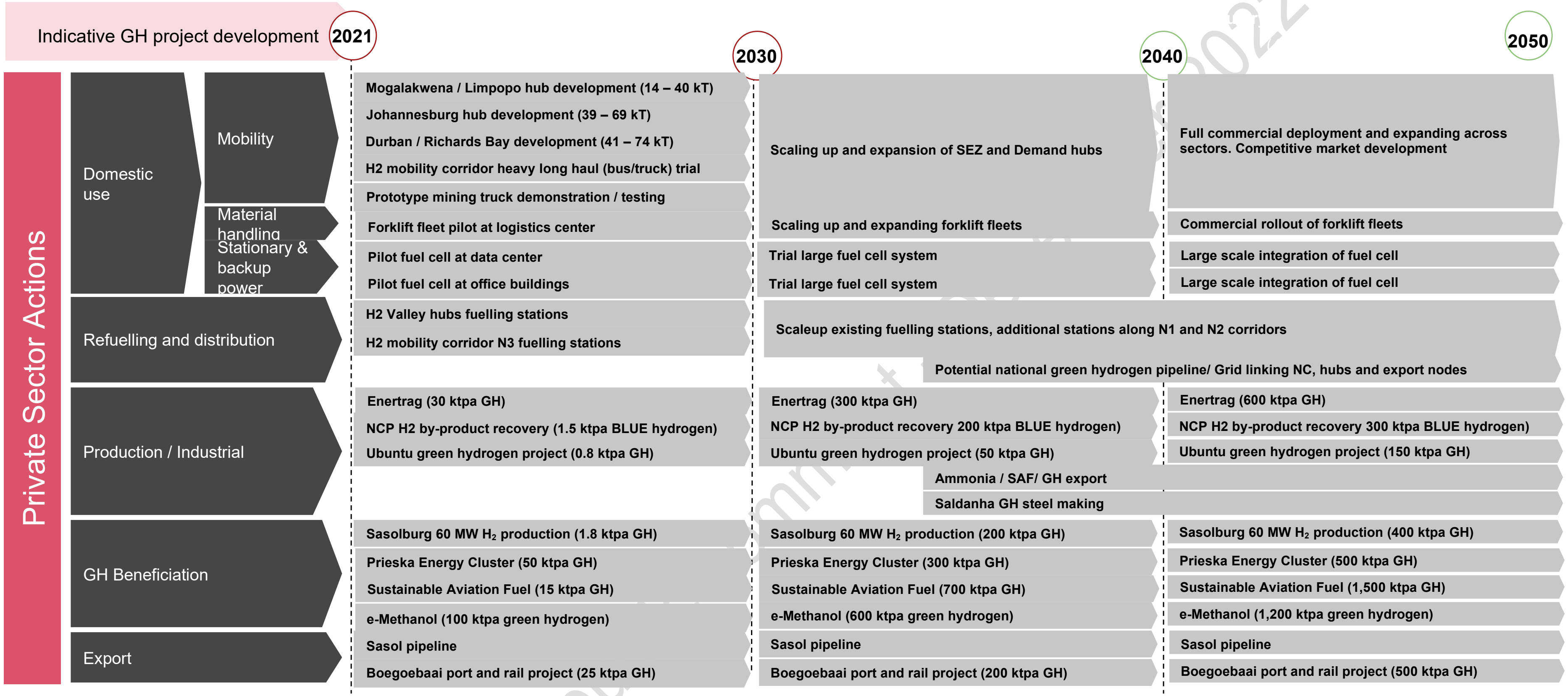
Public Sector Actions

GH project development		2021	2030	2040 – 2050
Enablers	Skills	Implement a socio-economic plan to contribute to just transition		
		Invest in local GH value chain/green skills capacity through upskilling and reskilling initiatives offered through SETA, technicons, colleges, and universities		
		Incentivise hydrogen/green skills training through budget allocation and training incentives, industry ecosystem partnerships, and cross-collaboration with adjacent industries		
		Invest in Research and Development opportunities to advance localisation of specialised skills		
		Balance the need to outsource GH value chain expertise to expedite local skills proliferation against local capacity building		
	Regulations	Implement a revised IRP incorporating GH capacity	Reduce tax incentives as industry matures	
		Introduce GH regulatory framework and standards (production, storage, refueling and transport)	Introduce explicit an implicit carbon pricing and revenue recycling mechanisms to drive investment in GH	
		Introduce regulatory incentives (reduced import duties and tax incentives)		
		Develop GH Guarantees of Origin system in order to secure product premiums		
	Finance	Negotiate favorable tariffs for hydrogen export	Secure long-term off-take arrangement with key countries / customers	
		Build up investment fund to support government investment into initial projects	Blended finance still required, but private sector scaling up	Competitive market financed by private sector
		Structure green financing instruments		
Capabilities	Technology Partners	Establish relationships with OEMs (electrolysers)	Manufacture established to support 1GW/year electrolysis capacity.	Expand manufacturing capability to meet demand.
		Auction electrolyser capacity, and invite global participation – min 10 MW (e.g. Chile)		
		Investigate direct air capture opportunities and biomass		
	Manufacturing	Demonstrate clean hydrogen as an input into existing plants and support fuel cell pilots	Expand replicable business model to other countries / regions	
		Promote >1 GW of local electrolyser / FC capacity, which incentivises OEMs to invest in local production capacity		Sector coupling – Long duration electricity storage
		Invest in local component manufacturers (CCM & MEA) Targeting 15% of global market. Leverage local PGM.	Increase investment in local component manufacturing (CCM & MEA) Targeting 25% of global market.	Increase investment in local component manufacturing (CCM & MEA) Targeting 30% of global market.
	Raw Materials	Target PGMs of 536 koz, 65 GW elect, 31 GW FC	Target PGMs of 1,51 moz, 90 GW elect, 145 GW FC	Target PGMs of 3,19 oz, 140 GW elect, 673 GW FC

Prioritised actions


GH project development
2021
Pilot projects (50 - 300 ktpa GH production)
2030
Maturing projects (2 - 4 mtpa GH production)
2040
Scale-up projects (4 - 6 mtpa GH production)
2050
Public Sector Actions
Strategy
Masterplan
Develop a benchmark large-scale GH project to anchor the hub (e.g. Saudi Arabia, NEOM)
Undertake land appraisal assessments for dedicated renewables and electrolysis.
Set up a single GH governance mechanism to support sector.
Make strategic ministerial or treasury announcements of a defined process rather than set targets
Expand Hub to co-locate green steel plants, leveraging Northern Cape's iron ore resources, pending a feasibility assessment
Reduce government stimulation and allow industry to privatise
Investigate the feasibility of a GH pipeline
Promote South Africa as a regional green aviation fuel hub
Create awareness of emissions embodied in fossil fuel commodities to help inform consumer choice.
International Strategy
Develop G-G relationships with off taking countries (EU, Germany, Japan, UK)
Engage with entities like International Maritime Organisation (IMO) and the International Carbon Reduction and Offset Alliance (ICROA) in order to promote SA as future shipping and aviation fuel supplier
Link to global strategic Hubs in target regions, e.g. Rotterdam Port, Netherlands; Muroran Port, Japan
Link to other Hubs in South Africa and regionally in Sub-Saharan Africa
Leverage SADC relationship to develop regional strategy
Leading Projects
Foundation
Generate support, awareness, and capital funding into South Africa's GH strategy, 2022 - 2050 development plans, and GH production milestones
Create a favourable regulatory and financial environment to incentivise private sector investment into GH production capacity
Promote GH hubs for export and domestic, manufacturing projects, and mobility projects
Review existing public infrastructure to determine infrastructure needed to support GH infrastructure development
Hubs
Support development of 2 GW electrolyser, 4 GW RE for export
Support expansion of additional 25 GW electrolyser, 46 GW RE for export
Support expansion of additional 17 GW electrolyser, 30 GW RE for export
Support local deployment of hydrogen through GH production and energy production
Support local deployment of hydrogen through EV, FCEV, pharmaceuticals, and FMCG manufacture
Vaal
Support development of 2 GW electrolyser, 4 GW RE for domestic use
Support expansion of additional 25 GW electrolyser, 46 GW RE for domestic use
Support expansion of additional 17 GW electrolyser, 30 GW RE for domestic use
Support local deployment of GH through green steel beneficiation and PGM processing
Support linking GH value chains into neighbouring SADC countries
Support linking GH value chains into Rest of Africa
Support linking of GH value chain locations across Rustenburg, Limpopo, Mpumalanga, and Gauteng
Support linking of GH value chain locations across Northern Cape, Eastern Cape, Western Cape, Free State, and Kwa-Zulu Natal
Additional development
Support local manufacturing of fuel cell, CMM and MEA electrolyser components, and green steel linking to GH production infrastructure locally
Support hydrogen mobility projects across all GH production and demand centres across the country
Boegoebaai
Expedite implementation of Boegoebaai port and rail infrastructure programme


Indicative GH project development
2021
2030
2040
2050
Private Sector Actions
Enablers
Skills
Budget allocation, skills assessment, and proliferation of hydrogen/green skills and tech training
Invest in Research and Development opportunities to advance localisation of specialised skills
Outsource GH value chain expertise to expedite local skills proliferation
Leading Projects
Foundation
Apply for GH funding from International green funds and South Africa investment support to meet GH production from 0.3 - 6 mtpa by 2050
Pre-feasibility and feasibility study at GH hub locations
Diversifying into niche industries, for example industry feedstock, heat and power (industrial and building), chemicals
Hubs
Design and construct 2 GW electrolyser, 4 GW RE for export
Design and construct expansion of additional 25 GW electrolyser, 46 GW RE for export
Design and construct expansion of additional 17 GW electrolyser, 30 GW RE for export
Local deployment of GH through GH production and energy production
Local deployment of GH through EV, FCEV, pharmaceuticals, and FMCG manufacture
Linking of GH value chain locations across Eastern Cape, Western Cape, Free State, and Kwa-Zulu Natal
Vaal Triangle
Design and construct 2 GW electrolyser, 4 GW RE for domestic use
Design and construct expansion of additional 25 GW electrolyser, 46 GW RE for domestic use
Design and construct expansion of additional 17 GW electrolyser, 30 GW RE for domestic use
Local deployment of GH through green steel beneficiation, and PGM processing
Linking GH value chains into neighbouring SADC countries
Linking GH value chains into Rest of Africa
Linking of GH value chain locations across Rustenburg, Limpopo, Mpumalanga, and Gauteng
Linking of GH value chain locations across Northern Cape, Eastern Cape, Western Cape, Free State, and Kwa-Zulu Natal
Additional development
Conduct a pre-feasibility and feasibility study on the best site location for the manufacturing projects
Roll out hydrogen mobility projects across all GH production and demand centres across the country
Design and construct hydrogen refuelling infrastructure across the Anglo/DSI Hydrogen Valley and Hydrogen mobility corridor hubs
Design and construct local manufacturing of fuel cell, CMM and MEA electrolyser components, and green steel linking to GH production infrastructure locally


Indicative GH project development
2021
2030
2040
2050
Private Sector Actions
Domestic use
Mobility
Material handling
Stationary & backup power
Refuelling and distribution
Production / Industrial
GH Beneficiation
Export
Mogalakwena / Limpopo hub development (14 – 40 kT)
Johannesburg hub development (39 – 69 kT)
Durban / Richards Bay development (41 – 74 kT)
H2 mobility corridor heavy long haul (bus/truck) trial
Prototype mining truck demonstration / testing
Scaling up and expansion of SEZ and Demand hubs
Full commercial deployment and expanding across sectors. Competitive market development
Forklift fleet pilot at logistics center
Scaling up and expanding forklift fleets
Commercial rollout of forklift fleets
Pilot fuel cell at data center
Trial large fuel cell system
Large scale integration of fuel cell
Pilot fuel cell at office buildings
Trial large fuel cell system
Large scale integration of fuel cell
H2 Valley hubs fuelling stations
H2 mobility corridor N3 fuelling stations
Scaleup existing fuelling stations, additional stations along N1 and N2 corridors
Potential national green hydrogen pipeline/ Grid linking NC, hubs and export nodes
Enertrag (30 ktpa GH)
Enertrag (300 ktpa GH)
Enertrag (600 ktpa GH)
NCP H2 by-product recovery (1.5 ktpa BLUE hydrogen)
NCP H2 by-product recovery 200 ktpa BLUE hydrogen)
NCP H2 by-product recovery 300 ktpa BLUE hydrogen)
Ubuntu green hydrogen project (0.8 ktpa GH)
Ubuntu green hydrogen project (50 ktpa GH)
Ubuntu green hydrogen project (150 ktpa GH)
Ammonia / SAF/ GH export
Saldanha GH steel making
Sasolburg 60 MW H_2 production (1.8 ktpa GH)
Sasolburg 60 MW H_2 production (200 ktpa GH)
Sasolburg 60 MW H_2 production (400 ktpa GH)
Prieska Energy Cluster (50 ktpa GH)
Prieska Energy Cluster (300 ktpa GH)
Prieska Energy Cluster (500 ktpa GH)
Sustainable Aviation Fuel (15 ktpa GH)
Sustainable Aviation Fuel (700 ktpa GH)
Sustainable Aviation Fuel (1,500 ktpa GH)
e-Methanol (100 ktpa green hydrogen)
e-Methanol (600 ktpa green hydrogen)
e-Methanol (1,200 ktpa green hydrogen)
Sasol pipeline
Sasol pipeline
Sasol pipeline
Boegoebaai port and rail project (25 ktpa GH)
Boegoebaai port and rail project (200 ktpa GH)
Boegoebaai port and rail project (500 ktpa GH)

7.3. Short term funding plan (2023-2027)

Based on the projected production targets, required projects and the roadmap actions, investment needs for the period from 2023-2027 is summarised below.

Funding for project development (pre-feasibility and feasibility studies)	
Description	**ZAR billion**
Sustainable Aviation Fuel Production	0.10
e-methanol Production	0.12
Fuel Cell Manufacturing	0.16
GH and Green Ammonia Production	3.70
Green Steel Production	0.20
Hydrogen Mobility	0.10
Infrastructure	0.13
Port project development	1.00
TOTAL	**5.51**
Capital Costs for the implementation of the above projects	
Description	**ZAR billion**
Sustainable Aviation Fuel Production	8.00
e-methanol Production	12.00
Fuel Cell Manufacturing	1.40
GH and Green Ammonia Production	109.30
Green Steel Production	13.20
Hydrogen Mobility	6.60
Infrastructure	13.00
Port infrastructure capital	150
TOTAL	**313.5**
TOTAL FOR PROJECT DEVELOPMENT AND CAPITAL COSTS FOR IMPLEMENTATION	**319.01 ($18,4bn)**

7.4. Summary of Commercialisation Strategy

The successful implementation of the commercialisation strategy will depend on the execution of the six key elements :

1 PRIORITISE EXPORTS

Target exports of green hydrogen and green chemicals by leveraging on South Africa's proprietary Fischer Tropsch technology and utilising financing support mechanisms including grants, concessional debt and contract for difference / price subsidies to improve the financial viability of these projects

2 STIMULATE DOMESTIC MARKET

In parallel to the export strategy, develop projects along the value chain to stimulate demand for green hydrogen in South Africa. "Low hanging fruit" opportunities to be prioritised to provide confidence in the domestic market. Examples include green steel, hydrogen valley mobility programme and sustainable aviation fuel projects.

3 SUPPORT LOCALISATION

Develop local industrial capability to produce fuel cells, electrolyser, ammonia cracking and balance of plant equipment and components by leveraging on South Africa's PGM resources. Together with demand stimulation this will drive longer term GH_2 price reduction allowing penetration in various sectors.

4 SECURE FINANCING

"Crowd in" and secure funding from various sources and in various forms including grants, concessional debt and contract for differences.

5 PROACTIVE SOCIO ECONOMIC DEVELOPMENT

Maximise development impact (incl. skills and economic development and social inclusion).

Ensure gender equality, BBBEE and community participation.

Maximise job creation and alternative options for potential job losses.

6 ROLE OF GOVERNMENT IN POLICY AND REGULATORY SUPPORT

Position GH_2 as a key early contributor to decarbonization and a just transition in the country programme of work being collated by the JET-IP Task Team ensuring a fair proportion of climate finance is sourced to enable development of this industry.

Prioritize the execution of the green hydrogen commercialisation strategy and the development of a national GH_2 infrastructure plan

Drive the required policy and regulatory changes required to sustain long term growth of the new hydrogen industry.

Mobilise and coordinate the Government support required to support the development of this new industry for South Africa.

8. Appendix A: Work Package 1 - Assessment and summary of current literature

Table A.1: Assessment and Summary of Current Literature

Study	Author	Key Points
GH Panel report from 13/09/2021	GH Panel	The areas of the GH value chain that will need to be explored for commercialisation in South Africa will include: • Raw Materials sourcing and beneficiation. • Renewable Energy Generation. • Hydrogen Production. • Hydrogen Distribution and Storage. • Equipment and Components Manufacturing. • Mobility Applications. • Decarbonisation of hard to abate industries. • Chemical's production including ammonia and aviation fuel and • Export opportunities. The report also touches on the aim for a masterplan: • Providing steps that will enable the transition to a low carbon economy. • Contributing towards initiatives aimed at transitioning to a climate resilient economy. • Contributing to the global effort to stabilise and reduce greenhouse gas emissions by applying appropriate mitigation actions to climate change. • Promotion of air quality. • Black economic transformation. • Job creation. • SMME Development. • Youth and Women Development. • Skills Development • Creation of new industries for the manufacturing of equipment and components. The above is in line with overall government objectives articulated in the National

Study	Author	Key Points
		Development Plan (NDP), Energy and Climate Change Strategy (ECCS) and various other policy prescripts.
NIP 2050	The Department of Public Works and Infrastructure	The NIP 2050 highlights a recipe for success: • Knowledge and innovation services for capability in planning, monitoring, budgeting, finance, procurement, project preparation, project management and sector-specific innovation • Public-private cooperation and stimulation of competition where appropriate in the delivery of public infrastructure • Blended project finance and innovative green finance • Executive management and Technical capability within the state and its entities, to be stable and able to lead and deliver with confidence • Economic regulation • Capacity and orientation that promotes industries that promote inclusive development and employment • An emphasis on industrial development and localisation in the design and approach to implementation. Examples include localisation of supplier industries to infrastructure projects, driving the establishment of Special Economic Zones around intermodal transport linkage nodes, and the stimulation of the civil construction and supplier industries. • Driving efficient modes of delivery • Delivering on an Africa regional infrastructure programme • The SA civil construction and supplier industries so that local industry gains from state infrastructure investment The NIP 2050 also covers a vision for infrastructure finance: • A full lifecycle planning approach be adopted • Value for money be optimized • Projects be designed to meet the risk and return needs of investors

Study	Author	Key Points
		• Projects be designed to minimise risk • Public-private partnerships be embraced where they deliver better value for money • Capital market development be supported by a steady and reliable pipeline of new projects • Monitoring and reporting be done in a way that builds investor confidence
NBI net zero- Just Transition and Climate Pathways Study for SA	NBI, BUSA, BCG	The NBI/BUSA Just Transition Pathways for Business report outlines the RE requirements for 2050 for the SA power grid. • By 2050, a renewables-dominated power system is the most cost-competitive system for South Africa. • Transitioning South Africa's power system to net-zero would require the deployment of **~150GW** wind and solar capacity by 2050 • This is **almost four times the total capacity of South Africa's coal power plants today** – and an investment of **~ZAR3 trillion within the next 30 years**, requiring significant expansion and upgrade to the transmission and distribution infrastructure. • To reach net-zero by 2050, South Africa would need to speed up deployment of renewable energy capacity; at **least 4GW of renewables will need to be installed every year – roughly ten times the current pace of new-build.** • Natural gas as a transition fuel will be critical in this journey – initially growing as an enabler to the integration of wind and solar into the power system at scale, gas will then be gradually replaced by other technologies to reach net-zero emissions. The report also highlights similar recommendations for success: • What is the role of GH in the decarbonisation of other sectors in South Africa, and what economic opportunities emerge? For instance, how can South Africa seize a potential opportunity to become an exporter of GH products in a growing global GH market?

Study	Author	Key Points
		• How could the demand for local green H2 and its derivatives be linked to exports, so it evolves over time in South Africa? • What are green GH production and delivery options and implied infrastructure requirements in light of potential demand scenarios? • What are the key policy decisions and frameworks needed to enable the development of a successful local GH economy in South Africa? • Develop a national GH strategy that clearly articulates where in the value chain SA should play and where SA has a 'right to win'. Kick-off GH pilot projects in partnership with potential long-term off-take markets e.g., Germany (particularly test appetite for cheaper sources of finance, e.g., at 2% WACC)
IRP 2019	DMRE	An allocation for wind and solar builds of 17 GW between 2023 and 2030.
NDC (and changes suggested at 14/09 meeting)	DFFE	Changed to 350-420 million tonnes of carbon dioxide equivalent (Mt CO2e) by 2030. Adds to motivation towards building the Hydrogen economy
IHS Super H2ighroad Scenario Market	IHS Markit	The study concludes that with a supportive commercial and policy environment, a production of 3.8 million tonnes per annum of hydrogen could be developed in South Africa by 2050 (0.75 mtpa by2030). Of this, over 2.0 mtpa would be for domestic consumption -equal to between 6 and 8 percent of final energy demand. Used in road transport FCV-HDVs, green ammonia and methanol production, industry – cement and non-ferrous metals, industry – green steel, refining/chemicals – GTL/CTL and power storage and balancing
National Hydrogen Roadmap for Australia	Commonwealth Scientific and Industrial Research Organisation	This report details Australia's potential in the hydrogen market, their export capabilities and maps out their current activities. The report then deep dives into the value chain, highlighting general considerations (R&D, Policy, Commercial implications and opportunities and Social licence), hydrogen production, storage, transport

Study	Author	Key Points
		and utilisation. The report concludes with a roadmap synthesis and key action points.
CSIR Powerfuels Report	CSIR	This report covers the emerging power fuels market and the applicability of power fuels in South Africa. The report also covers a SA legislative and policy overview and the industries that are likely to benefit from power fuels. Multiple countries have published their Hydrogen Strategies with their projected demands reported in the CSIR Report: **Japan:** • By 2025: Reduce the cost of H_2 delivered to Japan to ¥30/Nm3 (about USD3/kg). • 2030: Begin bulk import of H_2 from overseas to Japan • 2040: All imported H_2 is to be CO_2-free. • The volumes of H_2 to be imported from 2030 begin at about 300 000 tonnes annually, growing to 5 to 10 million tonnes by about 2050 **Germany:** • The NHS states that Germany is expected to need an annual volume of hydrogen of between 90-110 TWh (2.7-3.3 Mt) by 2030 • Of this total, it plans to generate 14 TWh (420 kt) annually in Germany, from 5 GW of new renewable electricity generation capacity11. • A further 5 GW of RE capacity are to be added between 2035 and 2040. **Netherlands:** • The domestic demand for hydrogen is expected to increase to approximately 14 Mt per year by 2050. • If half of this volume is sourced via Rotterdam, the port will be handling some 7 Mt in throughput. • According to prognoses, there will also be a sizeable demand from neighbouring countries (and specifically Germany) for hydrogen via Rotterdam: approximately 13 Mt by 2050
EU Hydrogen Policy	Gregor Erbach and Liselotte	EU Hydrogen Policy displays the collaborative effort for net-zero and decarbonisation targets:

Study	Author	Key Points
	Jensen, Climate Action Research and Tracking Service, Members' Research Service	• **Research and industrial innovation in hydrogen applications is an EU priority and receives substantial EU funding through the research framework programmes.** • Almost **all EU Member States recognise the important role of hydrogen** in their national energy and climate plans for the 2021-2030 period. About half have explicit hydrogen-related objectives, focussed primarily on transport and industry. • In the European Parliament, the Committee on Industry, Research and Energy (ITRE) adopted an own-initiative report on the EU hydrogen strategy in March 2021. • Studies have shown **that an integrated energy system making use of existing gas infrastructure would be more cost effective** than one focussed on maximal electrification and requiring costly grid upgrades and storage solutions. All climate-neutrality scenarios in the Commission's climate target plan project a growing demand for hydrogen, which would account for around 9% of the EU's final energy demand by 2050. • There are only around 5 000 km of hydrogen pipelines today, mainly in the US (2 600 km), Belgium (600 km) and Germany (400 km), compared with some **3 million km of natural gas pipelines**. Injecting hydrogen into the gas grid could significantly reduce the upfront capital costs of hydrogen projects. • Developing the hydrogen economy will depend on a number of factors: **creating a market for clean hydrogen, cutting its production costs and creating an infrastructure for its transport and storage.** • According to an extensive study by the Florence School of Regulation, a key challenge to the cost-effective design of energy innovations is finding an optimal balance between research, development and demonstration of new technologies ('technology push'), ensuring support for key infrastructure projects and creating demand through production subsidies, public procurement and mandates ('market pull').

Study	Author	Key Points
		• For clean hydrogen to become a tradeable commodity, **guarantees of origin are needed** to prove the GHG emissions during its production. The CertifHy project works to establish harmonised guarantees of origin schemes that are to be applied by national certification bodies across Europe • The focus in the **first phase is on scaling up manufacturing of large (up to 100 MW) electrolysers**, decarbonising existing hydrogen installations and facilitating the take-up of hydrogen in end-use applications. Planning for transport infrastructure and laying down regulatory frameworks to ensure a well-functioning hydrogen market are key policy actions. • In the **second phase** (2024-2030), **infrastructure will be increasingly deployed,** starting with local networks on islands, remote areas or local hydrogen clusters, where hydrogen would be used not only for renewable energy balancing but also in industry and transport applications and for residential and commercial heating. •
Hydrogen for EU Report	Consortium composed of IFP Energies Nouvelles, SINTEF Energi AS and Deloitte Finance SAS	The Hydrogen4EU study analyses the European Demand: • European hydrogen demand in our pathways **exceeds 30 Mt by 2030, which is triple the current policy objective described in the EU hydrogen strategy.** Demand for hydrogen ramps up substantially over the 2030s and 2040s and **exceeds 100 million tons (Mt) by 2050 in both pathways**. • More than half of hydrogen demand (above 50 Mt) comes from **the transport sector,** either for consumption in fuel cells, as intermediary feedstock for the production of synthetic fuels, or for use in biorefineries. **By 2050, demand for hydrogen for e-fuels reaches around 20 Mt, with the majority being used in the transport sector and especially aviation.**
CSIR Renewable Hydrogen Generation and Transport Costs	CSIR	This report looks at a complete bottom-up landed cost of GH produced in South Africa and landing in Japan across different technology pathways and different vectors of hydrogen.

Study	Author	Key Points
		It demonstrated that based on similar input costs, the landed cost for a kilogram of ammonia in Kobe, Japan (from a hybrid RE production source and including shipping costs), considering all value chain costs are currently at $4/kg H2 component cost and is expected to decline to $2.45/kg in 2050 for H2 generated from low-temperature electrolysis. PEM is a low-temperature electrolysis technology. Under the same assumptions and business case, H2 in GH based ammonia can be landed at a H2 cost of $3.7/kg in 2020 and is expected to decline to $2.4/kg of H2 in 2050 for high-temperature electrolysis technologies.
McKinsey Hydrogen Insights 2021	McKinsey	The McKinsey Report summarises activities across the word across the value chain: • At the beginning **of 2021, over 30 countries have released hydrogen roadmaps**, the industry has announced more than **200 hydrogen projects** and ambitious investment plans, and **governments worldwide have committed more than USD 70 billion in public funding.** • 85% of global projects originating in Europe, Asia, and Australia, and activity in the Americas, the Middle East and North Africa accelerating as well. • If all projects come to fruition, **total investments will exceed USD 300 billion** in hydrogen spending through 2030 – the equivalent of 1.4% of global energy funding. This means new renewable and grey hydrogen supply could hit cost parity in the best regions by 2028, and between 2032 and 2034 in average regions. • We see **several cluster types gaining traction**, including: — Port areas for fuel bunkering, port logistics, and transportation — Industrial centres that support refining, power generation, and fertilizer and steel production — Export hubs in resource-rich countries • Successful clusters will likely **involve players along the entire value chain to optimize costs**, tap into multiple revenue streams and maximize the utilization of shared assets. They should be open to additional players

Study	Author	Key Points
		and infrastructure should allow for ready access where possible
Basic Hydrogen Strategy METI-Japan	METI	The short report highlights the need for Hydrogen in Japan, its significance and importance. It then highlights key next steps for realising a hydrogen-based society: • Realising low-cost hydrogen use • Developing international hydrogen supply chains • Renewable energy expansion in Japan and regional revitalisation • Utilising regional resources and regional revitalisation • Potential hydrogen uses in industrial process and heat utilisation • Utilisation of fuel cell technology • Utilising innovative technologies • International expansion • Promoting citizens understanding and regional cooperation
XODUS the UK Hydrogen Centre	XODUS	This report explores the UKs potential in the green and blue hydrogen space. The report outlines their advantages and advancements in CCUS technology making blue hydrogen a viable option. The report explores GH production, transportation and potential for pipelines. The report also covers the UKs risks and opportunities and outlines a way forward.
PwC Thought Leadership-Unlocking H2 Potential	PwC	This PwC thought leadership outlines the five challenges for decarbonisation and the role that hydrogen can play to bridge those gaps: • Renewable energy variation • Transportation of energy • Grid buffering • Difficult to electrify sectors • Industrial and chemical processes The report also highlights the production of hydrogen, the application areas and opportunities for South Africa
StatsSA demand 2017	StatsSA	The team looked for a baseline on local hydrogen demand. The StatsSA Report combines several gases together and only reports on the R'000 value of the group as of 2017: • Hydrogen, nitrogen, oxygen, carbon dioxide and rare gases, inorganic oxygen compounds of non-metals- 5 520 454

Study	Author	Key Points
TIPS- Hydrogen as an export commodity	Trade and Industrial Policy Strategies- Muhammed Patel	The TIPS report outlines many of the same themes as the interim report • Methodology of hydrogen production • Hydrogen uses • Electrolysis technology • Historic demand • Hydrogen activity in SA • SA Competitive Advantage • More detailed review on SAF
Enertrag Presentation	Enertrag	This report outlines the global demand for fertilizer, shipping fuel, aviation fuel and green steel and the demand for hydrogen for the production of each of these end-uses. The report also outlines the percentage market share SA could take up in each of these sectors. €8 bn/a export potential for fertilizer, €25 bn/for shipping fuel, €50 bn/for aviation fuel and €bn/for green steel.
Unlocking Australia's hydrogen opportunity	Australian Hydrogen Council	This report focussed on Australia's domestic production and demand for GH. The report covers the following: • **the scale of assets and infrastructure required to meet Australia's hydrogen objectives**, finding that the task ahead will need whole-of-economy planning that addresses multiple hydrogen production, delivery and use pathways, and encourages co-location of projects. In this chapter we argue that policy and funding should prioritise the demand side, and demand for harder to abate applications with opportunities to build scale should take precedence. • the need to consider **how we can reuse existing gas infrastructure** to get to scale, noting that we need to be careful to plan for the economic lives of assets already in the ground to support energy affordability for consumers. **Hydrogen also creates 'sector coupling' opportunities.** We also address the relatively easy way that demand can be stimulated by implementing a 10 per cent target for **hydrogen to be blended into the natural gas system.**

Study	Author	Key Points
		• **a key demand to be served, and one that we suggest is no regrets: heavy road transport**. Diesel is already close to price parity with hydrogen, and heavy transport is also hard to abate with electricity and batteries. The problem with this market is that the refuelling infrastructure isn't in place and the vehicles are not yet in the country. In this chapter we recommend a programme of heavy and lighter truck (and bus) trials that will start the necessary refuelling backbone. • the **second key set of markets for demand: manufacturing products that already use hydrogen as a feedstock or fuel**, and the use of hydrogen in new markets that can grow Australia's manufacturing capabilities. The markets identified here are iron and steel, ammonia, methanol, and alumina and aluminium. The report also makes a series of recommendations for the country to prioritise: • Plan in the national interest • Establish a net-zero fund • Prioritise hard to abate and scalable demand sources • Build sector-coupling into planning • Blend hydrogen into natural gas to create demand • Trial heavy transport
Copy of EE Webinar PwC Presentation	PwC	The PwC presentation at the EE Business Intelligence webinar covered the four elements of the economic value chain: 1. Unique SA opportunities (land, wind, solar, network and port capability- Need clear planning to leverage and optimise value 2. Common/global opportunities (equipment cost of wind, solar, electrolysers and desalination)- important to track trends and form partnerships 3. Enabling environment (utilisation of assets, logistics, policy, regulations, financing and managing risk)- state to create an enabling environment to incentivise private investment

Study	Author	Key Points
		4. Levelling the playing field (carbon tax regimes both global and domestic will enable the asset base shift)
Hydrogen FactBook Final	Kearney Energy Transition Institute	The report covers the following in technical detail (down to the chemical equations): • Role of H2 in the energy transition • H2 value chain, including different methods and technologies to produce H2 and the various transportation vectors • Key H2 applications including a deep dive into fuel cell technology and options • H2 business models mapping out the country-specific strategies and the integration of hydrogen into these economies
Commercialisation Roadmap Only	H2 Taranaki Roadmap	This was used for the format in which the roadmap is displayed
Conf. Africa H2 Partnership-Economic Impact on Africa	Siggi Huegemann, Co-founder of African Hydrogen Partnership	This presentation highlights the following: • Africa Trade Deficits and the potential to rebalance with hydrogen • Petrodollar and Persistent Deficits • Joint, Combined- Transformation, Relocation and Refinance • Benefits of Hydrogen
Conf. Africa H2 Partnership	Siggi Huegemann, Co-founder of African Hydrogen Partnership	This presentation covers: • African Hydrogen Partnership (AHP) Initiative • Challenges, Leapfrogging, Opportunities • Africa: Low-cost hydrogen and abundant resources • Infrastructure development • Hydrogen landing zones
IEA The Future of Hydrogen Part 1 and 2	IEA	This is a very holistic report covering the following topics: • Production of hydrogen and hydrogen-based products • Storage, transmission and distribution of hydrogen • Present and potential industrial uses of hydrogen • Opportunities for hydrogen n transport, buildings and power • Policies to boost momentum in key value chains

Study	Author	Key Points
		The report also included a list of 7 key recommendations for upscaling hydrogen: • Establish a role for hydrogen in long-term energy strategies • Stimulate commercial demand for clean hydrogen. • Address investment risks of first movers. • Support R&D to bring down costs • Eliminate unnecessary regulatory barriers and harmonise standards. • Engage internationally and track progress. • Focus on four key opportunities to further increase momentum over the next decade.
IEA The Future of Hydrogen Assumptions Annex	IEA	This report supported the IEA The Future of Hydrogen Part 1 and 2 Report
IRENA Green Hydrogen Policy 2020	IRENA	This report outlined the status of hydrogen, its drivers and barriers. It also outlined the pillars for GH policy making: • National strategies • Establish policy priorities for GH • Guarantee of origin scheme • Governance system and enabling policies The report then outlines the supporting policies required for GH: • Support for electrolysis • Support for hydrogen infrastructure • Support for hydrogen in industrial applications • Support for synthetic fuels in aviation • Support for hydrogen use in maritime shipping
REGEN Hydrogen Insight Paper v4	REGEN	This report focuses on the critical role that hydrogen can play in the UK economy. It highlights a success criterion for sector intervention: • It must be very low carbon – there is no case for policies that might continue the production of high carbon grey hydrogen, or inefficient production processes that are not compatible with a net zero energy future17. • It needs to scale up quickly, to drive down costs and open new markets, but not to embed incumbents with less efficient solutions or at a pace that creates market volatility.

Study	Author	Key Points
		• It needs to support on-going innovation and create opportunities for new disruptive solutions to replace older technology. • It should be market value and consumer led, encouraging investment where there is inherent customer value. • It should be competitive, avoiding the creation of new monopolies or incumbent-dominated markets. • It should be strategic. Interventions should support the UK's long-term energy strategy. For example, allowing GH to play a multi-vector role to support higher levels of renewable electricity and offshore wind. • It should create economic value, including long-term employment, skills, and export opportunities for UK businesses. • Interventions should be clear, manageable, and sustainable in terms of levy budget control, consumer or taxpayer value and the political support that follows. Policies that break budgets or lead to runaway boom and bust cycles should be avoided.
Green H2 opportunity in SA	Independent Research Report	This report is key to the demand section of this strategy and outcomes are discussed within the report. The report also investigates three different archetypes of production: 1. Colocation of production and demand 2. Decentralising RE and Electrolyser 3. Decentralise the RE and collocate electrolyser with demand node

Table A.2: Supporting Literature for the Report

Supporting Literature for the Report	
South African Hydrogen Valley	Prepared for the South African Dept of Science and Innovation by Engie Impact (2021)
Africa's green manufacturing crossroads - Choices for a low carbon industrial future	McKinsey & Company (2021)
Global Hydrogen Review	IEA (2021)
National Green Hydrogen Strategy Chile	Gobierno de Chile (2020)
Sasol Limited Climate Change Report	Sasol Limited (2021)
Development of Water Electrolysis in the European Union	Bertuccioli, et al (2014)
The Rise of Hydrogen: Policy, Practice and Projects	Baker McKensie (2020)
Roadmap for the establishment of a well-functioning EU hydrogen GO system	CertifHy (2016)
Hydrogen Program Plan	USA DoE (2020)
Commercialisation Strategy for Fuel Cell Electric Buses in Europe	The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) (2015)
How hydrogen empowers the energy transition	Hydrogen Council January 2017
Hydrogen Scaling Up	Hydrogen Council 2017
Path to hydrogen competitiveness: A cost perspective	Hydrogen Council 2020
ROAD MAP TO A US HYDROGEN ECONOMY	Fuel Cell & Hydrogen Energy Association
Renewable power generation costs in 2020	IRENA
Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolysers	Mayyas, et al. 2019
GREEN HYDROGEN COST REDUCTION, Scaling up electrolysers to meet the 1.5oC climate goal 2020	IRENA

Supporting Literature for the Report	
Assessment of Hydrogen Production Costs from Electrolysis: United States and Europe	CHRISTENSEN, 2020
European Hydrogen Backbone	Enagás, Energinet, Fluxys Belgium,Gasunie, GRTgaz, NET4GAS, OGE,ONTRAS, Snam, Swedegas, Teréga
Green Hydrogen Value Chain Analysis - IDC R&I (16 March 2021) FINAL EXTERNAL	IDC
Hydrogen Markets Study 1 November	US Trade and Development Agency
IDC Clean Energy Objective 5 3 Hydrogen Storage Study	US Trade and Development Agency
IRENA Green Hydrogen Cost 2020	IRENA
IRENA Green Hydrogen Supply 2021	IRENA
Path to Hydrogen Competitiveness Full Study	Hydrogen Council
Presentation Dr Kgosientso Ramogopa	Infrastructure South Africa
South Africa fuelling the future of shipping	By Ricardo & Environmental Defence Fund
Offshore Wind Energy – Journal of Energy in Southern Africa	Gordon Rae *, Gareth Erfort Department of Mechanical and Mechatronic Engineering, Stellenbosch University
European Hydrogen Backbone	Enagás, Energinet, Fluxys Belgium,Gasunie, GRTgaz, NET4GAS, OGE,ONTRAS, Snam, Swedegas, Teréga

9. Appendix B: Work Package 2 - Hydrogen Demand and Supply Estimation and Benchmarking

Overview of hydrogen and ammonia demand today

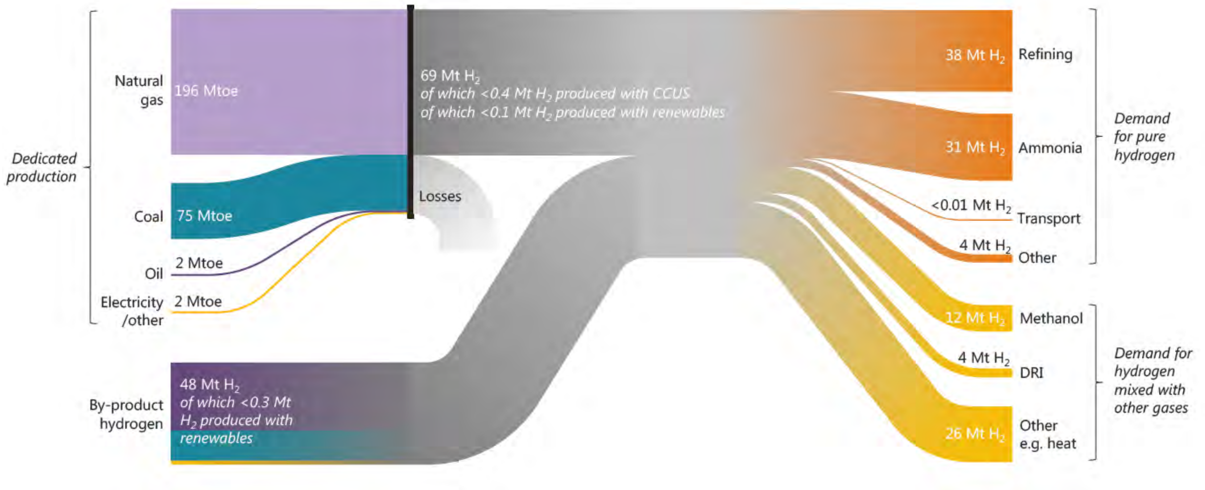


Figure B.1: Hydrogen and Use Cases

In 2020, demand for hydrogen was 90 Million tonnes (Mt), mainly produced from fossil fuels (mostly natural gas) and emitting close to 900 Mt CO_2. This worldwide demand is for “pure” hydrogen, with “pure” meaning that the specific applications require hydrogen with only small levels of additives or contaminants tolerated (Figure B.1). The main applications for this hydrogen are oil refining and ammonia production, mainly for fertilisers. A further 45 Mt of demand exists for hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock. The main applications for hydrogen as part of a mixture of gases are methanol production and steel production. While one-third of hydrogen demand today is for transport sector applications in a broad sense – in refineries and for methanol used in vehicle fuel – less than 0.01 Mt per year of pure hydrogen (less than 0.03 Million tonnes of oil equivalent, Mtoe) is used in FCEVs, most of which is derived from natural gas.

The overwhelming majority of hydrogen produced today is from fossil fuels, and around 60% of it is produced in “dedicated” hydrogen production facilities, meaning that hydrogen is their primary product. Most of this is produced from natural gas, though some comes from coal, and a small fraction comes from water electrolysis (a process that produces hydrogen from water and electricity).

One-third of global supply is “by-product” hydrogen, meaning that it comes from facilities and processes designed primarily to produce something else. This by-product hydrogen often needs dehydrating or other types of cleaning, and can then be sent to a variety of hydrogen-using processes and facilities. Most hydrogen is currently produced near to its end use, using resources extracted in the same country.

Overall, less than 0.7% of current hydrogen production is from renewables or from fossil fuel plants equipped with Carbon Capture Utilisation and Storage (CCUS). In total, hydrogen production, which is mainly blue and grey hydrogen, today is responsible for 830 Mt CO_2/yr.

Trading of hydrogen and ammonia today

In order to assess the future markets for hydrogen and ammonia, data on current hydrogen and ammonia production and trading was sourced and analysed.

The current market for the export of hydrogen is small. In 2019, the top 10 exporting countries exported ~85 kt (kt) (Figure B.2) of hydrogen and just two countries make up 82% of the total imported hydrogen at ~70 kt. The top 10 importing countries imported ~56 kt (Figure B.3) of hydrogen and the EU and USA make up 93% of the total imported hydrogen at ~54 kt. These numbers reflect the current use cases for hydrogen as an industrial gas and not the energy vector that it will become over the next few years as the global economy transitions to lower carbon alternatives. It must also be noted that international trade in energy products takes time to develop, with the Liquified Natural Gas (LNG) market taking a period of 30 years to reach the scale as Qatar and Australia became large-scale exporters of LNG. To date there has been no trade in hydrogen using a vessel dedicated to shipments of pure hydrogen.

Figure B.2: 2019 - Hydrogen Exports by Country (top 10) – kt

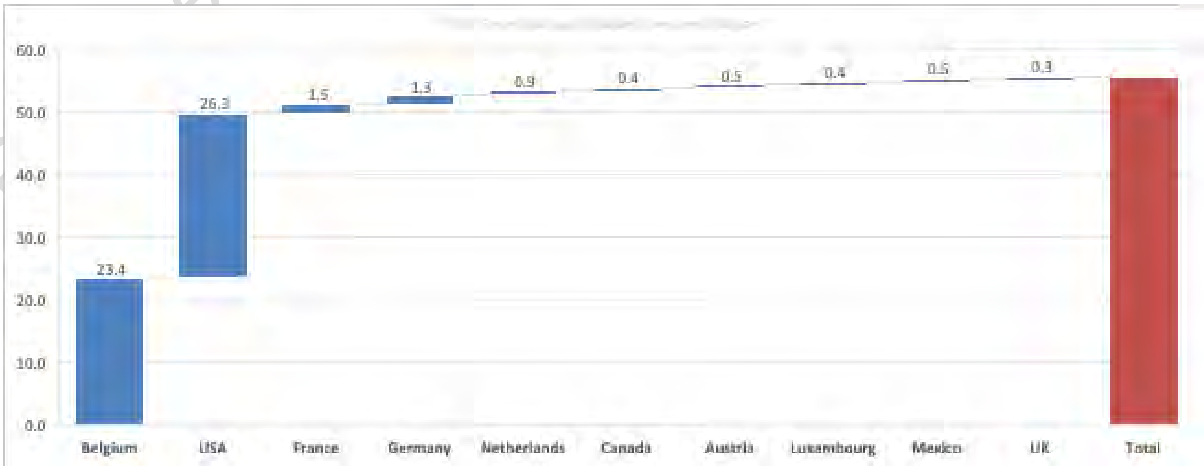


Figure B.3: 2019 - Hydrogen Imports by Country (top 10) – kt

The international market for ammonia is well developed, having commenced international trading as early as the 1960s. In 2019, the top 10 exporting countries exported ~14 Mt of ammonia containing ~2.5 Mt of hydrogen (Figure B.4) and the top 10 importing countries imported ~16 Mt ammonia containing ~2.8 Mt of hydrogen (Figure B.5). Total global trade in ammonia is ~16.9 Mt of ammonia containing ~ 3 Mt of hydrogen. Exports are dominated by Saudi Arabia and the Russian Federation, which make up ~66% of the total exports. Imports are dominated by the EU, India, USA and South Korea. The current EU demand makes up ~29% or ~4.6 Mt of ammonia containing ~ 0.8 Mt of hydrogen. These numbers reflect the current use cases for ammonia as an industrial chemical and not the energy carrier and director energy vector that it will become over the next few years as the global economy transitions to lower carbon alternatives. The maritime industry sees ammonia as pivotal to achieving decarbonisation targets, replacing diesel, heavy fuel oil and other carbon-based fuels.

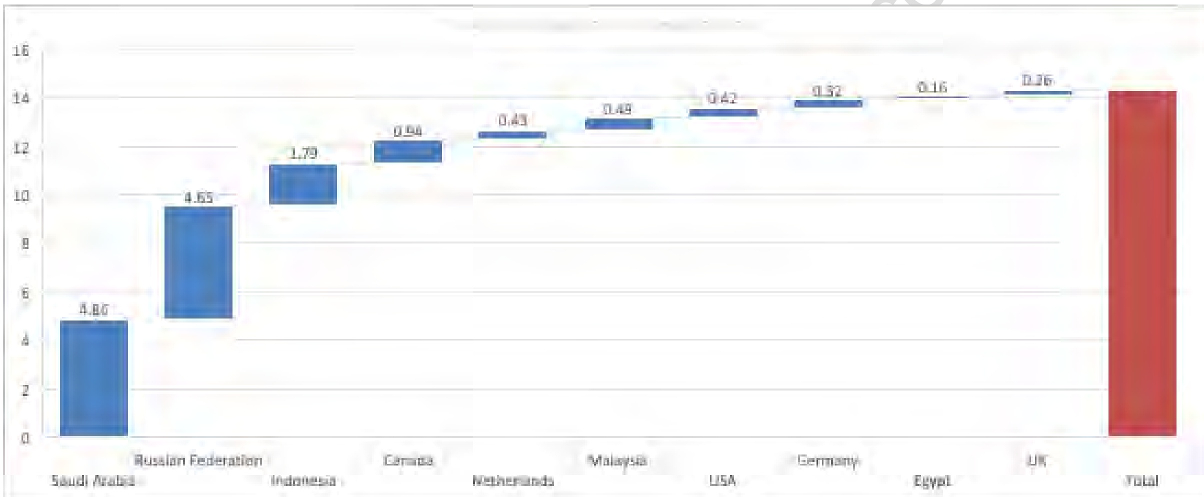


Figure B.4: 2019 - Ammonia Exports by Country (top 10) – Mt

Figure B.5: 2019 - Ammonia Imports by Country (top 10) – Mt

Export demand drivers

The size range for the import market will be between 18 and 27 Mt of GH, refer to Figure B.6.

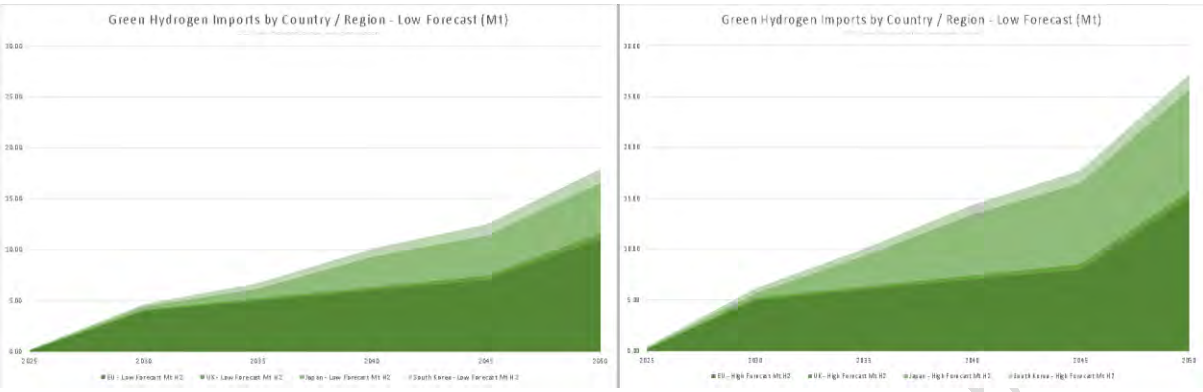


Figure B.6: Import Market Size Range (low and High) – 2025 to 2050

The demand profiles of the countries from 2025 to 2050 in five-year increments are presented in Figures B.7 and B.8.

GH costs will evolve over time as countries implement pilot projects followed by large scale projects to gain practical experience and capitalise on efficiencies through learning curves and scale effects on production equipment, such as electrolysers. Refer to Figures B.9 and B.10.

To supply the demand of between 18 and 27 Mt of GH in 2050, and assuming that all logistics will be undertaken with ammonia, the total investment required by all countries will be between US$0.5 to $0.8 trillion to 2050 based on a declining cost curve, which reflects learning rates for renewable energy (wind, solar), hydrogen and ammonia production (electrolysers and balance of plant) and transmission infrastructure. In 2021 money terms and costs, the installed costs total between $0.7 and $1.2 trillion to 2050. To supply the 2025 target of 200 to 400 kt of GH will require between $15 and $31 billion by 2025. Refer to Table B.1.

All exporting countries will need to make significant investments to meet the import demand.

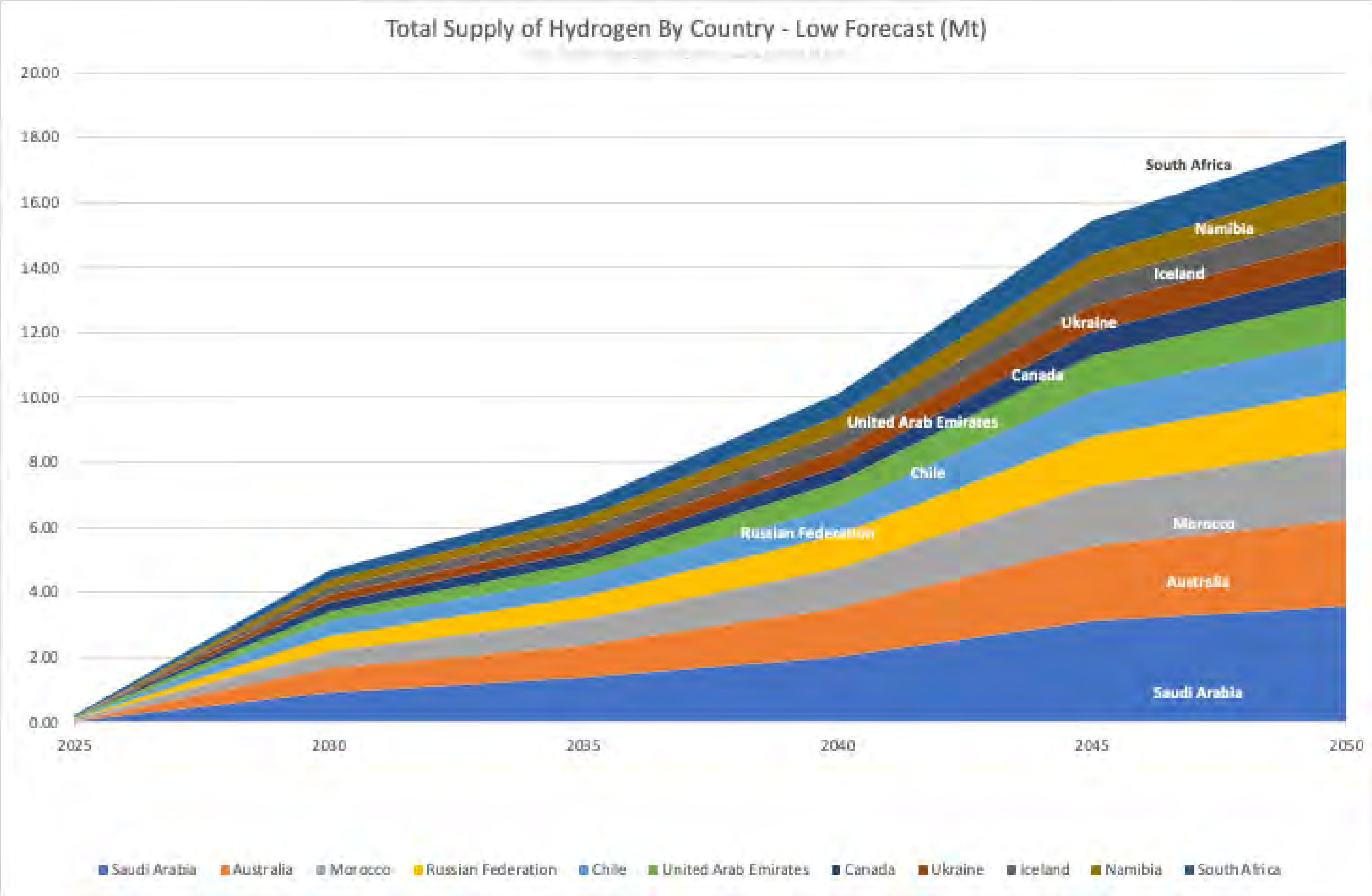


Figure B.7: Total Supply of Hydrogen By Country - Low Forecast (Mt)

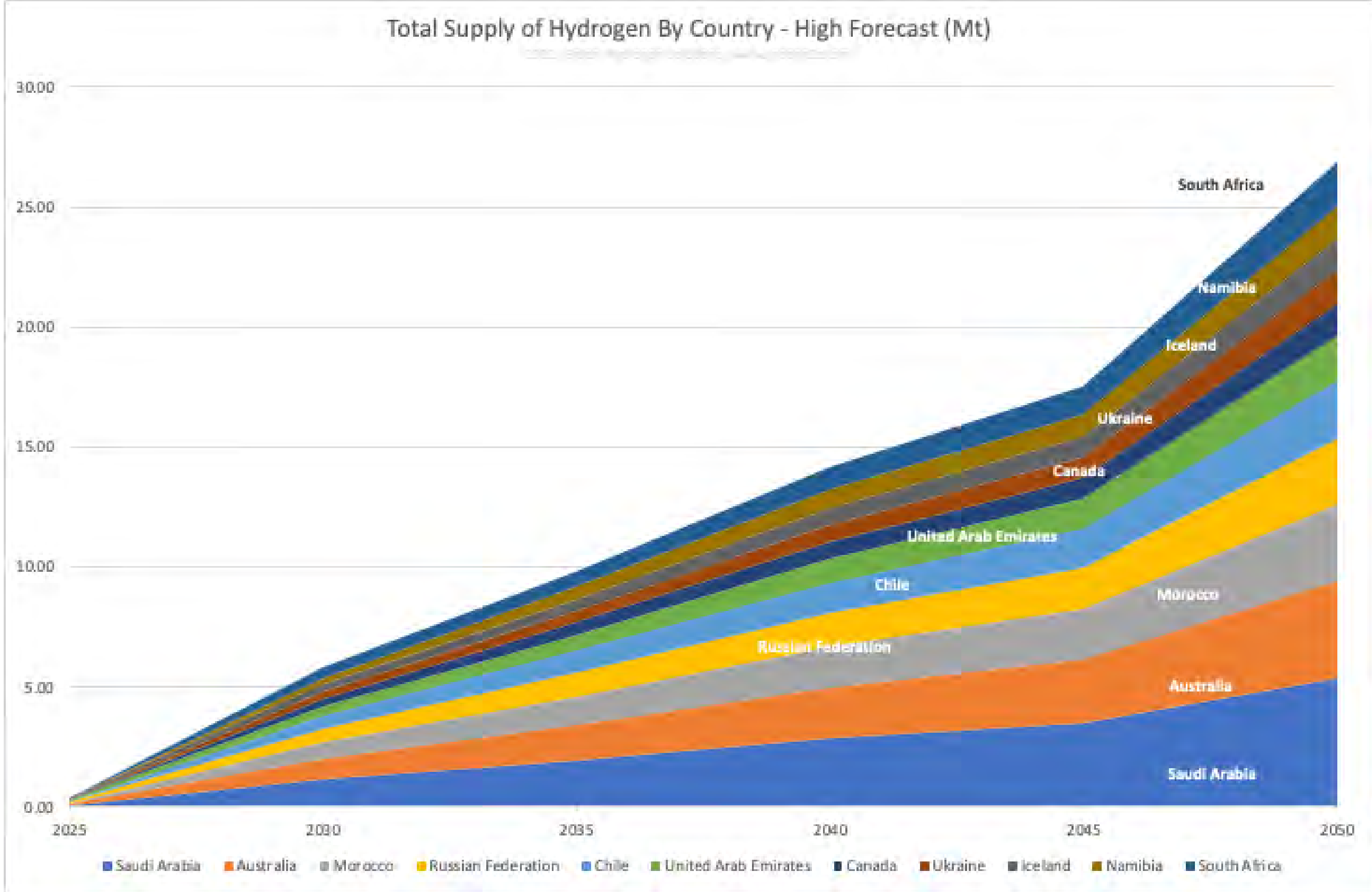


Figure B.8: Total Supply of Hydrogen By Country - Low Forecast (Mt)

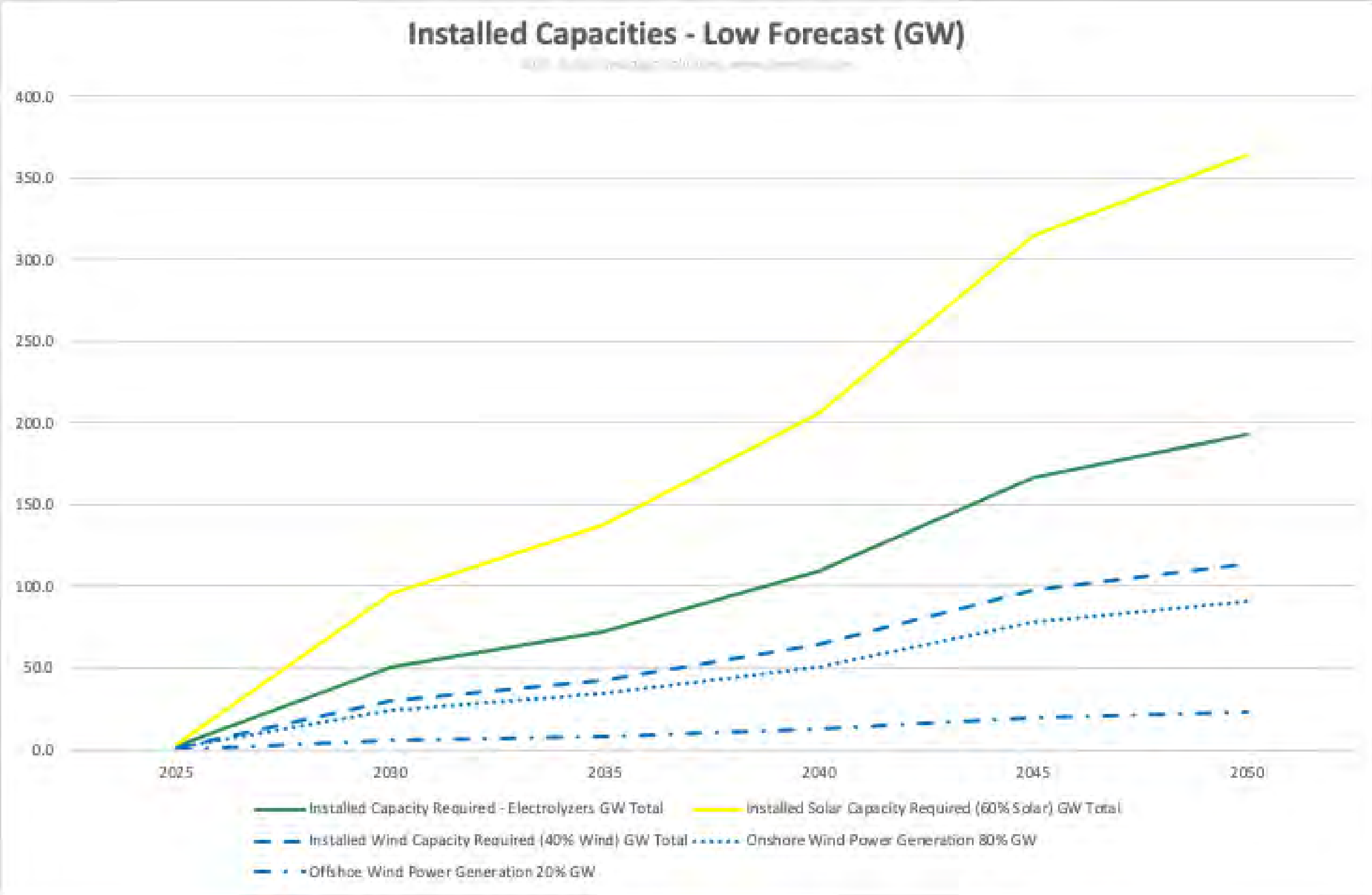


Figure B.9: Global Installed Capacities - Low Forecast (GW)

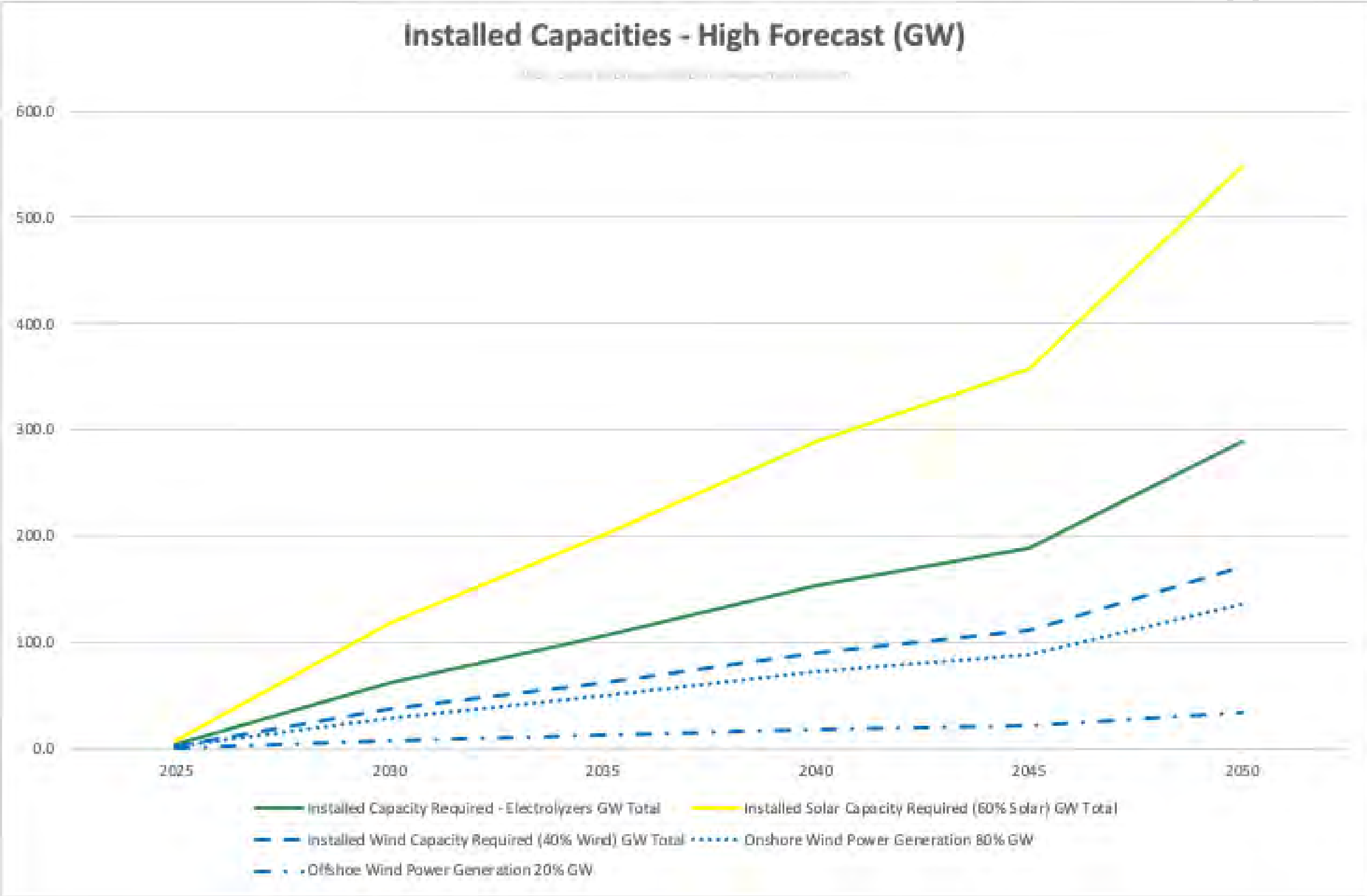


Figure B.10: Global Installed Capacities – High Forecast (GW)

Table B.1: Global Installed Costs Required to Meet Demand

INSTALLED COSTS BUILD-UP (CAPEX) - 2021 Terms		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Electrolysis and Balance of Plant	$/kW	740	888	650	780	480	576	360	432	270	324	200	240		
Electrolysis and Balance of Plant	$ B	1.6	3.8	31.5	45.3	10.6	25.1	13.0	20.2	15.5	11.7	5.3	24.2	**77**	**130**
Installed Cost - Solar	$/kW	696	766	592	651	503	553	428	470	363	400	309	340		
Installed Cost - Solar	$ B	2.8	6.2	54.2	71.6	21.0	45.6	29.2	41.7	39.6	27.3	15.4	64.7	**162**	**257**
Installed Cost - Wind	$/kW	1 606	1 767	1 365	1 502	1 160	1 276	986	1 085	838	922	713	784		
Installed Cost - Wind	$ B	2.0	4.5	38.9	51.3	15.1	32.7	20.9	29.9	28.4	19.6	11.1	46.4	**116**	**184**
Installed Cost - Ammonia	$ / t NH_3	994	1 094	900	990	850	935	800	880	706	776	588	647		
Installed Cost - Ammonia	$ B	1.1	2.5	22.9	30.2	9.8	21.4	15.1	21.6	21.3	14.7	8.1	34.2	**78**	**125**
Installed Cost - Transmission	$ M / km	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9		
Installed Cost - Transmission	$ B	7.0	13.5	6.6	12.7	6.2	12.0	5.8	11.3	5.5	10.6	5.1	10.0	**36**	**70**
Total Capex	$ B	15	31	154	211	63	137	84	125	110	84	45	179	**471**	**766**

Installed Costs are based on a declining cost curve, which reflects learning rates for renewable energy (wind, solar), hydrogen and ammonia production (electrolysers and balance of plant) and transmission infrastructure. In 2021 money terms, the installed costs total between $0.7 and $1.2 trillion.

Maritime demand for hydrogen and ammonia

Figure B.11 provides details of Maritime Demand for Hydrogen and Ammonia from 2025 to 2050.

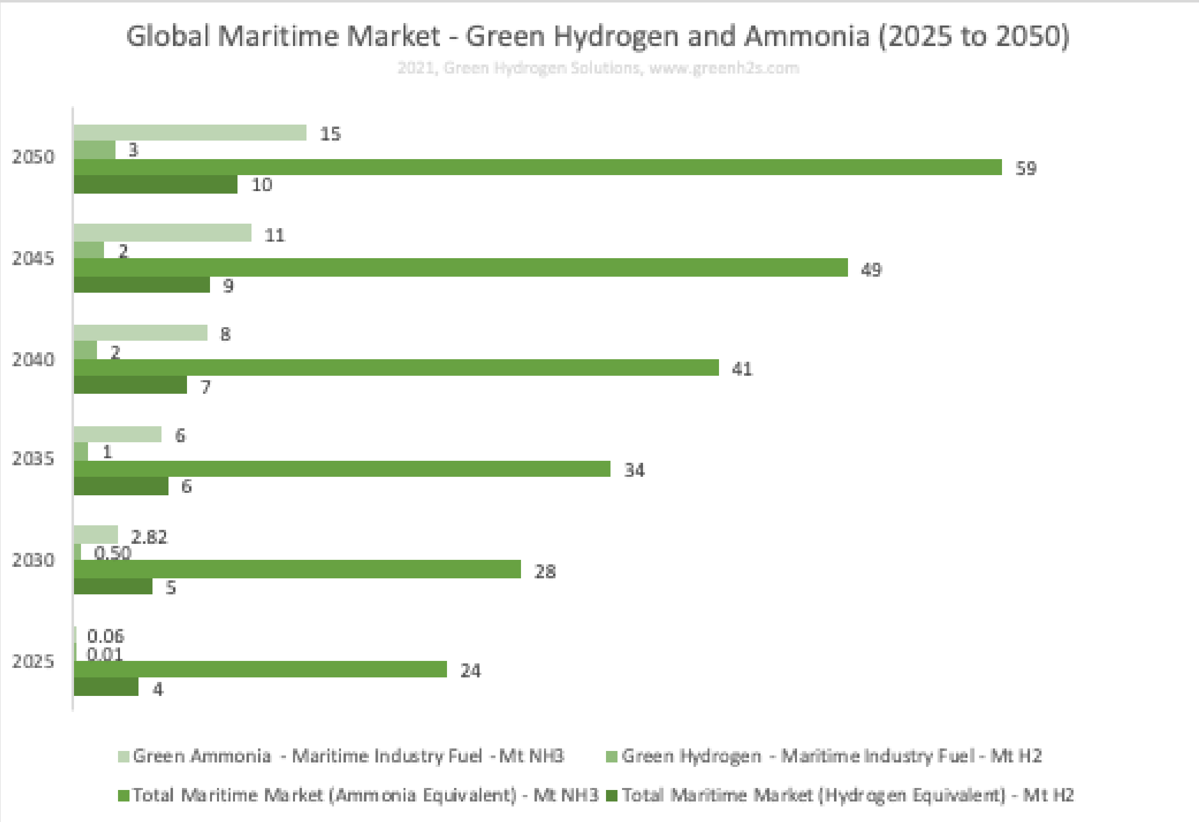


Figure B.11: Maritime Demand for Hydrogen / Ammonia – 2025 to 2050

South Africa key statistics

GH costs will evolve over time as South Africa implements pilot projects followed by large scale projects to gain practical experience and capitalise on efficiencies through learning curves and scale effects on production equipment, such as electrolysers. To supply 1.7 to 2.2 Mt of GH (Figures B.13 TO B.16) for the domestic market will require a total investment between US$68 to $100 billion (R1.0 to 1.5 trillion) to 2050 based on a declining cost curve, which reflects learning rates for capital equipment (US$82 to $122 billion or R1.2 to 1.8 trillion in 2021 money terms and costs). Refer to Table B.2 and B.3.

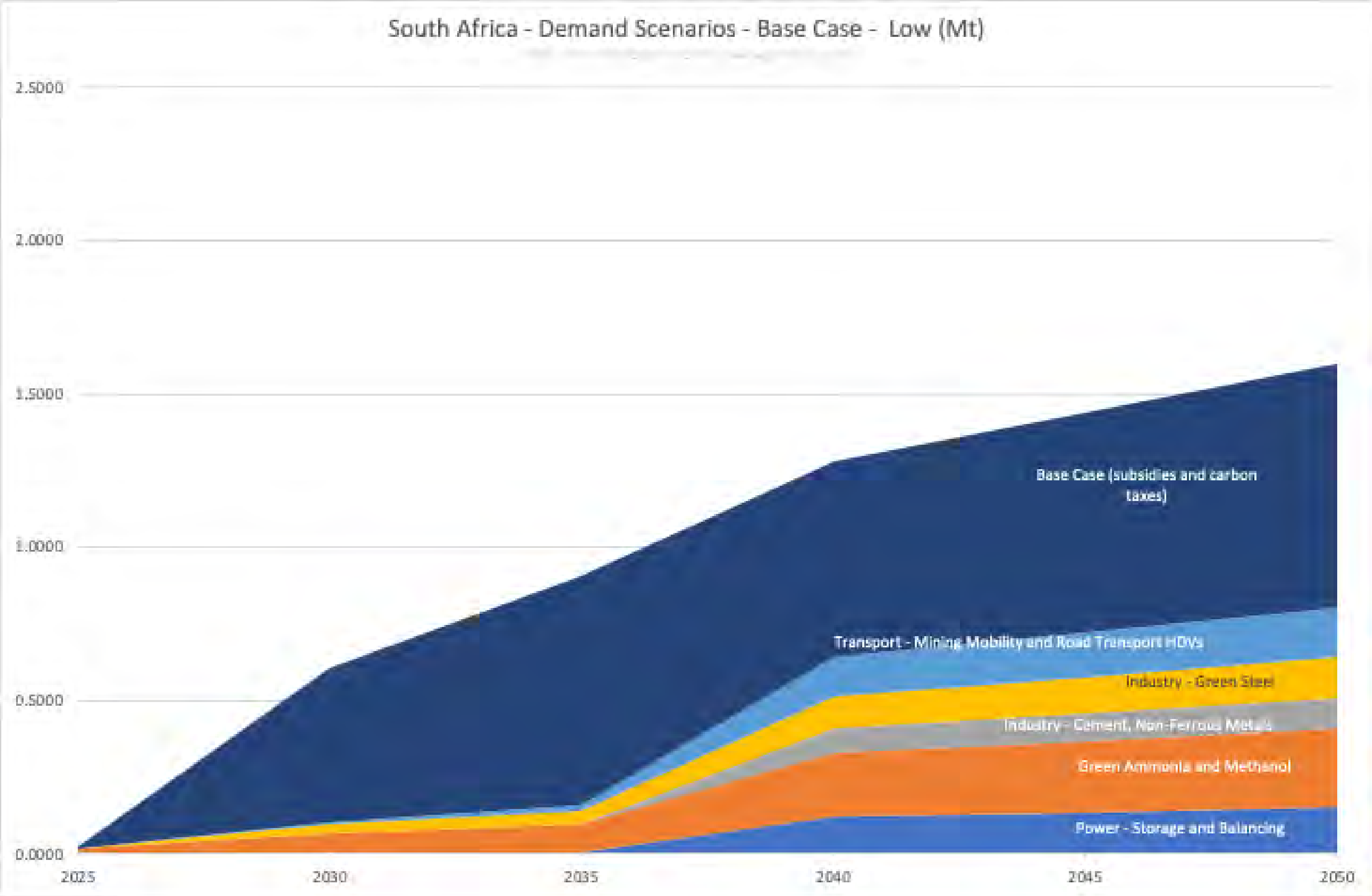


Figure B.13: South Africa Domestic Demand Scenario – Base Case – Low

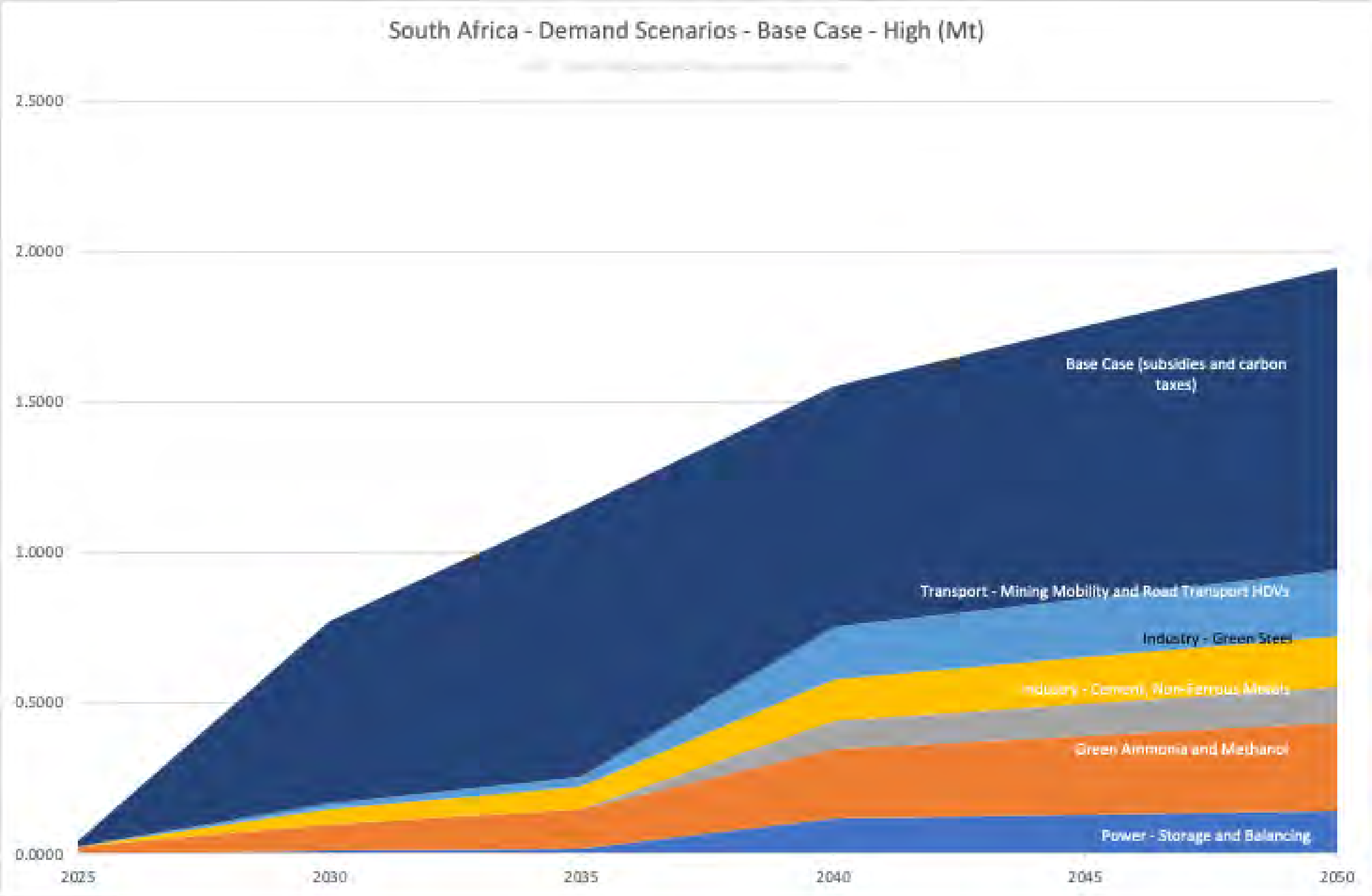


Figure B.14: South Africa Domestic Demand Scenario – Base Case - High

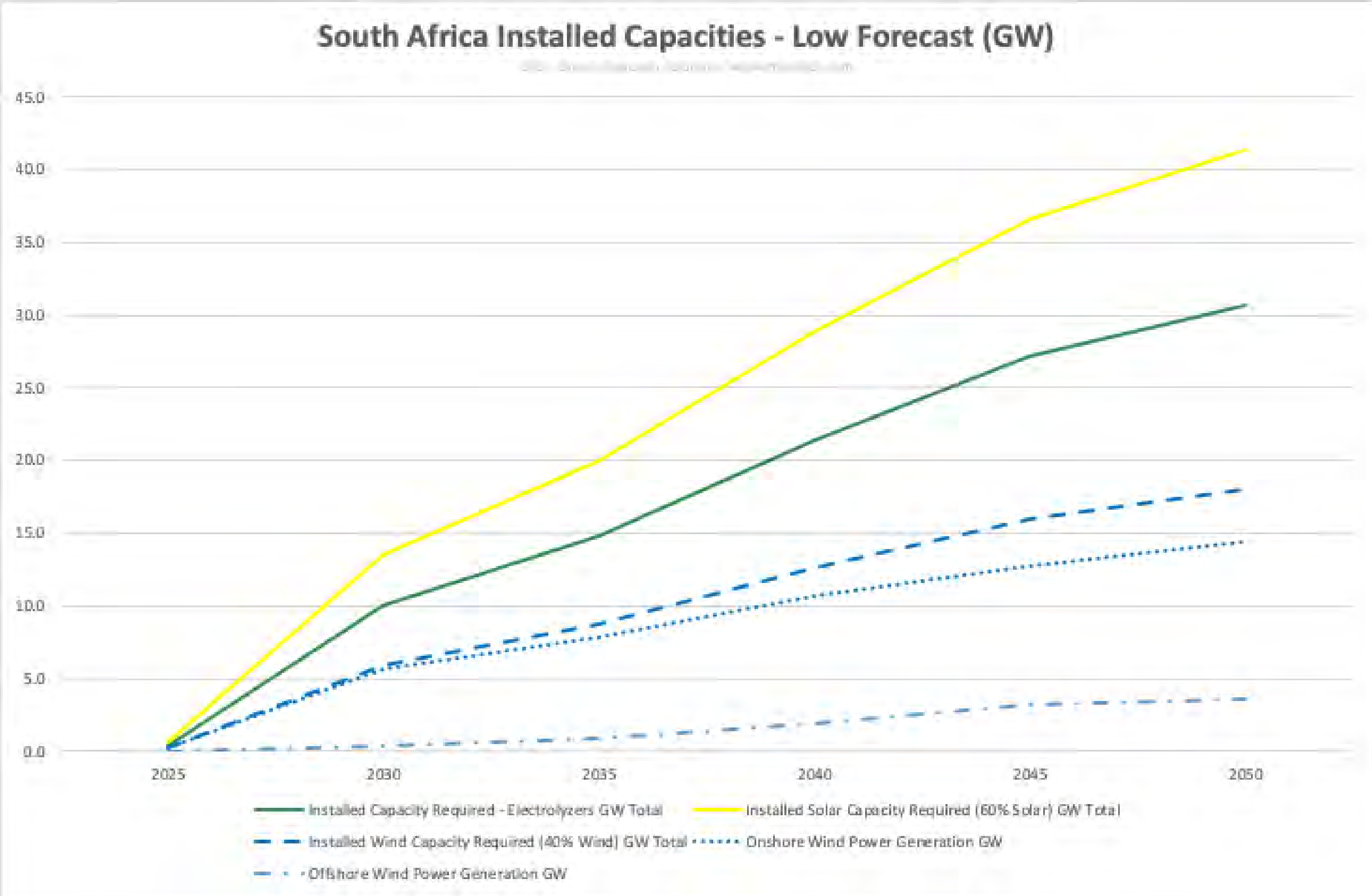


Figure B.15: South Africa Installed Capacities – Base Case – Lo

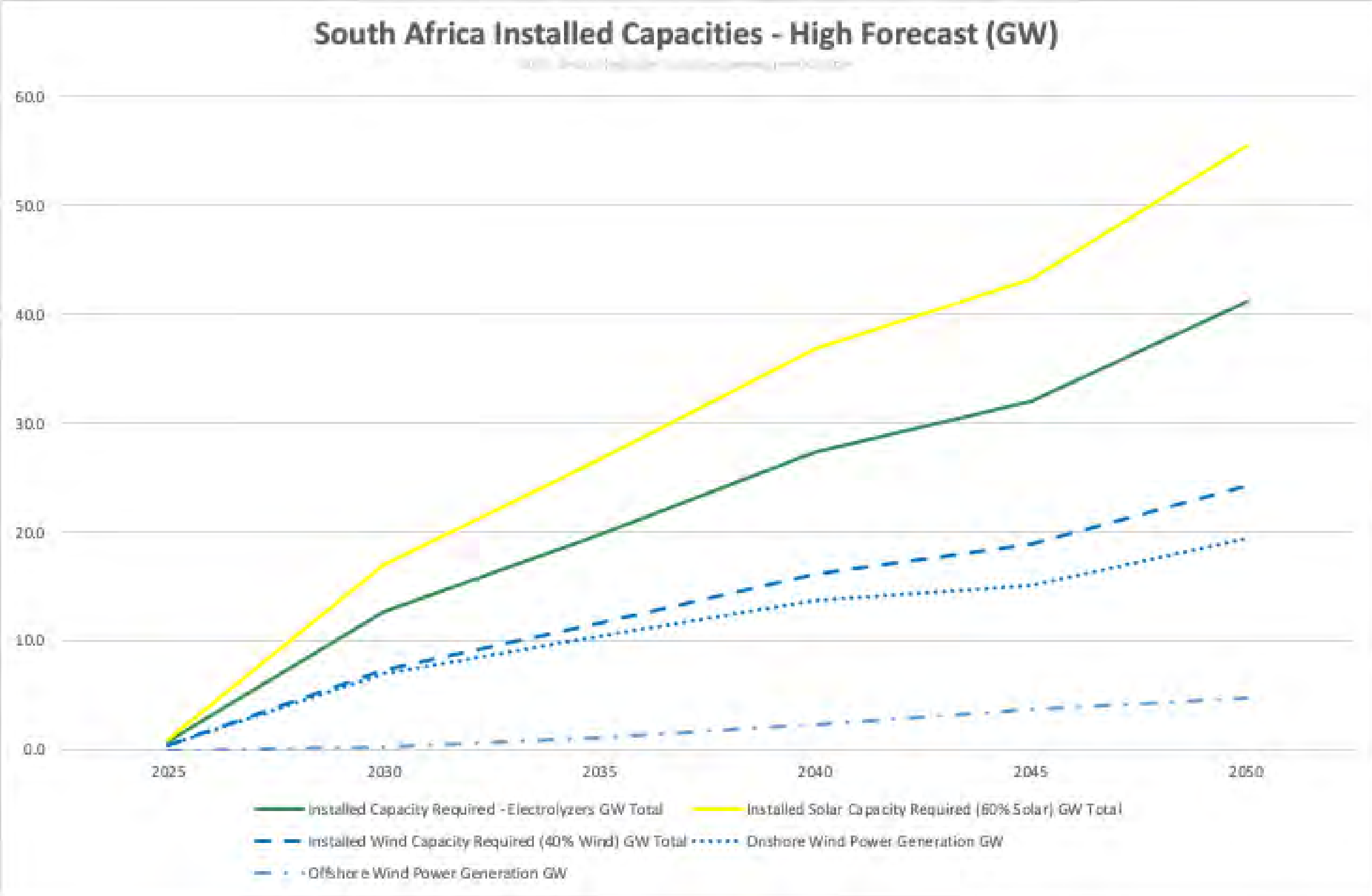


Figure B.16: South Africa Installed Capacities – Base Case – High

Table B.2: South Africa – Installed Costs Required to Meet Demand – US$

DOLLAR CAPITAL COSTS 2021, Green Hydrogen Solutions	www.greenh2s.com	2025		2030		2035		2040		2045		2050		Total	
INSTALLED COSTS BUILD-UP (CAPEX) - 2021 Terms		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Electrolysis and Balance of Plant	$/kW	740	888	650	780	480	576	360	432	270	324	200	240		
Electrolysis and Balance of Plant	$ B	0.3	0.7	6.3	9.3	2.3	4.1	2.4	3.3	1.6	1.5	0.7	2.2	**13**	**21**
Installed Cost - Solar	$/kW	696	766	592	651	503	553	428	470	363	400	309	340		
Installed Cost - Solar	$ B	0.4	0.8	7.7	10.4	3.3	5.4	3.8	4.8	2.8	2.5	1.5	4.2	**19**	**28**
Installed Cost - Wind	$/kW	1 606	1 767	1 365	1 502	1 160	1 276	986	1 085	838	922	713	784		
Installed Cost - Wind	$ B	0.4	0.8	7.7	10.5	3.3	5.4	3.8	4.8	2.8	2.5	1.5	4.2	**20**	**28**
Installed Cost - Ammonia	$ / t NH_3	994	994	900	900	850	850	800	800	706	706	588	588		
Installed Cost - Ammonia	$ B	0.1	0.2	1.7	2.1	0.8	1.5	1.3	1.6	1.5	1.0	0.6	2.2	**6**	**9**
Installed Cost - Transmission	$ M / km	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9		
Installed Cost - Transmission	$ B	1.8	3.4	1.7	3.2	1.6	3.0	1.5	1.4	1.4	1.3	1.3	1.3	**9**	**14**
Total Capex	$ B	3	6	25	36	11	19	13	16	10	9	6	14	**68**	**100**

Installed Costs are based on a declining cost curve, which reflects learning rates for renewable energy (wind, solar), hydrogen and ammonia production (electrolysers and balance of plant) and transmission infrastructure. In 2021 money terms, the installed costs total between $82 and $122 billion for 1.7 to 2.2 Mt per year.

Table B.3: South Africa – Installed Costs Required to Meet Demand – R

RAND CAPITAL COSTS 2021, Green Hydrogen Solutions	www.greenh2s.com	2025		2030		2035		2040		2045		2050		Total	
INSTALLED COSTS BUILD-UP (CAPEX) - 2021 Terms		**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Electrolysis and Balance of Plant	**R/kW**	11 008	13 209	9 669	11 603	7 140	8 568	5 355	6 426	4 016	4 820	2 975	3 570		
Electrolysis and Balance of Plant	**R B**	4.6	10.0	93.1	138.0	34.3	61.6	35.0	48.7	23.1	22.2	10.6	32.6	**201**	**313**
Installed Cost - Solar	**R/kW**	10 357	11 393	8 804	9 684	7 483	8 231	6 361	6 997	5 407	5 947	4 596	5 055		
Installed Cost - Solar	**R B**	5.9	11.6	114.2	155.1	48.4	79.7	55.9	71.4	41.9	37.0	22.1	62.2	**288**	**417**
Installed Cost - Wind	**R/kW**	23 892	26 281	20 308	22 339	17 262	18 988	14 672	16 140	12 472	13 719	10 601	11 661		
Installed Cost - Wind	**R B**	5.9	11.7	115.1	156.3	48.7	80.4	56.4	72.0	42.2	37.3	22.2	62.7	**291**	**420**
Installed Cost - Ammonia	**R / t NH_3**	14 788	14 788	13 388	13 388	12 644	12 644	11 900	11 900	10 500	10 500	8 750	8 750		
Installed Cost - Ammonia	**R B**	1.8	3.3	25.5	31.1	11.3	21.9	19.7	23.7	23.0	14.8	9.1	33.1	**90**	**128**
Installed Cost - Transmission	**R M / km**	19	18	18	17	17	16	16	15	15	14	14	13		
Installed Cost - Transmission	**R B**	26.2	50.7	24.6	47.7	23.2	44.9	21.8	21.1	20.5	19.9	19.3	18.7	**135**	**203**
Total Capex	**R B**	44	87	372	528	166	289	189	237	151	131	83	209	**1 005**	**1 482**

Installed Costs are based on a declining cost curve, which reflects learning rates for renewable energy (wind, solar), hydrogen and ammonia production (electrolysers and balance of plant) and transmission infrastructure. In 2021 money terms, the installed costs total between R1.2 trillion and $1.8 trillion for 1.7 to 2.2 Mt per year.

10. Appendix C: Work Package 3 - Identification, and assessment of strategic hydrogen hubs

South Africa's Natural Endowments

South Africa possesses a unique combination of advantages which place it in a good position to enter the future global hydrogen market.

South Africa has ideal weather conditions for solar and wind generation, which are the renewable energy options typically deployed in GH production. High solar and wind availability factors increase the utilisation factors of the hydrogen electrolysers, ultimately lowering the cost of clean hydrogen production and make investments attractive to investors (Polity, 2019).

According to the CSIR, South Africa has excellent conditions for wind and solar energy, which can be generated and then stored using hydrogen as a medium. South Africa's combined solar and wind power could provide a hydrogen production capacity factor of almost 100% during daylight hours (Engineering News, 2019a). In the evening, wind generation could be harnessed to produce hydrogen at a capacity factor of about 30%, which exceeds the international norm of approximately 22% (Engineering News, 2019a).[9]

For details on South Africa's relative endowments of sun hours and wind hours refer to Figures C.1 to C.2.

South Africa can leverage its strategic location and infrastructure to access GH import markets and to accelerate the growth of use of GH in marine transport, refer to Figure C.3 indicating marine traffic in the Indian and Atlantic Oceans in proximity to South African waters.

South Africa has close proximity to platinum supplies, which can reduce the costs of transport and the other costs associated with importation of key materials. The proximity to platinum, which is an essential component of the PEM system, allows costs advantages to filter to the final hydrogen production price, increasing the competitiveness of South African GH. [10]

For details on South Africa's platinum endowment refer to Figure C.4.

[9] TIPS - GREEN HYDROGEN: A POTENTIAL EXPORT COMMODITY IN A NEW GLOBAL MARKETPLACE, November 2020

[10] TIPS - GREEN HYDROGEN: A POTENTIAL EXPORT COMMODITY IN A NEW GLOBAL MARKETPLACE, November 2020

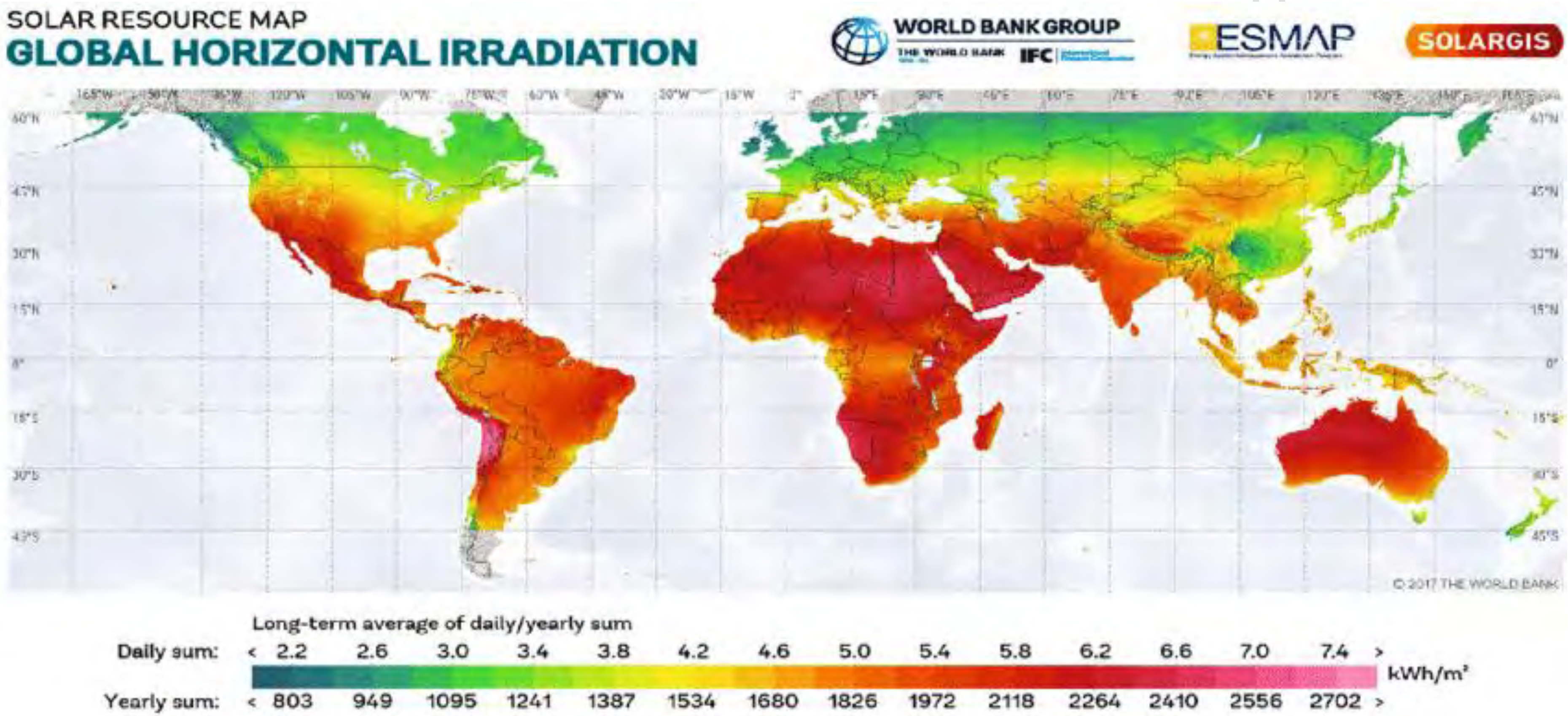


Figure C.1: South Africa – Relative Solar Resources

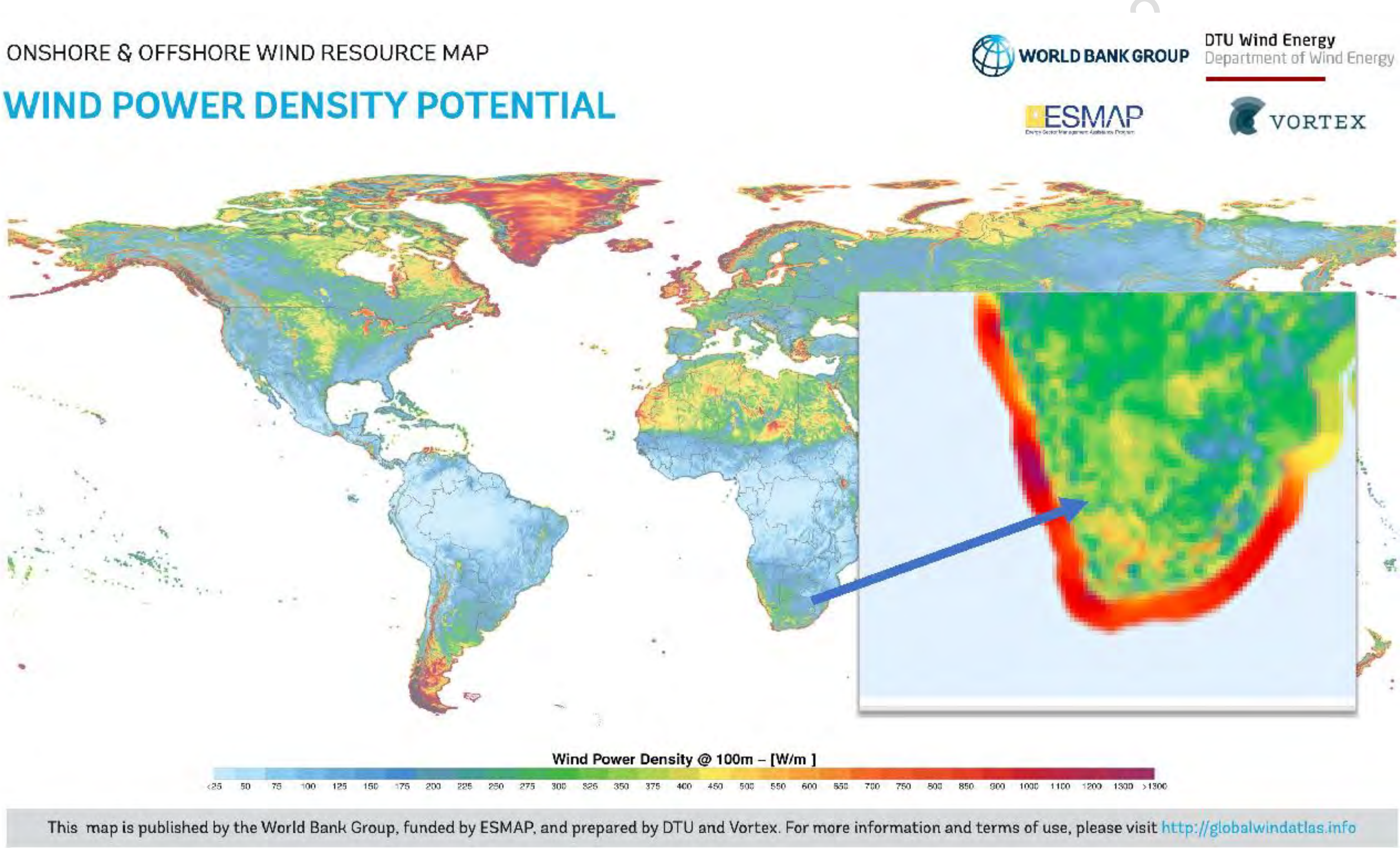


Figure C.2: South Africa – Relative Wind Resources

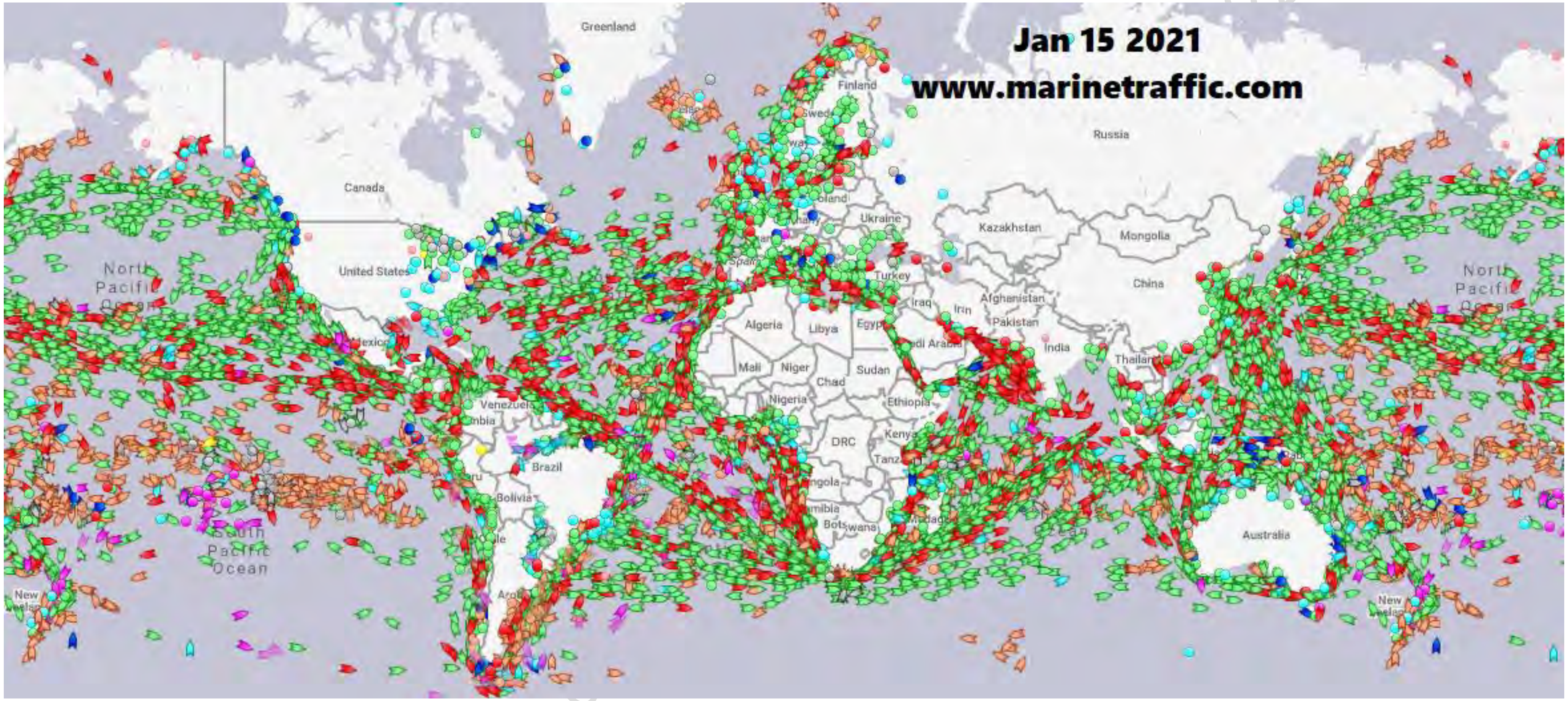


Figure C.3: South Africa – Ocean Resources and Shipping Traffic

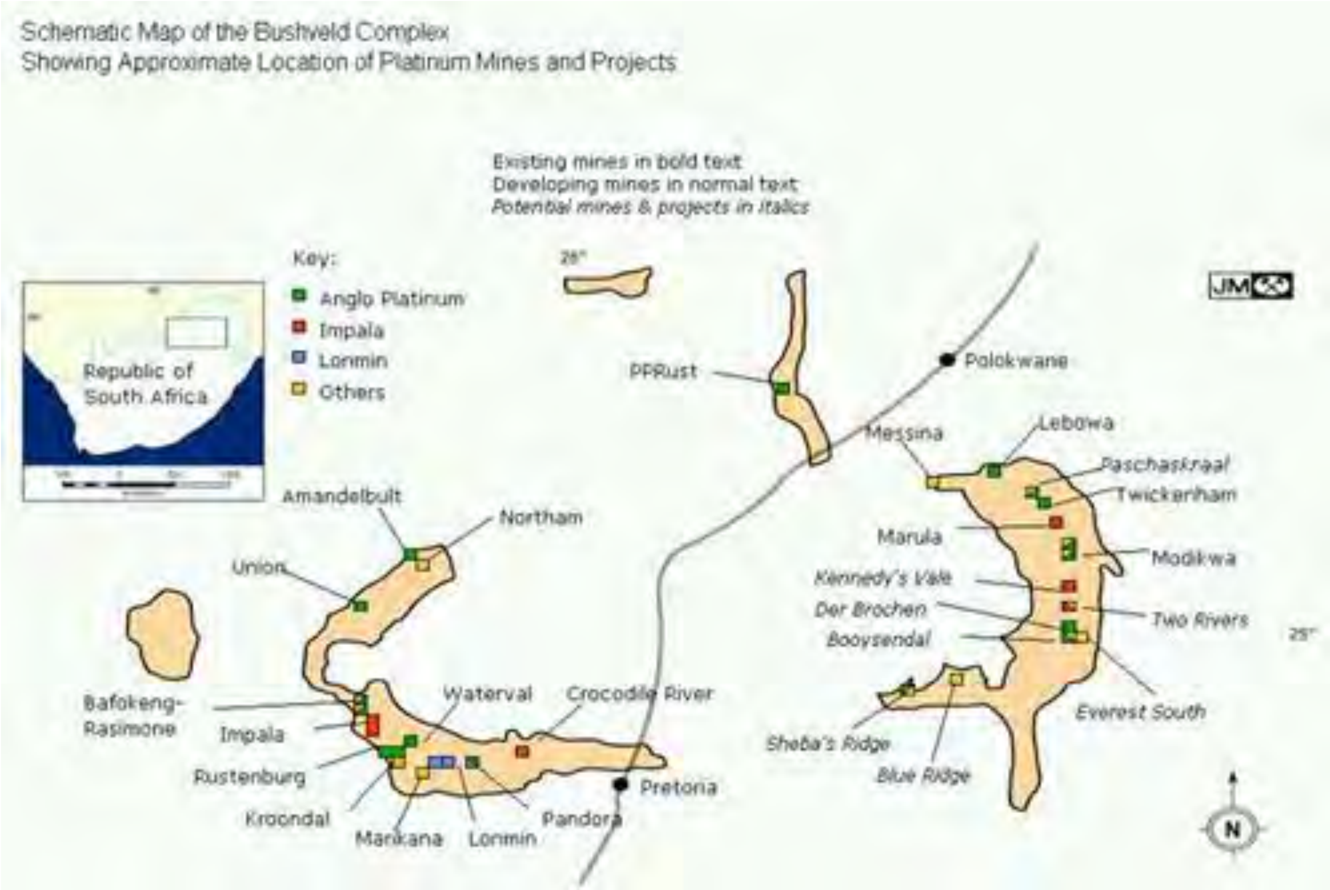


Figure C.4: South Africa – PGM Resource Map

Multi Use Case GH Pilot Plant (20 MW)

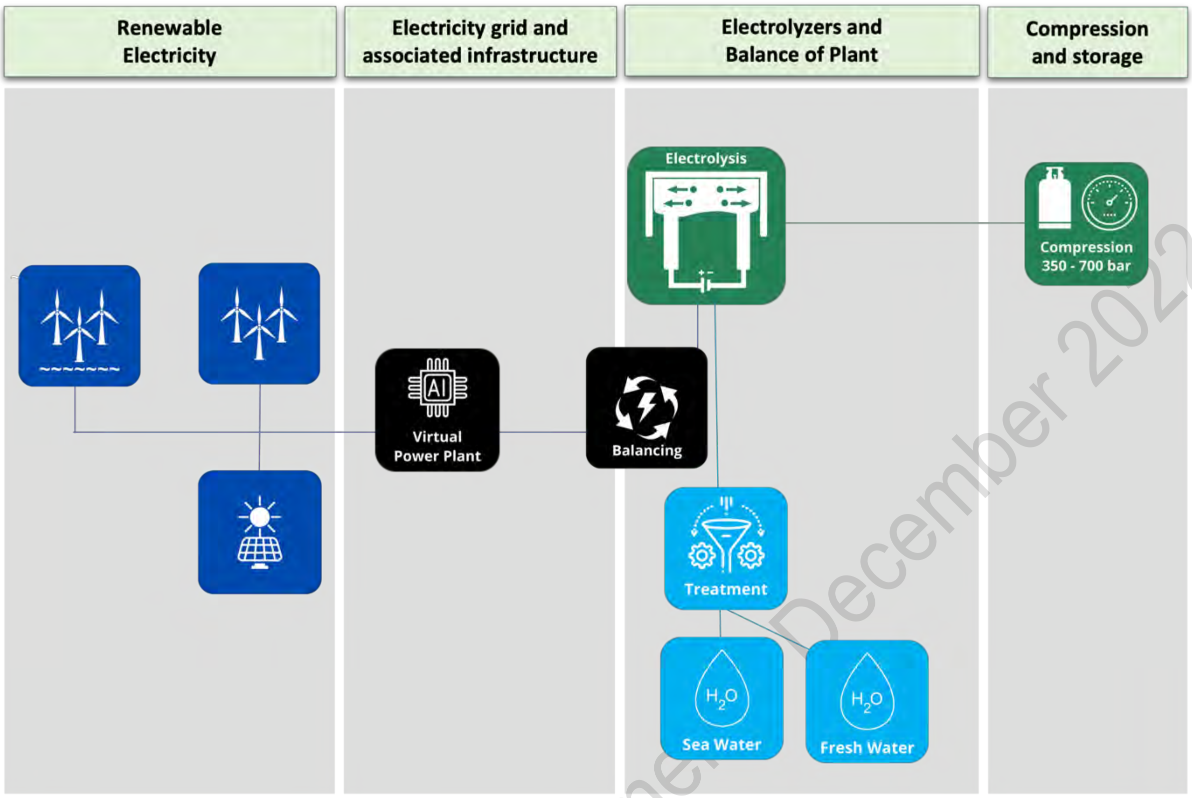


Figure C.5: Example of GH Pilot Plant

Noting the key requirements for project success, cross-sensitivities are provided for:

1. Renewable electricity prices.
2. Renewable electricity hours.
3. Electrolyser and Balance of Plant cost; and
4. Hydrogen price.

Table C.1: Cross Sensitivity – Operating Hours and Renewable Electricity Price

Red (IRR<15%), Orange (15%≥IRR≤20%), Green (IRR>21%)		Full Load Hours				Green Hydrogen Solutions, www.grennh2s.com				
		12	13	14	15	16	17	18	19	20
		4 453	4 818	5 183	5 548	5 913	6 278	6 643	7 008	7 300
ELECTRICITY PRICE (USDc / kWh)	6.50	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%	5.8%
	6.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	6.6%	10.0%
	6.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	6.6%	10.0%
	5.75	0.0%	0.0%	0.0%	0.0%	0.7%	5.8%	10.1%	13.9%	16.8%
	5.50	0.0%	0.0%	0.0%	-0.1%	5.1%	9.5%	13.4%	17.0%	19.8%
	5.25	0.0%	0.0%	-1.3%	4.3%	8.8%	12.7%	16.4%	19.8%	22.5%
	5.00	0.0%	0.0%	3.2%	7.8%	11.9%	15.6%	19.1%	22.4%	24.9%
	4.75	0.0%	1.8%	6.7%	10.9%	14.7%	18.2%	21.5%	24.7%	27.2%
	4.50	0.1%	5.4%	9.7%	13.6%	17.2%	20.6%	23.8%	26.9%	29.3%
	4.25	3.7%	8.3%	12.3%	16.0%	19.5%	22.7%	25.9%	28.9%	31.3%
	4.00	6.7%	10.9%	14.7%	18.2%	21.5%	24.7%	27.8%	30.8%	33.1%
	3.75	9.2%	13.1%	16.8%	20.2%	23.4%	26.6%	29.6%	32.5%	34.7%
	3.50	11.4%	15.2%	18.7%	22.0%	25.2%	28.2%	31.2%	34.0%	36.3%
	3.25	13.4%	17.0%	20.4%	23.7%	26.8%	29.8%	32.7%	35.5%	37.7%
	3.00	15.1%	18.6%	22.0%	25.2%	28.2%	31.2%	34.0%	36.8%	38.9%
	2.75	16.7%	20.1%	23.4%	26.5%	29.5%	32.4%	35.2%	38.0%	40.1%

Table C.1 demonstrates that the lowest renewable energy price for the longest hours increases returns and feasibility.

Table C.2: Cross Sensitivity – Operating Hours and Capex

Red (IRR<15%), Orange (15%≥IRR≤20%), Green (IRR>21%)		Full Load Hours				Green Hydrogen Solutions, www.grennh2s.com				
		12	13	14	15	16	17	18	19	20
		4 453	4 818	5 183	5 548	5 913	6 278	6 643	7 008	7 300
CAPITAL EXPENDITURE (USD Nm3 H2 / h)	7 028	0.0%	0.0%	2.1%	6.5%	10.3%	13.8%	17.0%	20.1%	22.4%
	6 708	0.0%	0.0%	2.6%	7.2%	11.1%	14.7%	18.0%	21.2%	23.6%
	6 389	0.0%	0.0%	3.2%	7.8%	11.9%	15.6%	19.1%	22.4%	24.9%
	6 069	0.0%	0.0%	3.8%	8.6%	12.8%	16.6%	20.3%	23.7%	26.4%
	5 750	0.0%	0.0%	4.4%	9.4%	13.8%	17.8%	21.6%	25.2%	28.0%
	5 431	0.0%	-1.4%	5.1%	10.3%	14.9%	19.1%	23.1%	26.9%	29.8%
	5 111	0.0%	-0.8%	5.9%	11.3%	16.1%	20.6%	24.8%	28.8%	31.8%
	4 792	0.0%	-0.2%	6.7%	12.4%	17.5%	22.2%	26.7%	30.9%	34.1%
	4 472	0.0%	0.4%	7.7%	13.7%	19.1%	24.2%	28.9%	33.3%	36.6%
	4 153	0.0%	1.2%	8.8%	15.2%	21.0%	26.4%	31.4%	36.1%	39.6%
	3 833	0.0%	2.0%	10.1%	17.0%	23.3%	29.0%	34.4%	39.2%	42.9%
	3 514	0.0%	3.0%	11.7%	19.2%	26.0%	32.2%	37.8%	42.9%	46.6%
	3 194	0.0%	4.1%	13.6%	21.9%	29.3%	35.9%	41.8%	47.0%	50.8%
	2 875	0.0%	5.5%	16.0%	25.3%	33.4%	40.4%	46.4%	51.7%	55.5%
	2 556	0.0%	7.3%	19.3%	29.8%	38.4%	45.6%	51.7%	56.9%	60.7%
	2 236	0.0%	9.6%	23.9%	35.6%	44.5%	51.6%	57.6%	62.7%	66.3%

Table C.2 demonstrates that the higher the cost of the electrolyser, the more operating hours are required to increase returns and feasibility.

Table C.3: Cross Sensitivity – Hours and GH Price

Red (IRR<15%), Orange (15%≥IRR≤20%), Green (IRR>21%)		Full Load Hours				Green Hydrogen Solutions, www.grennh2s.com				
		12	13	14	15	16	17	18	19	20
		4 453	4 818	5 183	5 548	5 913	6 278	6 643	7 008	7 300
HYDROGEN PRICE (H2 USD / kg)	6.12	0.0%	0.0%	0.0%	0.0%	0.0%	3.2%	7.2%	10.7%	13.3%
	6.48	0.0%	0.0%	0.0%	-1.4%	3.7%	7.8%	11.5%	14.9%	17.4%
	6.84	0.0%	0.0%	0.0%	3.7%	8.0%	11.9%	15.4%	18.7%	21.3%
	7.20	0.0%	0.0%	3.2%	7.8%	11.9%	15.6%	19.1%	22.4%	24.9%
	7.34	0.0%	-0.6%	4.8%	9.3%	13.3%	17.0%	20.5%	23.8%	26.3%
	7.49	0.0%	1.2%	6.4%	10.8%	14.7%	18.4%	21.9%	25.2%	27.7%
	7.63	0.0%	3.0%	7.9%	12.2%	16.1%	19.8%	23.2%	26.5%	29.1%
	8.09	-1.4%	4.6%	9.3%	13.6%	17.4%	21.1%	24.6%	27.9%	30.4%
	8.24	0.4%	6.1%	10.7%	14.9%	18.7%	22.4%	25.9%	29.2%	31.8%
	8.39	2.1%	7.5%	12.0%	16.2%	20.0%	23.7%	27.2%	30.5%	33.1%
	8.54	3.7%	8.8%	13.3%	17.4%	21.3%	24.9%	28.4%	31.8%	34.4%
	8.69	5.1%	10.2%	14.6%	18.7%	22.5%	26.2%	29.7%	33.0%	35.6%
	8.84	6.5%	11.4%	15.8%	19.9%	23.7%	27.4%	30.9%	34.3%	36.9%
	8.99	7.8%	12.7%	17.0%	21.1%	24.9%	28.6%	32.1%	35.5%	38.1%
	9.14	9.1%	13.9%	18.2%	22.3%	26.1%	29.8%	33.3%	36.7%	39.3%
	9.29	10.3%	15.0%	19.4%	23.4%	27.3%	31.0%	34.5%	37.9%	40.5%

Table C.3 demonstrates that the lower the hours of operation, the higher the GH price to increase returns and feasibility.

Table C.4 Cross Sensitivity – Electricity Price and Capex

Red (IRR<15%), Orange (15%≥IRR≤20%), Green (IRR>21%)		ELECTRICITY PRICE (USDc / kWh)				Green Hydrogen Solutions, www.grennh2s.com				
		6.50	6.25	6.00	5.75	5.50	5.25	5.00	4.75	4.50
CAPITAL EXPENDITURE (USD N m3 H2 / h)	7 028	4.7%	8.6%	11.9%	14.9%	17.6%	20.1%	22.4%	24.5%	26.5%
	6 708	5.2%	9.3%	12.7%	15.8%	18.7%	21.2%	23.6%	25.8%	27.9%
	6 389	5.8%	10.0%	13.6%	16.8%	19.8%	22.5%	24.9%	27.2%	29.3%
	6 069	6.5%	10.8%	14.6%	17.9%	21.0%	23.8%	26.4%	28.8%	31.0%
	5 750	7.2%	11.7%	15.6%	19.1%	22.3%	25.3%	28.0%	30.5%	32.8%
	5 431	8.0%	12.7%	16.8%	20.5%	23.9%	27.0%	29.8%	32.4%	34.8%
	5 111	8.9%	13.8%	18.2%	22.0%	25.6%	28.8%	31.8%	34.5%	37.0%
	4 792	9.9%	15.1%	19.7%	23.8%	27.5%	31.0%	34.1%	36.9%	39.5%
	4 472	11.1%	16.6%	21.4%	25.8%	29.8%	33.4%	36.6%	39.6%	42.3%
	4 153	12.4%	18.3%	23.5%	28.2%	32.4%	36.2%	39.6%	42.6%	45.4%
	3 833	14.0%	20.3%	25.9%	30.9%	35.4%	39.3%	42.9%	46.1%	48.9%
	3 514	15.9%	22.8%	28.9%	34.2%	38.9%	43.0%	46.6%	49.9%	52.8%
	3 194	18.2%	25.8%	32.4%	38.0%	42.9%	47.1%	50.8%	54.1%	57.0%
	2 875	21.3%	29.6%	36.7%	42.6%	47.5%	51.8%	55.5%	58.8%	61.7%
	2 556	25.3%	34.5%	41.8%	47.8%	52.8%	57.0%	60.7%	63.9%	66.8%
	2 236	30.7%	40.5%	47.9%	53.8%	58.6%	62.8%	66.3%	69.4%	72.1%

Table C.4 demonstrates that the key focus of any project is to ensure the lowest possible renewable electricity price and lowest capex costs.

Islanded GH Pilot Plant (1.1 MW Base Load Power-to-Power)

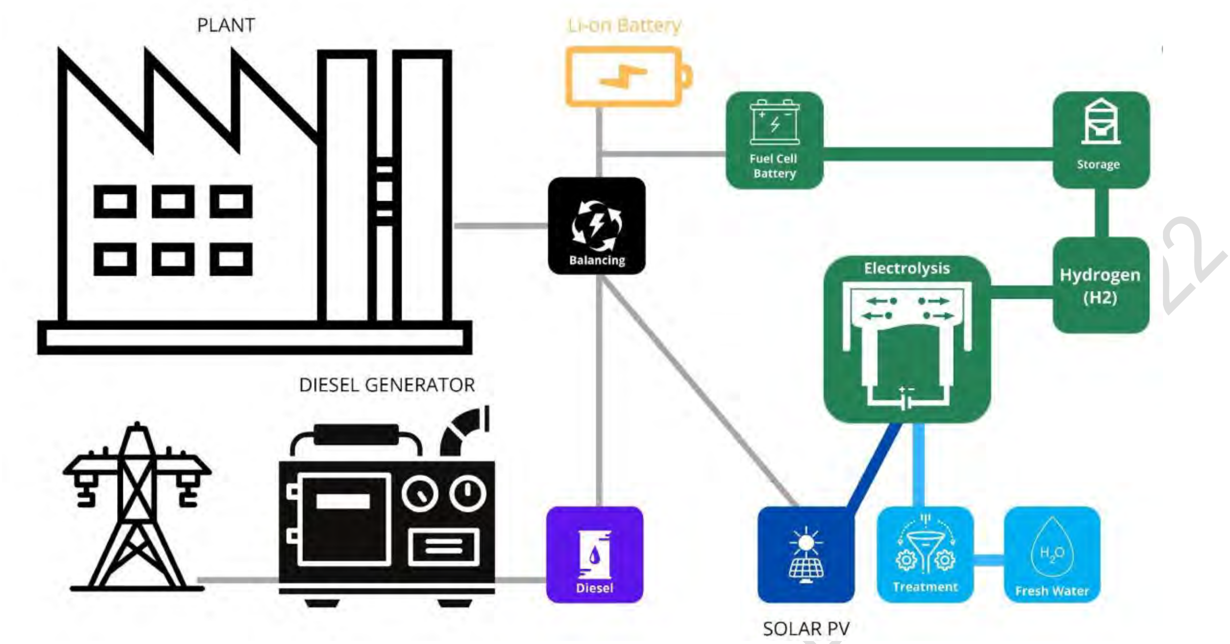


Figure C.6: Example of Islanded Power-to-Power system

GH is stored and deployed to displace diesel during non-solar hours always ensuring a supply of 1 100 kW to the plant for 12 hours per day. The plant, in a developing country is paying US$0.25/kWh for grid and diesel power, and with an islanded GH solution using Li-ion Batteries to supplement solar power could reduce its electricity price to US$0.21/kWh with carbon taxes and incentives. Essentially the plant could supply its own demand for electricity.

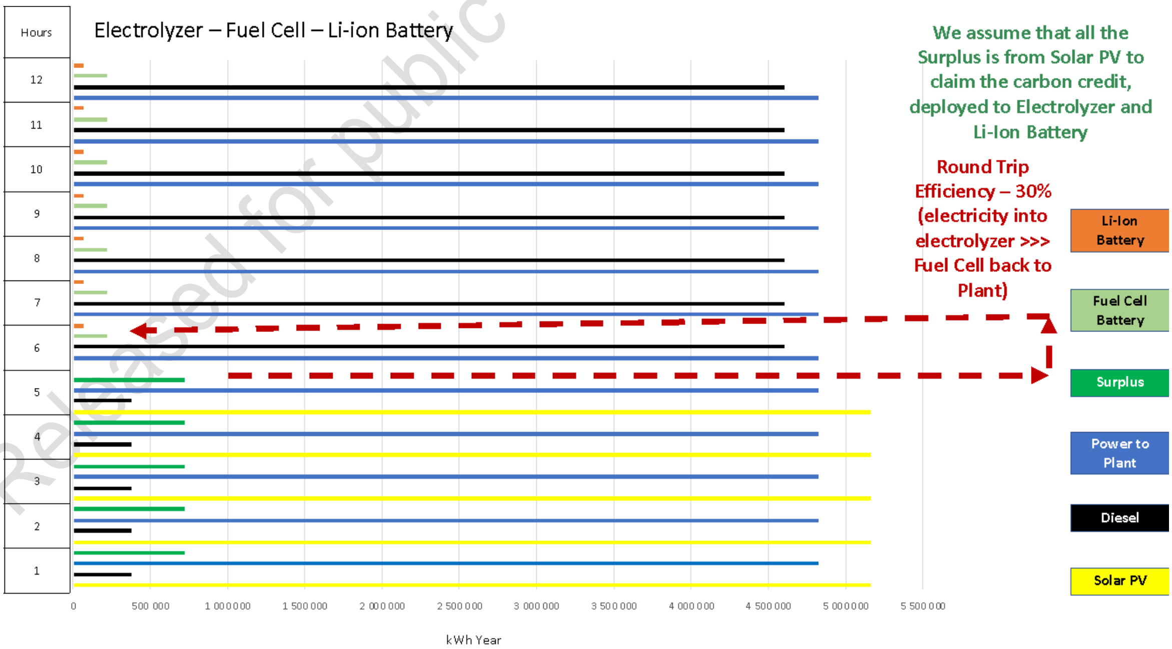


Figure C.7: Integration of Generation Options for Islanded Power-to-Power System

11. Appendix D: Work Package 5 - Equipment and Component Localisation

Table D.1 provides the priority with high level description of criteria.

Table D.1 Priority ranking of local manufacturing development.

Rank	Description
High priority	Low hanging fruit; Existing local capabilities and/or IP; Requires low initial or additional investment but current industry can pivot; Short term implementation; Competitive in a domestic market
Medium priority	Some components to be imported; Activity is based on fabrication and assembly; Medium investment needed or medium risk; Requires OEM license and/or offtake; Medium to short term implementation
Low priority	Invariably high value, high technology components will be imported in the short-medium term; Advanced manufacturing capability will be dependent on international OEM partnerships; Localisation will require substantial investment support and time development; Might not be globally cost or otherwise competitive

Table D.2 gives the supply chain component priorities for potential localisation of PEM electrolyser-based equipment, components, stacks and systems.

Table D.2. High and medium priority localisation potential for key PEM electrolysis components.

Component	Priority	Enablers and barriers
PGMs (Platinum, Iridium) catalyst	High	**Enabler** • Existing local industry. • SA leads global PGM supply with 90% of global resources. • PGM market will grow with H2 industry. • Cathode catalyst and anode catalyst contribute respectively 2% and 6% of electrolyser stack costs. **Barriers** • Reduced PGM loading. • Export of RAW material – requires beneficiation into higher value components locally.
CCM/MEA	High	**Enabler** • Established local manufacturing (small scale).

Component	Priority	Enablers and barriers
		● Existing local IP. ● Still relatively small and new market. ● MEA manufacturing contributes approx. 10% to the stack costs. **Barriers** ● No local electrolysis stack manufacturers. ● Requires scale up early-on to match future market growth. ● Possible loss of current momentum if there is a lack of funding support. ● Lack of high value-added Supported catalyst supplier.
End application (System integration/O&M)	High	**Enablers** ● Strong local specialized services (environmental analysis, legal services, finance, engineering design, location assessment, etc.) **Barriers** ● Establishment of local GH manufacturing.
PEM stack	Medium	**Enablers** ● International OEMs eager to establish in SA due to the GH potential market and PGM supply dominance. ● Potential for component export. ● Beneficial ratio of expertise vs. labour cost. ● Will enable the growth of non-PGM raw material supply chains. **Barriers** ● Requires substantial local market (e.g., 1 GW). ● Requires incentives to attract OEMs (tax, etc). ● Export of RAW materials and import of high value-added materials and components.
BoP	Medium	**Enablers** ● Majority of components can be sourced locally. ● Expertise exists for engineering and after sales service. ● **Barriers** ● Many components are imported and only supported locally. ● Detailed assessment is required to determine local content (%)of BoP subcomponents and suppliers.
PEM system	Medium	**Enablers** ● Expertise exists for engineering and after sales service. ● To attract international OEMs o High ratio expertise vs. labour cost. o High potential for local market based on SAs RE resources for GH production **Barriers** ● To attract international OEMs o Need for large domestic demonstration projects to build confidence for international OEMs to establish local facilities. o Government policies and incentive
Recycling	Medium	**Enablers** ● Bipolar plates, endplates and pressure components can be recycled. ● Dependent on local GH industry - potential for import and recycle. ● Supports local supply of high value add material (e.g., Ti, steel, PGM, etc).

Component	Priority	Enablers and barriers
		• Strong metal recycling industry **Barriers** • Will only be required in the medium to long term. • High energy intensive industry.

Table D.3 gives the supply chain component priorities for potential localisation of PEM fuel cell electrolyser-based equipment, components, stacks and systems.

Table D.3. High and medium priority localisation potential for key PEM fuel cell components.

Component	Priority	Enablers and barriers
PGMs (Platinum) catalyst	High	**Enabler** • Existing local industry. • SA leads global PGM supply with 90% of global resources. • PGM market will grow with H2 industry. • Catalyst Ink and application contribute approx. 50% of PEM fuel cell stack costs. **Barriers** • Reduced PGM loading. • Export of RAW material – lack of local beneficiation into higher value components
MEA	High	**Enabler** • Established local manufacturing (small scale). • Existing local IP. • Still relatively small and new market. • MEA manufacturing contributes approx. 8% to the stack costs. **Barriers** • No local fuel cell stack manufacturers to prove concept. • Requires scale up to match future market growth – fine line • Possible loss of current momentum if there is a lack of funding support.
System integration/O&M	High	**Enablers** • Existing system assembly locally (Chem Energy SA.) • Existing local expertise in EPC and manufacturing. • The hydrogen industry globally is still in a development phase. Many technology (Electrolyser and fuel cell) manufacturers must still establish large-scale operations and retain flexibility in selecting where to deploy production facilities. • SAs comparative advantage in PGM supply. **Barriers** •
PEM stack	Medium	**Enablers** • International OEMs eager to establish in SA due to the GH potential market and PGM supply dominance. • Potential for component export. • Beneficial ratio of expertise vs. labour cost.

Component	Priority	Enablers and barriers
		Barriers ● Requires incentives to attract OEMs (tax, etc). ● Export of RAW materials and import of high value-added materials and components.
BoP	Medium	**Enablers** ● Majority of components can be sourced locally. ● Expertise exists for engineering and after sales service. ● **Barriers** ● Many components are imported and only supported locally. ● Detailed assessment is required to determine local content (%)of BoP subcomponents and suppliers.
PEM FC systems	Medium	**Enablers** ● Expertise exists for engineering and after sales service. ● High ratio expertise vs. labour cost. **Barriers** ● Requires policies and incentives to attract international OEMs
Manufacturing FCEVs	Medium	**Enablers** ● Growing automotive sector to transition from producing ICEVs to FCEVs or BEVs. Several major automotive OEMs are already present in South Africa. ● With a potentially growing demand for FCEVs globally and locally, the industry is well positioned to manufacture them locally for both the domestic and export markets.
Recycling	Medium	**Enablers** ● Bipolar plates, endplates and pressure components can be recycled. ● Dependent on local GH industry - potential for import and recycle. ● Supports local supply of high value add material (e.g., Ti, steel, PGM, etc). ● Strong metal recycling industry **Barriers** ● Will only be required in the medium to long term. ● High energy intensive industry.

The impact on PGM resource requirement for SA has not been considered due to lack of information of the potential hydrogen pathways (Source: GHP interim report of 13 August). Pathways identified are:

- Export (either GH, green ammonia, or other green products e.g., steel)
- Equipment localisation for local and export market
- Industry decarbonization
- Heavy duty mobility applications

A more detail analysis and prediction of the end-use demand for SA (export and domestic) applications are required to better determine the PGM resource requirement. A Typical PGM loadings for the various applications are provided in Table E.4.

Table D.4. PGM loading in different applications (source : US DOE).

Application	kW	Current Loading (g/kW)	Thrifted loading (g/kW)
PEM electrolysis (platinum)		0,6	0,13
PEM electrolysis (iridium)		1,2	0,4
Heavy duty trucks	200	0,9	0,3
Buses	100	0,8	0,3
Passenger vehicles (large & medium)	80	0,9	0,125
Passenger vehicles (small)	30	0,94	0,125

The global electrolysis low and high expected install base is provided in Figure B9 and Figure B.10 to be around 190 to 295 GW by 2050. Figure E.1 shows the expected main PGMs to benefit from the implementation of hydrogen technologies (Platinum and Iridium).

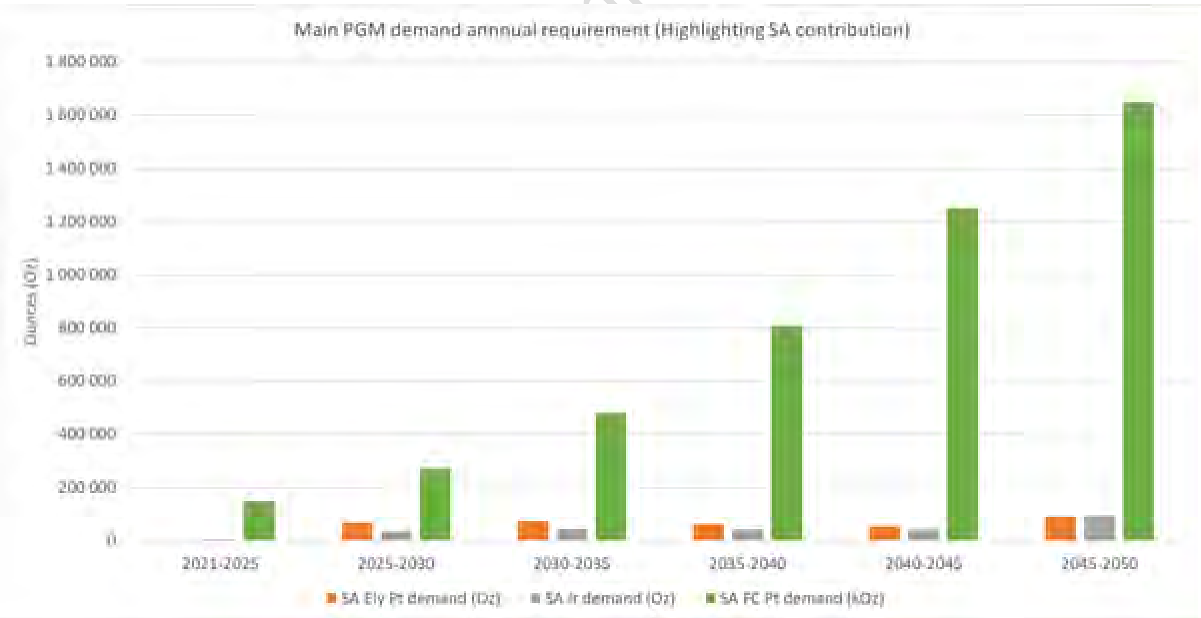


Figure E.1 PGM demand for the hydrogen economy (PEM electrolysers and PEM fuel cells for mobility) for South Africa.

Assumptions used include:

- Electrolysis demand based on Figure B9 and Figure B.10.
- For PEM fuel cell for vehicle demand conservative values based on

- Reduction in PEM electrolyser and fuel cell PGM loadings are linearised between 2025 and 2050 based on Table E.4 current and thrifted values.
- SA global Pt contribution to global demand is approx. 75%.
- SA global Ir contribution to global demand is approx. 80%.
- PGM recycling increases from 30 to 40% between 2025 and 2050.
- Steady increase in PEM electrolyser efficiencies to 70% in 2050.
- Steady increase in PEM electrolyser contribution to global GH production from 1% in 2025 to 50% in 2050.

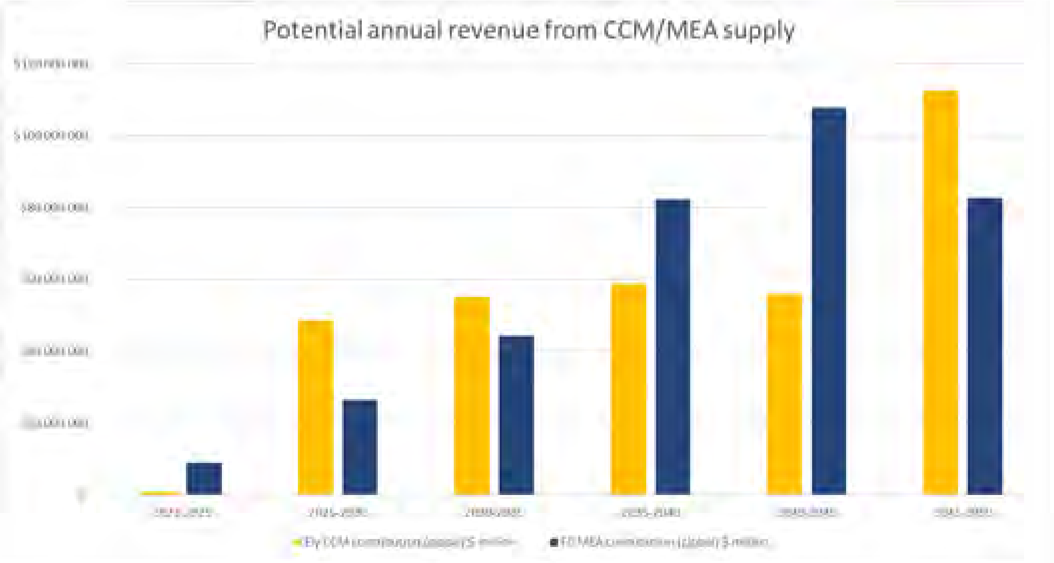


Figure D.2. Potential revenue from CCM/MEA supply into the global market for PEM electrolysers and fuel cells.

Figure D.3 Potential PGM (Pt) demand from both electrolysers and fuel cells required in the H2 valley.

Existing local manufacturers of PEM electrolyser and fuel cell components and/or systems.

- Hydrox Holdings - Hydrox Holdings is a South Africa company that have developed IP for a membrane-less Alkaline electrolyser. They have in the past received funding from Shell to develop a scaled-up demonstration system.
- HyPlat – HyPlat is a UCT/HySA spinoff company to commercialised MEA IP developed. HyPlat supplies low numbers and sizes of PEM fuel cell MEAs into the international market and are currently in the process of quiring funding to scale up production to 1m units per year.

- Chem Energy SA – Chem's head office is based in Taiwan. They have established a local fuel cell system assembly plant in Durban, South Africa located in the Dube trade Port.
  HYENA Energy - Remote FC based power packs
- Isondo Precious Metals (IPM) – IPM have obtained equipment to localise MEA manufacturing under license. They have received funding from DTIC and are in the process of construction of their manufacturing facilities (Date announced: 16 July 2021).

Global major electrolyser manufacturers by type gives a list of current global major electrolyser OEMs for the three main electrolyser technologies: PEM, alkaline and high temperature (solid oxide) electrolysers.

Table D.5. Global major electrolyser manufacturers by type.

PEM electrolysers	Alkaline Electrolysers	Solid Oxide Electrolysers
Framatome/Areave - France GH Systems - Denmark H-Tec Systems - Germany ITM Power - UK Siemens - Germany Nel Hydrogen/Proton Energy - USA PlugPower/Giner - USA Cummins/Hydrogenics Corporation - Canada	McPhy - France Nel Hydrogen - Norway ThyssenKrupp - Germany Elygrid - Spain De Nora (Chloralkali)- Italy Johncockerill Enapter (AEM) - Germany CHP (Membraneless) - UK	Sunfire - Germany Halder Topsoe - Denmark Ceres Power - UK Elcogen - Estonia Oxeon Energy - USA

Table D.6 Global major fuel cell manufacturers by type.

PEM fuel cells (PEMFC)	Solid Oxide fuel cells (SOFC)	Phosphoric acid fuel cells (PAFC)
Cummins/Hydrogenics Ballard Plug Power Nuvera Altergy Power Cell Loop Energy Proton Motor Fuel Cell Energy Nedstack ElringKlinger Horizon Schaeffler Toshiba Intelligent Energy Advent (High Temp PEM)	Bloom Energy New Enerday Adaptive Energy Ceres Power Solid Power Mitshubishi Panasonic	Phosphoric acid fuel cells (PAFC) Doosan Fuji electric Alkaline fuel cells (AFC) GenCell AFC Energy Direct Methanol Fuel Cell SFC Energy

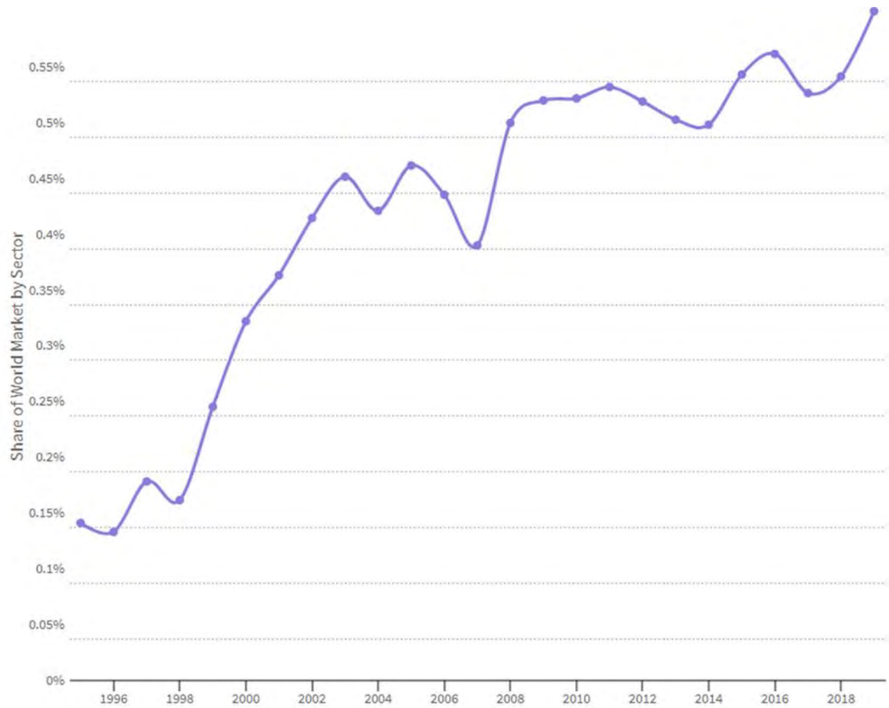


Figure D.5 South Africa's global share of vehicle export.

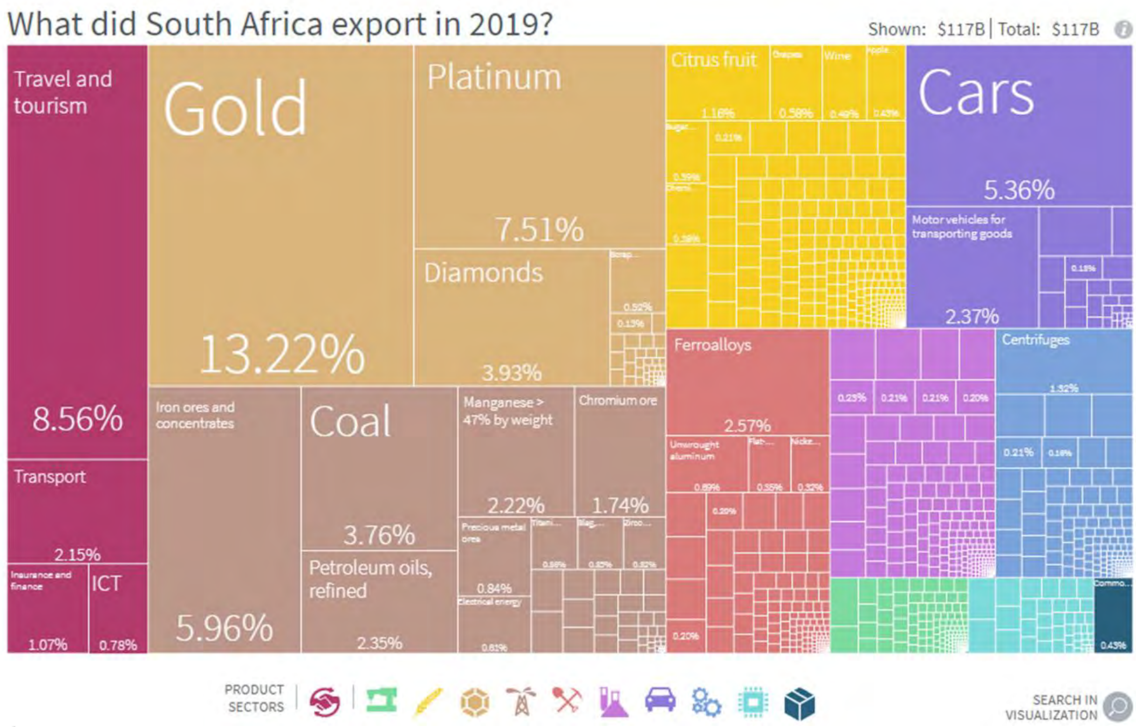


Figure D.6. South Africa's export by Sector.

12. Appendix E: Work Package 5 - Initiatives and demonstration/catalysing projects in South Africa

Table E.1: Initiatives and demonstration/catalysing projects in South Africa

#	Project	Type/Status	Description	Stakeholders
1.1	Isondo Precious Metals	Local component manufacture/IP procured. facility being constructed	Isondo Precious Metals (IPM) is establishing an industrial scale, high-tech, fuel cell and electrolyser component manufacturing facility within the OR Tambo Special Economic Zone (SEZ)	IPM. DTIC
1.2	Chem Corporation	Local assembly/Facilities established	CHEM ENERGY SA, a subsidiary of Taiwanese conglomerate CHEM Corporation, which has opened its $200-million fuel cell production factory in KwaZulu-Natal at the Dube TradePort Special Economic Zone.	CHEM Energy SA
1.3	Hydrox Holdings	Local IP development/R&D	Hydrox Holdings Ltd. AAE technology has been demonstrated with integration in a full balance of plant with production capacities noted as small scale.	Hydrox Holdings

#	Project	Type/Status	Description	Stakeholders
1.4	HyPlat	Local IP development and component manufacture/Operating	Low volume manufacturing of MEAs and CCMs	HyPlat
1.5	Mitochondria	Feasibility study in progress	Bankable feasibility study for Project Phoenix which entails the design of a 250kW Solid Oxide Fuel Cell (SOFC) system, construction of a facility to commercially manufacture the SOFC units and commercial manufacturing and sale of the SOFC units.	Mitochondria, IDC, DBSA
2.1	Air products	GH beneficiation cooperation agreement/Signed	Air Products and ThyssenKrupp sign exclusive strategic cooperation agreement for world-scale electrolysis plants to generate GH.	Air Products, ThyssenKrupp
2.2	Sustainable Aviation Fuel	GH beneficiation cooperation agreement/Announced	SASOL intends on developing a sustainable aviation fuel production demonstration facility, based on GH, at its Secunda operations, in Mpumalanga to be bid in the first round of the H2Global auction programme.	Sasol, Enertrag, Navitas, Linde

#	Project	Type/Status	Description	Stakeholders
2.3	e-methanol feasibility study	GH beneficiation feasibility study/Unknown (requires more detail)	An agreement for the development of a greenfield facility in Humansdorp, in the Eastern Cape, to manufacture zero-carbon e-methanol for sale locally and for export has been concluded by a consortium comprising Earth and Wire, ENERTRAG South Africa and 24Solutions. The proposed 120 000 t/y facility will produce e-methanol by combining GH, produced through an electrolyser using renewable electricity and desalinated seawater, with a synthesis gas, derived from a mixed feedstock of locally sourced biomass and unrecyclable municipal solid waste fed into a gasifier.	Enertrag South Africa, Earth and Wire, 24Solutions
2.4	Prieska Energy Cluster	GH beneficiation feasibility study/Scoping	The project entails the development of Green Ammonia Production facility in Prieska, Northern Cape. The Project will inject R6.3 billion in capital investments in the first phase, with an additional R48 billion in investments during the expansion phase. The first phase of the Project, which will be located 10km outside Prieska in the Northern Cape, South Africa, will result in the production of 70,000 tons/annum of green ammonia with a GH content of approximately 12,350 tons.	Mahlako a Phahla investments and Central Energy Corporation (Cenec).

#	Project	Type/Status	Description	Stakeholders
2.5	Boegoe Bay GH Port	GH beneficiation feasibility study (memorandum of agreement signed)	Port, Rail and Infrastructure Project driven by the Northern Cape Provincial Government. The port has a capital value of approximately R13 billion and is underpinned by the export of mining commodities. 60,000 hectares of well irradiated land adjacent to the site would support a 30 GW solar and wind farm (6 times SA's current installed renewable energy capacity) and support 5 GWs of electrolysers	Northern Cape Economic Development, Trade and Promotion Agency, Sasol, IDC
2.6	Green H2 & NH3 zero emission marine fuel for export	GH beneficiation feasibility study/Pre-feasibility	GH & green ammonia production and storage at Richards Bay port or alternatively suitable port	African Renewable Development
2.7	Ubuntu GH Project	GH beneficiation feasibility study/Unknown	20MW GH production project in the Northern Cape	Ubuntu Green Energy
2.8	Mainstream GH production	GH beneficiation feasibility study/In progress	GH production.	South Africa Mainstream Renewable Power Developments (pty) Ltd
2.9	Renew e waste hydrogen power generation	GH beneficiation feasibility study/Pre-feasibility	Use of waste hydrogen to generate electricity for mobility application.	Renew e

#	Project	Type/Status	Description	Stakeholders
2.10	Enertrag GH Production	GH beneficiation feasibility study/Completed	Generation of GH; green-hydrogen based products (green ammonia production).	ENERTRAG AG
3.1	Telecoms Towers	Stationary power demonstration/Various stages (Detail unknow)	As early as 2010, Vodacom South Africa deployed 89 fuel cell systems at base stations in South Africa to confirm the value proposition of fuel cells and demonstrate the growing trend of telecom service providers to support and promote more eco-friendly initiatives. MTN also has various towers powered with fuel cell solutions.	Vodacom, MTN
3.2	Military One Hospital Fuel cell field deployment	Stationary power demonstration/Operating	PPP for seven fuel cell systems to power a field facility at 1 Military Hospital in Pretoria. Bambili Energy focuses on the hydrogen economy, providing solutions to complement various forms of alternative energy, and is committed to commercialising intellectual property developed through the Hydrogen South Africa (HySA) programme.	DSI, DPWI, DoD, HyPlat, Bambili Energy, PowerCell, Horizon Fuel Cell Technologies, Element 1 Corporation
3.3	Mitochondria	Stationary power demonstration/Operating	In 2015, the IDC and Mitochondria successfully launched a 100 kW Combined heat and Power Phosphoric acid Fuel Cell at the Chamber of Mines offices in Johannesburg.	Mitochondria, DTI, Chamber of Mines

#	Project	Type/Status	Description	Stakeholders
3.4	Naledi Trust Project Anglo American	Stationary power demonstration/Completed (decommissioned)	In 2014, Amplats started a rural electrification pilot project in Kroonstad to power 34 homes in a remote community in the Free State province in a 12-month trial period. Amplats invested around $20 million in the “mini-grid”, which functioned independently from the national grid. The pilot system generated 15 kilowatts (kW) and a maximum of 60 kW with battery storage.	Amplats, Ballard Power Systems
3.5	Poelano school RE H2 energy system	Stationary power demonstration/Completed (decommissioned)	An off-grid energy system was installed and operated at Poelano High School. The energy system consisted of PV, Batteries, a PEM electrolyser unit, hydrogen low pressure storage and a fuel cell. The system operated from March 2018 until the electrolyser and fuel cell were removed at the end of 2020. The PV system and batteries are still supplying the school with energy, along with an Eskom connection.	DSI, HySA Infrastructure/NWU, HySA Systems/UWC, HySA Catalysis/UCT/HyPlat
3.6	Cofimvaba Rural Schools fuel cells	Stationary power demonstration/Completed (decommissioned)	Three schools in the Cofimvaba district (Arthur Mfebe Senior Secondary School, St Marks Junior Secondary School, Mvuzo Junior Secondary School) were supplied with fuels cells as back up power. Hydrogen was supplied by Air Products to the school in cylinders.	DSI, Amplats, Air Products, Clean Energy Investments.

#	Project	Type/Status	Description	Stakeholders
3.7	Windsor Clinic Fuel cell	Stationary power demonstration/Completed (decommissioned)	The Windsor Clinic in Randburg was supplied with a fuels cell as back up power for their vaccine refrigerators and pharmacy air-con to prevent regular power cuts from causing unused vaccines and medicines to be discarded. Hydrogen was supplied by Air Products to the school in cylinders.	DSI, Amplats, Air Products, Clean Energy Investments.
3.8	Cofimvaba Science center RE H2 energy system	Stationary power demonstration/Operating	An off-grid energy system is installed and operated at Cofimvaba Science Center in the Eastern Cape. The energy system consisted of a small wind turbine, PV, Batteries, a PEM electrolyser unit, hydrogen low pressure storage and a fuel cell. The system started operating early 2021.	DSI, Hysa Infrastructure/NWU, Western Cape
4.1.1	Hydrogen Valley Feasibility Investigation - Johannesburg hub	Mobility feasibility study started	Driven by H2-based sectors switching from gray H2, feedstock substitution for ethylene production, fuel and catalyst for iron & steel, public buildings and buses and future private building demand.	DSI, Anglo American, Engie, SANEDI, Bambili Energy
4.1.2	Hydrogen Valley Feasibility Investigation - eThekwini/Richards Bay hub	Mobility feasibility study started	Driven by fuel for heavy- and medium- duty trucks via N3 freight corridor, fuel for port activities including handling equipment and electricity, oil refining switching from grey H2, medium grade temperature	DSI, Anglo American, Engie, SANEDI, Bambili Energy

#	Project	Type/Status	Description	Stakeholders
			heating, and some export potential (to be sized).	
4.1.3	Hydrogen Valley Feasibility Investigation - Mogalakwena/Limpopo hub	Feasibility study started	Driven by mining trucks fuel for diamond, copper, titanium, and platinum and some demand from heavy- and medium-duty trucks via N1.	DSI, Anglo American, Engie, SANEDI, Bambili Energy
4.2	RHynbow H2 freight corridor project	Mobility feasibility study/Started	Investigates the creation of the first H2 corridor in South Africa between Limpopo-Gauteng-KZN. Work is aligned with the overall Hydrogen society roadmap and the H2 Valley feasibility study. Focused on HD trucks, long distance buses and city buses in this geographic region Anglo American, Bambili Energy and Engie have been developing a GH corridor between Limpopo-Gauteng-KZN since January 2020. Focused on HD FC truck, FC coaches and FC city buses	Anglo American, Bambili Energy and Engie
4.3	Impala Platinum	Mobility demonstration project/Operating (Unknown)	Hydrogen fuel cell forklift and refuelling station at the Impala Platinum Refineries in Springs	Impala Platinum, HySA Systems

#	Project	Type/Status	Description	Stakeholders
4.4	Anglo Platinum	Mobility demonstration/Being implemented	Anglo American announces its agreement with ENGIE, a leading global energy and energy services company, to develop and fuel the world's largest hydrogen-powered mine haul truck.	Anglo American, ENGIE
4.5	GH Mobility Ecosystem	Mobility demonstration/Concept phase	The project aims to produce blue and GH, establish distribution infrastructure, and sell the hydrogen to the mobility market for use in hydrogen fuel cell vehicles	Sasol, Toyota
4.6	Hydrogen Mobility Corridor along N3	Mobility demonstration/Concept phase	The development of a "hydrogen mobility corridor" pilot project along the key N3 freight route between Durban and Johannesburg. This includes building hydrogen refuelling infrastructure and sourcing of fuel-cell electric busses.	Sasol, Toyota
4.7	SAPO fuel cell scooters	Mobility demonstration/Operating	Three fuel cell scooters have been developed and are being tested by the South African Post Office in Cape Town.	DSI, HySA Systems/UWC, SAPO

#	Project	Type/Status	Description	Stakeholders
5.1	Containerised hydrogen dispensing unit	Remote hydrogen production pilot/Operating	HySA Infrastructure have developed a containerised hydrogen production unit capable of producing 13kg hydrogen per day. They can be transported anywhere and requires any suitable 3 phase supply and potable water. Purification, cooling, compression to 350 bar, and composite storage is included. A 350-bar vehicle dispenser capable of slow filling is included. The unit is coupled to a 65-kW grid connected PV system and is used to produce H2 for hydrogen safety experiments and commercial fuel cell demonstrations.	DSI, HySA Infrastructure/NWU
6.1	BMU	Funding program/in progress	Germany's National Hydrogen Strategy provides 600 million euros which the BMU will use to fund the PtX Pathways project developing the PtX market in Morocco, Argentina and South Africa	Germany
6.2	BMWi	Funding program/in progress	Funding the 200-million-euro concessional financing for hydrogen projects in South Africa by KfW	Germany
6.3	BMBF	Funding program/in progress	Funding the Hydrogen Atlas for sub-Saharan Africa	Germany, SADC, ECOWAS

#	Project	Type/Status	Description	Stakeholders
6.4	BMZ	Funding program/in progress	Funding H2Global, which subsidises the import of green H2 into Germany	Germany