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South African National Energy Development Institute

ENGIE

South Africa Hydrogen Valley Final Report

October 2021

ENGIE Impact

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Executive summary (1/5)

1 Hydrogen Valley & Hydrogen Hubs

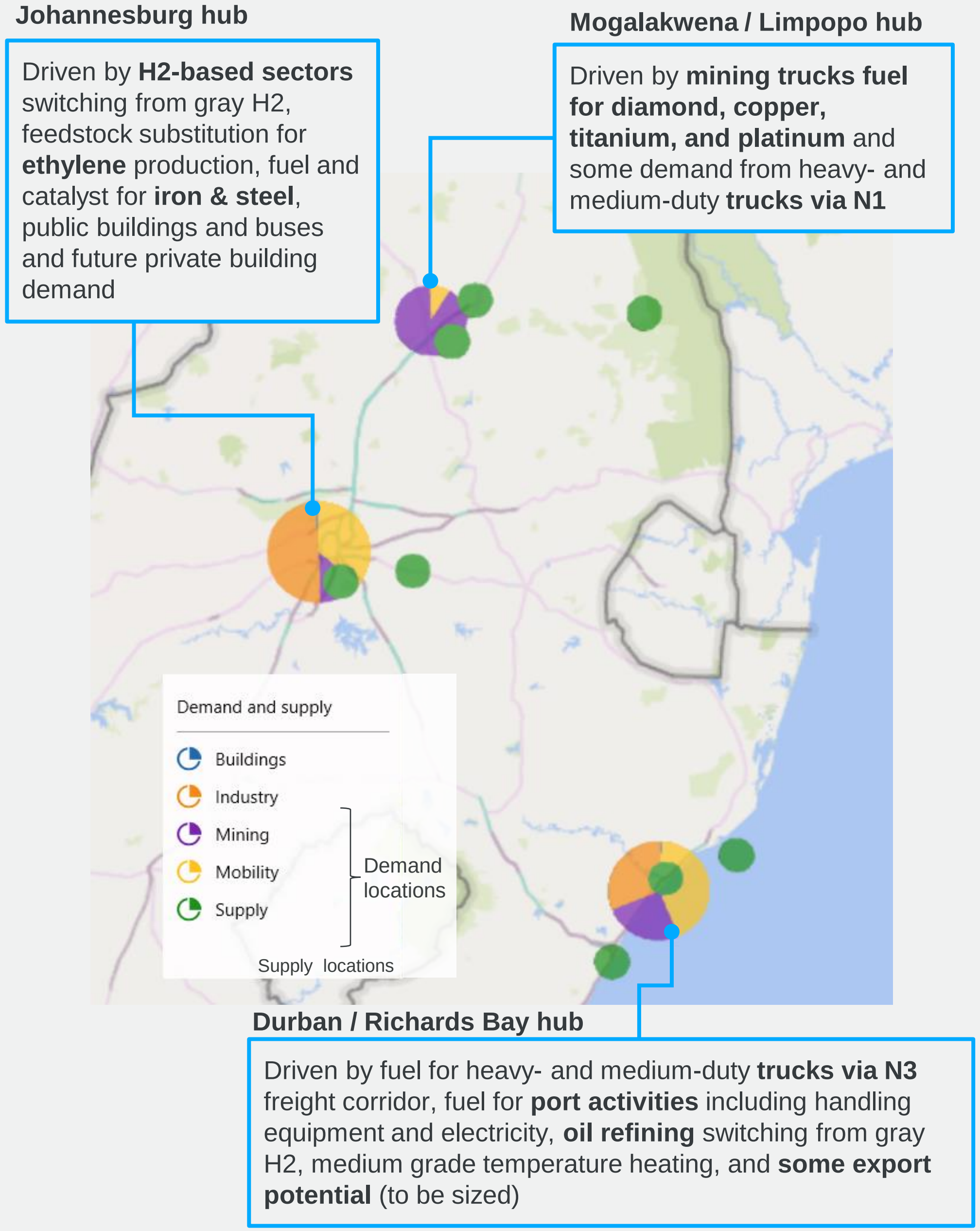
Hydrogen is a key priority for South Africa. In his last State of the Nation address, President Ramaphosa cited that hydrogen fuels cells are a **national priority** as an alternative energy source. Hydrogen presents a significant opportunity for economic development in South Africa, including the creation of new jobs and the monetization of the platinum industry. It is also a contributor to South Africa's decarbonization objectives, leveraging REIPP[1], REDZ[2] and other renewable development programs to produce green hydrogen, now at the centre of many sector-level green strategies (e.g., green steel, green buildings). Finally, global commitments towards hydrogen production and demand create an opportunity for South Africa to engage in energy export at the international level.

The South African government's Department of Science and Innovation (DSI), in partnership with Anglo-American, Bambili Energy and ENGIE are looking into opportunities to transform the Bushveld complex and larger region around Johannesburg, Mogalakwena and Durban into a **Hydrogen Valley.**

To realize these objectives for South Africa, Hydrogen Valleys can be **leveraged to kickstart the hydrogen economy**, leading to cost savings through shared infrastructure investments, improving the cost competitiveness of hydrogen production through economies of scale, enabling a rapid ramp-up of hydrogen production within a given territory, and leveraging an incubator for new pilot hydrogen project**.**

Three catalytic green hydrogen hubs have been identified in South Africa's Hydrogen Valley

These hubs have been identified based on locations with potential for a high concentration of future hydrogen demand, the possibility to produce hydrogen (e.g., access to sun/wind, water infrastructure), and contributions to the just transition—an economic development plan that brings positive social impact particularly to more fragile groups and communities. These hubs – in Johannesburg, Durban/Richards Bay, and Mogalakwena/Limpopo – will host pilot projects and contribute to the launch the hydrogen economy in the Hydrogen Valley.



Johannesburg hub

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

Mogalakwena / Limpopo hub

Driven by **mining trucks fuel for diamond, copper, titanium, and platinum** and some demand from heavy- and medium-duty **trucks via N1**

Durban / Richards Bay hub

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 gray H2, medium grade temperature heating, and **some export potential** (to be sized)

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(1) Renewable Energy Independent Power Producers Procurement
(2) Renewable Energy Development Zones

Key Insights

1

Three catalytic green hydrogen hubs have been identified in the Valley: In **Johannesburg hub** (JHB hub with spokes extending to Rustenburg and Pretoria); **Durban hub,** compassing both Durban and Richards Bay, and a third hub encompassing **Mogalakwena and Limpopo**

2

Hydrogen demand in these hubs could reach up to 185 kt H2 by 2030, or **40% (low case) to 80% of demand (high case)** of the draft national hydrogen roadmap[1].

3

By 2030, green H2 LCOH production is expected to be ~$4 per kg H2[2] across hubs, and is **still more expensive than gray hydrogen**, with a green premium of $2-$2.5.

4

The Hydrogen Valley has a strong potential to contribute to the just transition and could potentially add **3.9-8.8 bn USD to GDP** (including indirect contributions) by 2050, while also creating a total of **14,000 - 30,000+ jobs per year.**[3]

5

Key regulatory and policy enablers are required to launch hydrogen projects in the Valley and **assure a just transition in the Hydrogen Valley**

6

Nine promising pilot projects have been identified to kickstart the Hydrogen Valley in the mobility (mining trucks, buses), industrial (ammonia/chemicals) and buildings (fuel cell power) sectors.

(1) ~230 kt H2 demand by 2030, based on our calculation of 1-2% of global H2 demand

(2) includes cost of producing hydrogen (cost of renewable energy supply, electrolyzer, water treatment and storage); does not include transport costs

(3) Ranges based on high or low demand case

Executive summary (2/5)

2 Hydrogen Demand

Hydrogen demand in the Valley could reach up to 185 kt H2 by 2030, or 40% (low demand case) to 80% (high case) of demand in the national hydrogen roadmap.

Demand in the Valley has been developed based on a bottom-up assessment of technical potential of off-takers in each hub, complemented by hydrogen uptake curves reflecting the expected competitiveness of hydrogen in each application.

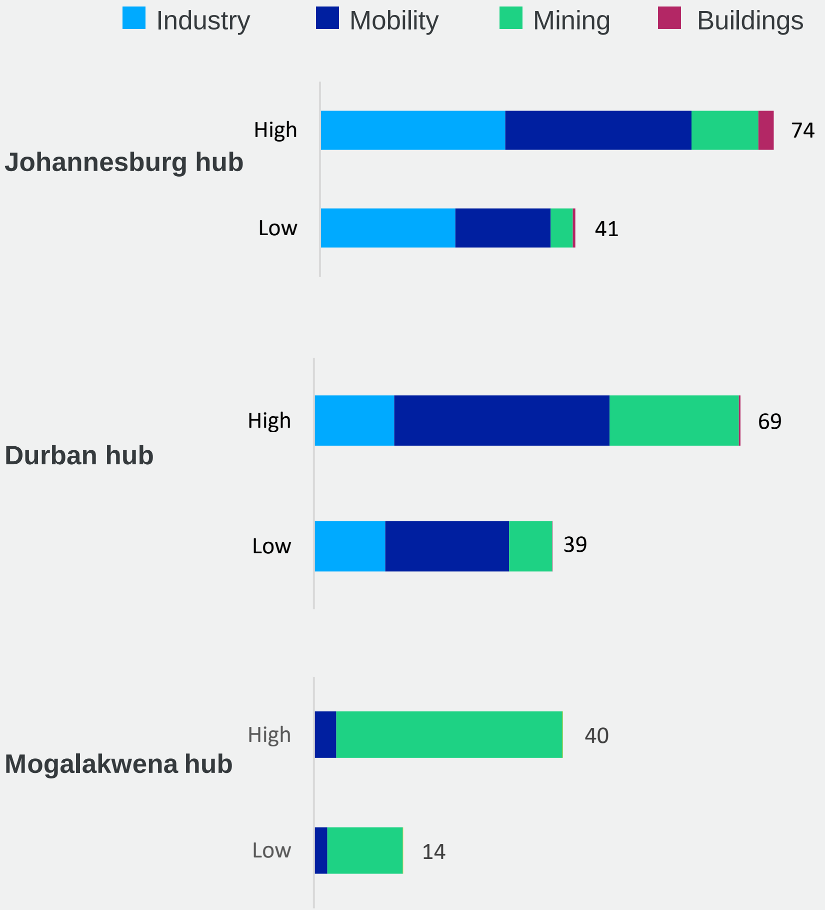
In Johannesburg, hydrogen demand could reach up to 74 kt by 2030 in a high uptake scenario. Demand is primarily driven by the **industrial sector**, with large H2 uptake in Sasolburg's chemical and iron and steel sectors. There is also significant demand from Heavy Duty trucks servicing the N3 freight corridor, and public buses and buildings within the Johannesburg/Durban metropoles.

In Durban, hydrogen demand could reach 70 kt by 2030 in a high uptake scenario. Demand is primary driven by the **mobility sector**, with the growth of fuel cell Heavy and Medium-duty trucks along the N3 freight corridor, as they reach cost parity with diesel trucks. The ports of Durban and Richards Bay present opportunities for hydrogen in port operational vehicles such as forklifts and cold ironing from fuel cells as well as marine bunkering in the long-term. Some industrial demand, such as pulp and paper factories, and public building demand is also foreseen.

Mogalakwena/Limpopo is positioned as the mining hub, with 90% of its nearly 40 kt of H2 demand driven by possible **demand from mining trucks** across the region's mines. The flagship Limpopo Science and Technology will also provide demand for fuel cells to power its building stock.

Hydrogen export could be a potential future source of demand; however, the Valley will face competition from other hydrogen exporting countries such as Morocco and Australia and from other ports in South Africa such as Boegoebaai. Nevertheless, the co-location of demand and supply gives synergies opportunities within the hub that will help initiate and scale up pilot projects. We therefore recommend that the Hydrogen Valley either consolidate domestic demand and create economies of scale before embarking on ambitious export projects, or take an opportunistic stance such as leveraging international funds to develop export infrastructure.

Demand technical potential in 2030 per sector
kT H2/year



Executive summary (3/5)

3 Hydrogen Supply

By 2030, green H2 LCOH is expected to be ~$4 per kg H2[1] across hubs, still more expensive than gray hydrogen, with a green premium of $2-$2.5 per kg.

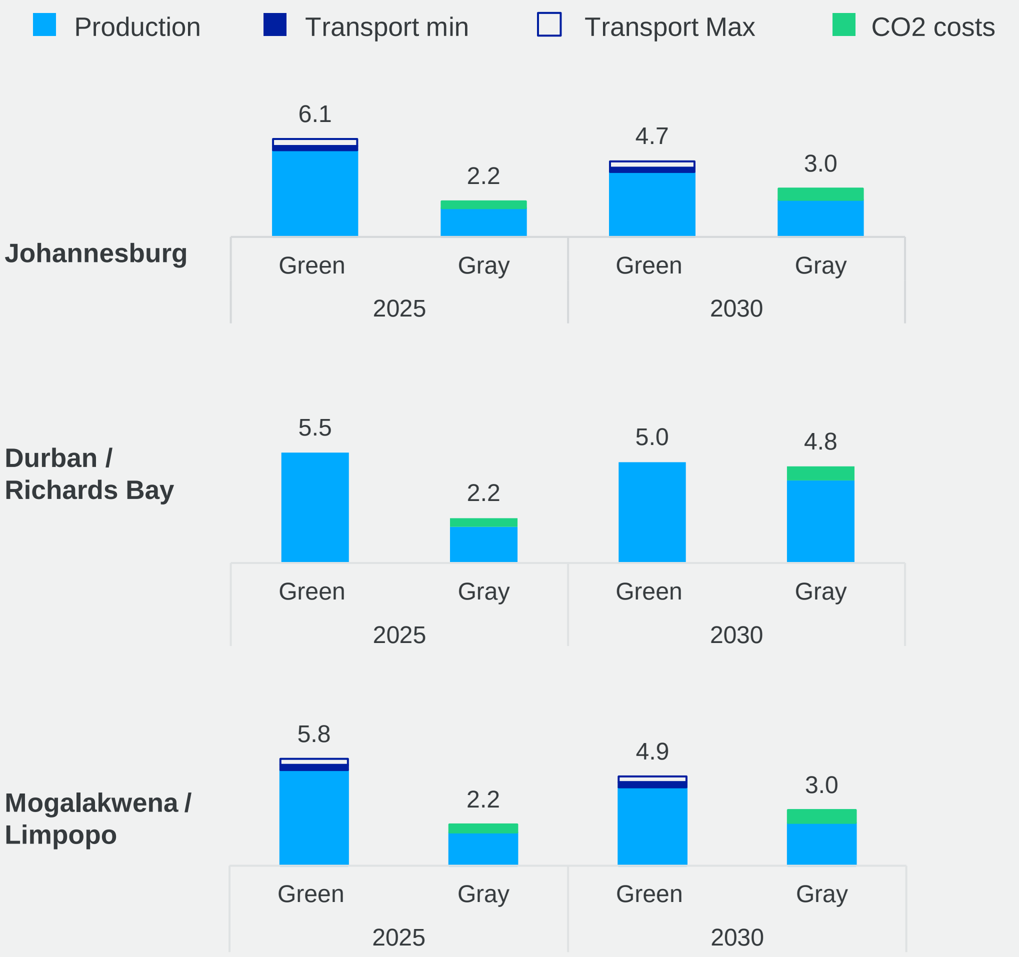
All three hubs see similar costs of hydrogen production. Costs in 2030 will be lower in Johannesburg (4.08-4.11 USD/kg H2)[4], compared to Durban (4.25-4.55 USD/kg H2) and Mogalakwena/Limpopo (4.10-4.27 USD/kg H2) due to higher solar irradiation levels. Additional transports costing up to 0.5 USD/kg H2 are considered to bring hydrogen from supply locations to off-takers within the hubs. With the addition of transport, hydrogen production costs reach 4.70 – 5.00 USD/ kg H2 by 2030 (*see graph).* For all hubs, we recommend using solar PV for green hydrogen production, with some onshore wind as the cost optimal supply mix.

SA H2 Valley LCOH estimates are higher than some other analyses, due to the use of PEM electrolyzers instead of alkaline electrolyzers, as well as conservative, yet significant cost-down assumptions (~60% between today and 2030), based on observations about the limited impact of economies of scale in electrolyzer installations. Our electrolyzer costs go beyond capex to include the full cost of installation. We have also taken a conservative approach in LCOH cost evolution and recognized that **further reductions are possible** depending on policy and technology evolution to 2030.

Given the estimated demand of hydrogen, the **optimal transport solution consists of transporting hydrogen through trucks** from the production site to off-takers, while hydrogen pilot projects take shape and begin to scale. Building a hydrogen pipeline requires high levels of hydrogen demand before becoming economically-viable.

The report anticipates infrastructure constraints and each hub must anticipate infrastructure requirements in electricity supply, water supply, pipeline infrastructure and storage. For electricity supply, a dedicated RES off-grid supply is recommended to mitigate grid reliability risks and avoid network charges and taxes. Most hubs are vulnerable to **water supply** and hubs may consider locating hydrogen supply next to existing water sources, desalination infrastructure, or implementing water recycling or truck delivery. With no extensive H2 network in the region, **existing gas pipelines** could be leveraged for H2 transport and distribution in the longer term. While underground **storage** is not feasible before 2030, above ground storage can be leveraged to lower LCOH.

Levelized cost of hydrogen production + transport [2,3] per hub
USD/kg H2



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(1) 1 includes cost of producing hydrogen (cost of renewable energy supply and electrolyzer only; does not include transport nor storage as demand assumed to be fully flexible)
(2) Transports in Mogalakwena not accounted for as production will be on localized
(3) Transport costs of gray hydrogen are not accounted for
(4) Ranges based on location within hub

Executive summary (4/5)

4 Socioeconomic Impact

The H2 Valley could potentially add 3.9-8.8 bn USD to GDP (direct and indirect contributions) by 2050, while also creating 14,000 - 30,000+ direct and indirect jobs per year.

Spending on capex and opex hydrogen production, from offsite renewable energy supply and electrolyzer capacity, for the full vision of the Hydrogen Valley is expected to have a positive impact on GDP and job creation. Estimates have placed the potential GDP impact, both direct and indirect, of the hydrogen projects at 3.9 billion USD (low demand case) to 8.8 billion USD (high demand case) should the full vision of the Hydrogen Valley be realized.

Estimates also indicate job creation opportunities from projects in the Valley, putting in place **~14,000 (low case) to 32,000 (high case) jobs per year by 2030**, should the **full vision of the project be realized**. These jobs are based on the RES and electrolyzer investment only; fuel cell investment may further contribute to job creation beyond these figures.

This job growth may be seen in sectors across the whole hydrogen value chain, starting at the sourcing of resources such as water resources management and platinum mining, to production including electrolyzer development, to transport including the pipeline and trucking industries, to storage such as liquefaction, to finally applications such as fuel cell manufacturing. Jobs span the entire hydrogen value chain from R&D, engineering, maintenance, training and outreach. This job creation also has the potential to contribute to the just transition; for example, jobs requiring training the workforce will put male and female workers on equal footing.

The **PGM sector** is expected to see a marginal increase in demand from the Hydrogen Valley, as platinum is a required raw material for both fuel cell and (PEM) electrolyzer manufacturing. However, the volume of platinum required for the Valley only constitutes a small percentage of platinum production today. No platinum supply constraint to satisfy the demand of the Valley is anticipated. The proposed projects in the Hydrogen Valley could bring up to 70 million **USD (high case)** to platinum industry in South Africa in 2030.

5 Regulatory & Policy Enablers

Regulatory and policy enablers are required to kickstart the hydrogen economy.

While South Africa has already put in place many policies that can nurture the hydrogen economy, multiple barriers still exist to scale up hydrogen in the Valley. These **barriers relate to sourcing green electricity** (grid reliability and limited green electricity on grid), **electrolyzer scale up** (high costs), **hydrogen demand** (lack of clear targets and strategies at the sector level), and **infrastructure** (missing hydrogen transport and storage regulation), among others.

Policy and regulatory enablers should **ease deployment of RES and electroyzers, make near-term Capex affordable, encourage H2 applications, create momentum for future demand, and formalize the hydrogen sector through standards and labels.** Supporting policies around RES deployment, land and water use must also be coherent with creating a hydrogen economy and sustainable future.

Across each of these categories, we recommend a suite of policy and regulatory instruments:

- To ease deployment of RES and electrolyzers, we recommend offering financial incentives to lower capex cost and fast track RES deployment through simplified permitting procedures.
- To make near-term capex affordable for hydrogen supply infrastructure, we recommend the following suite of policy instruments: direct financial support, financial incentives and CO2 taxes.
- To create momentum for future demand, it is important to put in place sector planning to provide transparency on future off-take and encourage technology partnerships between suppliers and off-takers to share risk of new projects.
- Finally, standards and labels are required to harmonize technology specifications and guarantee safety of hydrogen production, transport and of applications.

Executive summary (5/5)

6 Proposed Pilot Projects

Nine catalytic projects across the mobility, industrial and buildings sectors have been identified to kickstart the hydrogen economy in the Valley.

Across Johannesburg, Durban/Richards Bay and Mogalakwena/Limpopo, we have identified ~15 projects of interest in the Valley, with 9 promising pilot projects that should be the near-term focus of Valley developers.

In the mobility sector, there is already momentum in place to deploy mining trucks (e.g., project Rhyno in Mogalakwena) and heavy-duty trucks along the N3 corridor. Thorough analysis and a stakeholders meeting indicated piloting mobility applications in the Durban and Richards Bay port environment (e.g., forklifts), public buses and metropoles and berthing activities in the port of Durban powered by fuel cells. For longer-term activities, marine bunkering for ammonia could be deployed, as hydrogen in the maritime sector is a strategic priority[1] though not yet cost competitive. A fuel cell train between Durban and Richards Bay could be interesting once the technology is further developed.

The industrial sector already sees many pilot projects underway that could be supported by this project. Sasol has committed to developing ethylene and ammonia from green hydrogen. Green steel is a national priority, and there could be an opportunity to pilot green steel production with Arcelor Mittal at one of its sites near Johannesburg. The government is interested in reducing emissions in the paper and pulp sector, presenting an opportunity for Durban-based paper mills to switch from natural gas fuel to hydrogen.

In the buildings sector, the Limpopo Science and Technology Park, as well as Anglo-American corporate office buildings in Rustenburg, have already planned to install fuel cells for power. Other pilot opportunities have been identified on the field of public office buildings in metropoles and airport buildings at OR Tambo & King Shaka airports.[2] Data centres and corporate headquarters/private office buildings see rising interest in hydrogen fuel cells for stationary power, with potential for rapidly growing demand in the near future.[3]

Overview of Hydrogen Pilot Projects

☐ Selected as pilot

🟢 Johannesburg 🔵 Durban / Richards Bay 🟣 Mogalakwena

	Hubs	Projects
Mobility	🟢 🔵	☐ Buses conversion in Johannesburg, Pretoria & Durban
	🟣 🔵	☐ Mining trucks
	🔵	☐ FC drivetrain forklifts in Durban and Richards Bay ports
	🟢	☐ Forklifts and heavy-duty trucks in the Rustenburg area
	🟢 🔵	☐ Heavy duty trucks conversion with refueling stations
	🔵	Freight Trains between Durban & Richards Bay
	🔵	Marine bunkering for ammonia powered bulk carriers
	🔵	Berthing activities powered by H2 FC
Industry	🟢	☐ Ethylene in Sasolburg
	🟢	☐ Ammonia in Sasolburg
	🟢	Iron & steel with ArcelorMittal (e.g., Vereeniging & Vanderbijlpark)
	🔵	Durban paper mills converting natural gas to H2
Buildings	🟣	☐ Data center in Limpopo Science & Technology Park power supply
	🟢	☐ Anglo American corporate office buildings in Rustenburg
	🟢 🔵	Public offices in Johannesburg, Pretoria and Durban
	🟢 🔵	Buildings in OR Tambo & King Shaka International Airport

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(1) Ricardo, 2021

(2) Alternatively, airports may integrate fuel cells through mobility applications (e.g., buses, operational vehicles)

(3) Demand not sized in this report due to lack of data

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Developing a hydrogen economy has become a strategic priority for South Africa

Hydrogen provides a significant opportunity for economic development in South Africa.

The development of a local hydrogen economy bears the potential of a sizeable impact to boost **economic activities and job creation** (e.g., development of new industries, leveraging South Africa's solar and wind resources, valorization of platinum resources in the region), while contributing to decarbonization efforts.

In this year's Station of the Nation address, President Ramaphosa cited hydrogen fuel cells as an alternative energy source as a **national priority**.

Hydrogen is a contributor to South Africa's decarbonization objectives, and green targets at the sector level.

As a signatory to the Paris agreement, South Africa has planned to **reduce carbon emissions with a net-zero target by 2050**. While the backbone of its strategy is the IRRP (Renewable energy program), H2 serves as a vehicle to leverage new green RES and decarbonize hard to abate sectors.

In parallel, different sectors in South Africa are **launching their own green strategies** (e.g., Green Steel Strategy, Green Buildings Strategy), which will incorporate H2 as a lever.

Global commitments towards hydrogen create an opportunity for South Africa to engage in energy export at the international level.

The Hydrogen Valley positions South Africa for an export market through its **access to ports and strong solar irradiation**; however, it is important to ensure local supply chain, development of workforce skills to support the sector and security of supply to rapidly develop and scale hydrogen infrastructure, achieve economies of scale and consolidate domestic demand in preparation for export.

In light of this potential, a national hydrogen society roadmap is underway to capture the hydrogen potential in South Africa

Hydrogen Society Baseline Assessment Report

DRAFT

Draft version 2.0

Department of Science & Innovation a

Section A: Understanding South Africa’s Hydrogen Opportunity

The roadmap focuses on national ambitions, sector prioritization, overarching policy framework and macro-economic impact of the hydrogen economy throughout South Africa

- Assessment of ambitions and role/value of H2 for South Africa energy mix; understanding key drivers of hydrogen economy
- Assessment of South Africa’s existing hydrogen environment
- Overview of hydrogen value chain and how it might be established in South Africa, including storage, transportation and off-take
- Future scenarios of possible evolutions of H2 competitiveness and uptake across sectors at national level
- Estimations of hydrogen production costs
- Assessment of national policy initiatives to create the right framework for H2 development
- Macro-economic assessment at national level (GDP creation)
- Guiding Principles for a South Arica Hydrogen Economy
- Stakeholder perspectives on evolving hydrogen economy

The Hydrogen Valley roadmap study was intended to complement the National Strategy, with the Hydrogen Valley being the first geographic area of focus within South Africa and a mission to identify concrete projects (*see next page*)

Our objective is to kickstart a South African hydrogen economy through the creation of a Hydrogen Valley

Background

The South African government's Department of Science and Innovation (DSI), in partnership with Anglo-American, Bambili Energy and ENGIE are looking into opportunities to transform the Bushveld complex and larger region around Johannesburg, Mogalakwena and Durban into a **Hydrogen Valley.**

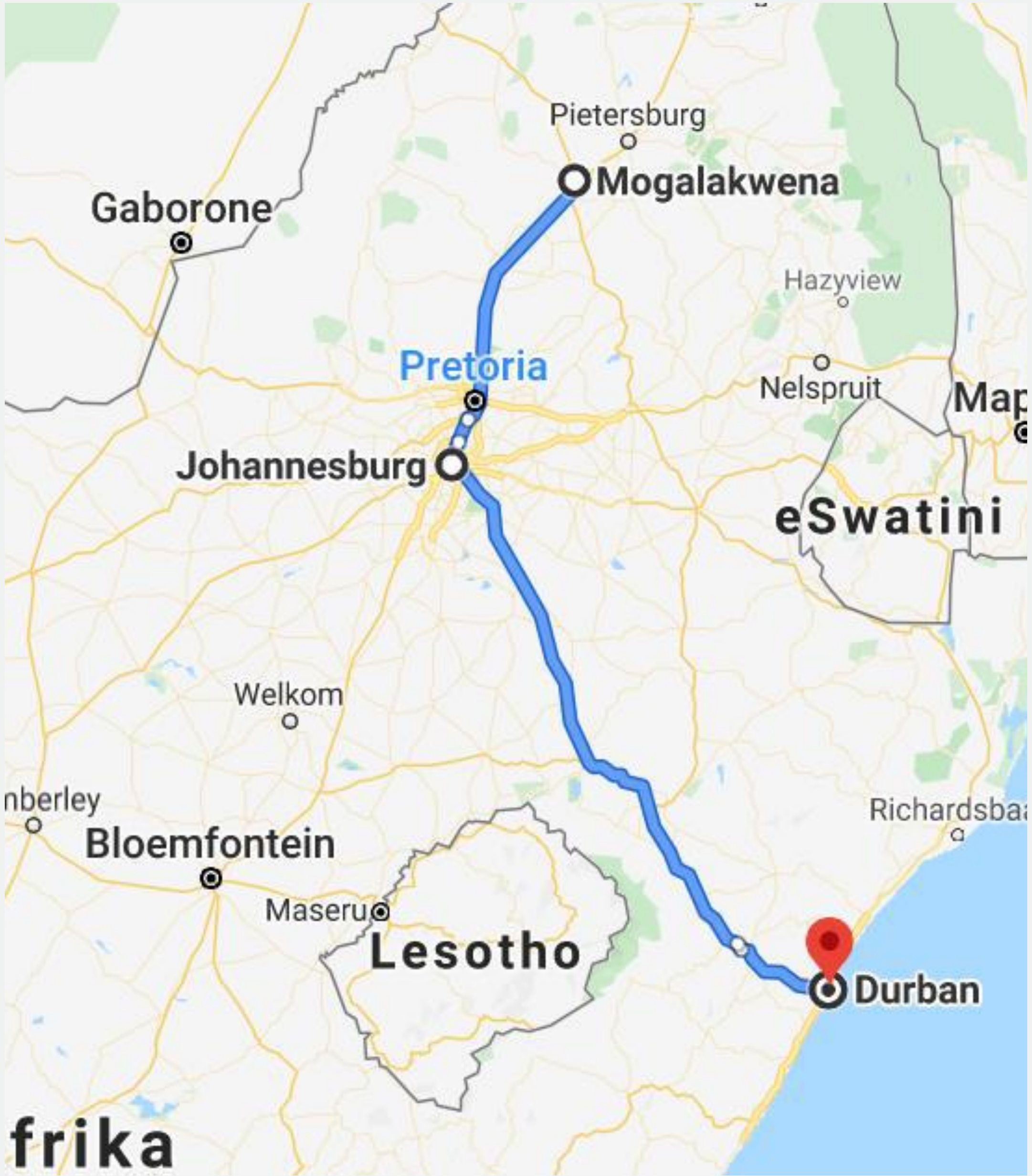
The selection of the corridor from Durban to Mogalakwena was based on existing hydrogen potential to switch many of the industrial, mobility and buildings activities to hydrogen fuel or feedstock. For example, the N1 corridor stretching form Durban and Johannesburg presents an opportunity to deploy Hydrogen trucks at scale. Pilot projects for H2 mining vehicles are already being piloted in Mogalakwena. The N3 corridor stretching from Durban and Johannesburg presents an opportunity to deploy Hydrogen trucks at scale; a project already under review that brings multiple benefits to the area including improvements to air pollution. In addition, projects for H2 mining vehicles are already being piloted in Mogalakwena. Finally, there is an opportunity to develop hydrogen in the maritime sector through the ports of Durban and Richards Bay.

What is a Hydrogen Valley?

A Hydrogen Valley aggregates multiple demand segments along key hydrogen production routes within a specific geographic region. Hydrogen Valleys have multiple advantages:

- Savings through sharing of infrastructure investments
- Cost competitiveness of H2 production through economies of scale
- Rapid ramp-up of hydrogen production and fast-tracking local supply chain development in a country/region
- Leverage as an incubator for pilot H2 projects in new applications and for related skills development

Within the Valley, project sponsors are interested in identifying hydrogen hubs which are local areas with high concentration of hydrogen customers/off-takers and nearby hydrogen producers. Hubs may also extend to neighbouring areas such as Johannesburg extending towards Rustenburg, mimicking a hub and spoke configuration.



A Hydrogen Valley offers many benefits to kickstarting the development of hydrogen projects

Developing a Hydrogen Valley through a hub-based approach sees the following benefits:

Future-proofing investments

In a hub-based analysis, we conduct a techno-economic assessment of the viability of the community, taking into account future evolutions of technology costs and regulation, in addition to **actual demand** from players already existing in the Valley. The techno-economic assessment acts as a business viability assessment to ensure that hydrogen projects are viable in the hub.

De-risking investments

The hub-based approach could help in de-risking investments by identifying a diversified set of off-takers in the hub across many sectors. De-risking could also be enabled through shared infrastructure investments between off-takers and producers.

Ensuring long-term commitment across stakeholders

Working at a hub-level allows for dialogue with possible project sponsors and off-takers, establishing a shared vision for the community and locking-in long-term commitment with hub members. A long-term commitment also allows for investments in skills development within the community and sets a foundation for developing local supply chains and unlocking enabling policy frameworks.

Building on existing funding opportunities

Several opportunities exist for hydrogen development in South Africa, especially from international donors. Organizing communities into hubs with a clear business case for development hydrogen projects creates a framework for applying for project funding and strengthens applications through proven viable projects.

Our Mission was to identify and design hubs in the Hydrogen Valley, assess economic viability and understand impacts on the hydrogen society

The goal of this study was to identify concrete, catalytic project opportunities in promising H2 hubs to kickstart H2 activities in the region. Promising ongoing initiatives like the H2 corridor project were leveraged in the selection of the hubs.

A techno-economic analysis was carried out to assess the business case of identified projects, map their potential for positive social impact and define necessary policy actions to create the conditions for implementation.

Project Outcomes:

- Select up to **3 hydrogen** hubs to kickstart the hydrogen economy and the Hydrogen Valley
- Complete a bottom-up assessment of technical **H2 demand potential** in each hub, based on actual companies and mobility operators already located in the hub
- Understand **cost of hydrogen production** in the hub, possible sites for production and green premium
- Select concrete projects in each of the hubs across all demand segments, with a **selection of concrete pilot projects for the near term**
- Analyse **macro impact** of these hydrogen projects on jobs, GDP and the just transition, as well as on the platinum sector
- Create an overview of **regulatory and policy enablers** required to kickstart pilot projects

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Our methodology followed a 6-step process:

	A Size potential demand	B Assess supply	C Form hubs	D Assess macro impacts	E Identify policy enablers	F Identify pilot projects
Activities	• Map existing **H2 demand anchors** across mobility, industry and transport sectors • **Interview stakeholders** to understand ambition and planned hydrogen off-take projects • Create **uptake curves for hydrogen** per subsector based on competitiveness	• Identify **supply sites** within hubs, by identifying locations close to demand, with access to water, storage, electricity etc. • Calculate **LCOH** of gray, blue and green hydrogen • Identify **existing hydrogen supply projects**	• Map supply sites and demand sites onto **hub map** • Assess **H2 transport method** from producer to off-taker	• Assess **macro impact** (GDP, jobs) using multipliers • Qualitatively assess **jobs impact**	• Identify **barriers** to project deployment and scale up • Develop guiding principles for policy selection • Understand policy options • Understand existing options • **Recommend policy options**	• Develop criteria for **pilot project selection** • Vet criteria with stakeholders • Select pilots • Create **timeline for deployment**
Demand	• Initial view on hydrogen demand • Hypothesis of hubs	• LCOH • Hubs selected	• Hub map • Transport mode and cost	• Pilot project overview and timeline	• Policy/regulatory recommendations	• Pilot project overview and timeline

A Size Potential Demand

The goal of this phase was to understand the technical potential of hydrogen demand within the Valley across different sectors. This demand mapping enabled us to identify locations with potentially high demand for H2 to select as hubs.

We mapped different potential usage for hydrogen across the mobility (fuel for vehicles), industry (catalyst, heat), mining (fuel for mining trucks) and building sectors (powering and back up). In each of these sectors, we identified potential main off-takers in the Valley and the amount of energy that could technically be replaced by hydrogen.

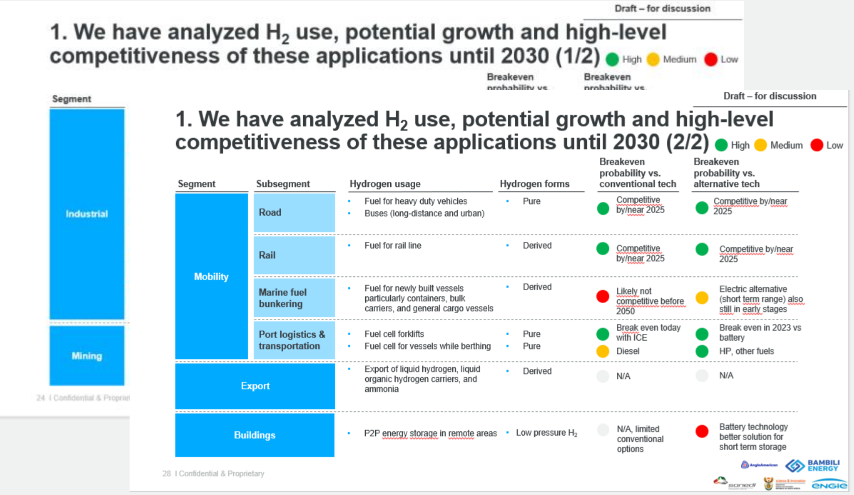
We then sized hydrogen uptake through quantitative and qualitive analysis:

A. Quantitative. To understand what share of this energy demand could be replaced by hydrogen, we created uptake curves for hydrogen by sectors and subsectors, based on TCO competitiveness, or the point at which a hydrogen application like a Fuel Cell truck becomes cost competitive with its conventional alternative such as a diesel truck. The uptake curves assumed a low uptake of hydrogen until the hydrogen application cost breaks even with its conventional alternative (e.g., 2025, 2030), at which point hydrogen penetration in the sector starts to increase.

More specifically, we considered an accelerated case and a low case, differing by the uptake start date. Applying these uptake curves to total technical hydrogen demand enabled us to map demand of hydrogen in the Valley and identify hubs where off-takers of hydrogen were significant.

B. Qualitative. To complement this analysis, we interviewed stakeholders from each sector and sub-sector to understand their ambition and planned hydrogen off-take projects as well as incorporated planned hydrogen application projects into the demand analysis. We also held a workshop with participants across the hydrogen and clean energy ecosystem in South Africa, seeking their feedback on promising segments for hydrogen demand and our first analysis on sizing demand potential.

1 Mapping of possible H2 demand across sectors



Draft – for discussion

1. We have analyzed H_2 use, potential growth and high-level competitiveness of these applications until 2030 (1/2) ● High ● Medium ● Low

Segment

Industrial

Mining

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Draft – for discussion

1. We have analyzed H_2 use, potential growth and high-level competitiveness of these applications until 2030 (2/2) 🟢 High 🟡 Medium 🔴 Low

Segment	Subsegment	Hydrogen usage	Hydrogen forms	Breakeven probability vs. conventional tech	Breakeven probability vs. alternative tech
Mobility	Road	Fuel for heavy duty vehicles Buses (long-distance and urban)	Pure	🟢 Competitive by/near 2025	🟢 Competitive by/near 2025
	Rail	Fuel for rail line	Derived	🟢 Competitive by/near 2025	🟢 Competitive by/near 2025
	Marine fuel bunkering	Fuel for newly built vessels particularly containers, bulk carriers, and general cargo vessels	Derived	🔴 Likely not competitive before 2050	🟡 Electric alternative (short term range) also still in early stages
	Port logistics & transportation	Fuel cell forklifts Fuel cell for vessels while berthing	Pure Pure	🟢 Break even today with ICE 🟡 Diesel	🟢 Break even in 2023 vs battery 🟢 HP, other fuels
Export		Export of liquid hydrogen, liquid organic hydrogen carriers, and ammonia	Derived	○ N/A	○ N/A
Buildings		P2P energy storage in remote areas	Low pressure H_2	○ N/A, limited conventional options	🔴 Battery technology better solution for short term storage

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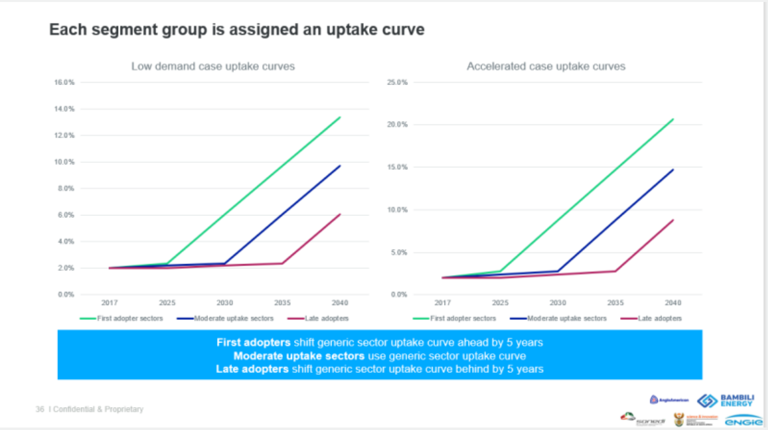
2 Create uptake curves for hydrogen



Each segment group is assigned an uptake curve

First adopters shift generic sector uptake curve ahead by 5 years
Moderate uptake sectors use generic sector uptake curve
Late adopters shift generic sector uptake curve behind by 5 years

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3 Sizing of future demand for Hydrogen in the Valley

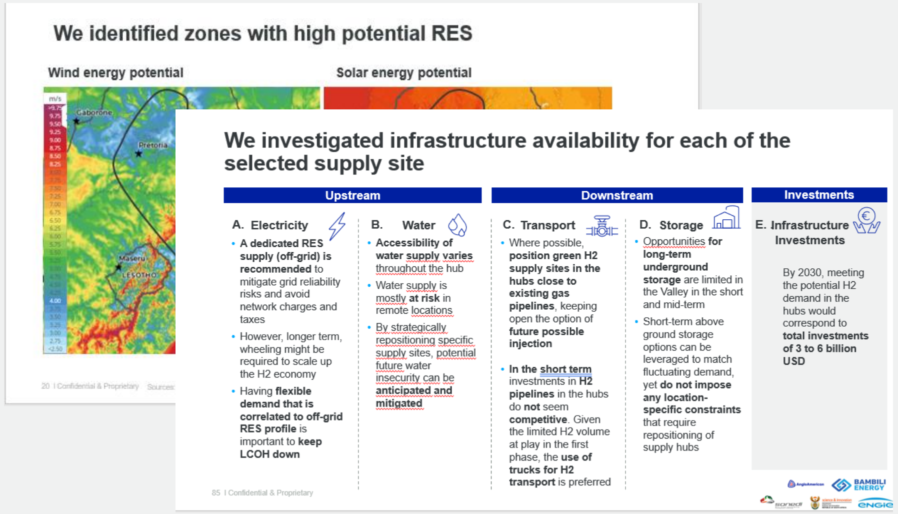
B Assess Supply

The goal of this phase was to identify how and where hydrogen could be supplied, and the costs it would represent. The results of this phase also supported our identification and selection of hydrogen hubs.

We identified potential locations for hydrogen production based on proximity to possible off-takers and access to high renewable energy potential. Once a few sites were selected based on these criteria, we further screened sites for access to water pipeline, gas infrastructure and **storage**. We also considered that as the location and size of existing hydrogen supply projects could be a starting point for hydrogen infrastructure, they were also considered when assessing possible supply sites.

We calculated Levelized Cost of Hydrogen (LCOH) at each production site including the cost of installing off-grid renewable energy supply and the cost of the electrolyzer. Green hydrogen production costs were compared to blue and grey hydrogen to understand the green premium. The possibility of transporting electricity or hydrogen from areas outside the hub, such as the Northwest, to our off-takers within the hub was assessed.

1 Infrastructure analysis resulting in optimal production site selection



We identified zones with high potential RES

Wind energy potential

Solar energy potential

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We investigated infrastructure availability for each of the selected supply site

Upstream		Downstream		Investments
A. Electricity	B. Water	C. Transport	D. Storage	E. Infrastructure Investments
• **A dedicated RES supply (off-grid) is recommended** to mitigate grid reliability risks and avoid network charges and taxes • However, longer term, wheeling might be required to scale up the H2 economy • Having **flexible demand that is correlated to off-grid RES profile** is important to **keep LCOH down**	• **Accessibility of water supply varies** throughout the hub • Water supply is mostly **at risk** in remote locations • By strategically repositioning specific supply sites, potential future water insecurity can be **anticipated and mitigated**	• Where possible, **position green H2 supply sites in the hubs close to existing gas pipelines**, keeping open the option of **future possible injection** • **In the short term** investments in **H2 pipelines** in the hubs do **not** seem **competitive**. Given the limited H2 volume at play in the first phase, the **use of trucks for H2 transport** is preferred	• Opportunities **for long-term underground storage** are limited in the Valley in the short and mid-term • Short-term above ground storage options can be leveraged to match fluctuating demand, yet **do not impose any location-specific constraints** that require repositioning of supply hubs	By 2030, meeting the potential H2 demand in the hubs would correspond to **total investments of 3 to 6 billion USD**

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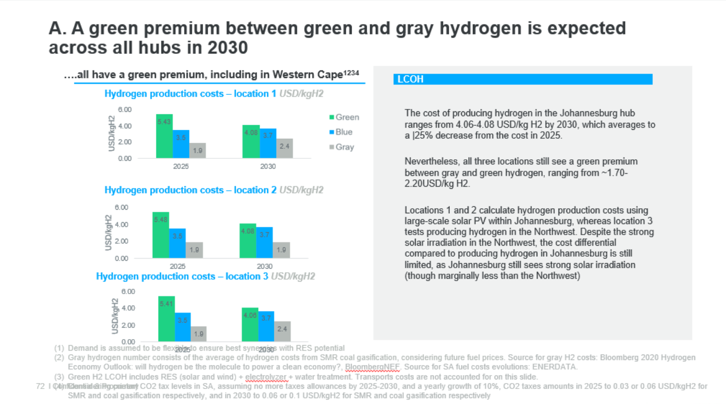
2 Hydrogen production (LCOH) cost assessment



A. A green premium between green and gray hydrogen is expected across all hubs in 2030

….all have a green premium, including in Western Cape[1234]

LCOH

The cost of producing hydrogen in the Johannesburg hub ranges from 4.06-4.08 USD/kg H2 by 2030, which averages to a |25% decrease from the cost in 2025.

Nevertheless, all three locations still see a green premium between gray and green hydrogen, ranging from ~1.70-2.20USD/kg H2.

Locations 1 and 2 calculate hydrogen production costs using large-scale solar PV within Johannesburg, whereas location 3 tests producing hydrogen in the Northwest. Despite the strong solar irradiation in the Northwest, the cost differential compared to producing hydrogen in Johannesburg is still limited, as Johannesburg still sees strong solar irradiation (though marginally less than the Northwest)

(1) Demand is assumed to be flexible to ensure best synergies with RES potential
(2) Gray hydrogen number consists of the average of hydrogen costs from SMR coal gasification, considering future fuel prices. Source for gray H2 costs: Bloomberg 2020 Hydrogen Economy Outlook: will hydrogen be the molecule to power a clean economy?, BloombergNEF. Source for SA fuel costs evolutions: ENERDATA.
(3) Green H2 LCOH includes RES (solar and wind) + electrolyzer + water treatment. Transports costs are not accounted for on this slide.
(4) Considering current CO2 tax levels in SA, assuming no more taxes allowances by 2025-2030, and a yearly growth of 10%, CO2 taxes amounts in 2025 to 0.03 or 0.06 USD/kgH2 for SMR and coal gasification respectively, and in 2030 to 0.06 or 0.1 USD/kgH2 for SMR and coal gasification respectively

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C Form Hubs

The goal of this phase was to identify hydrogen hubs within the Valley, based on demand and supply assessments and contributions towards the just transition.

We used three criteria to identify promising hubs:

- Critical concentration of potential green H2 demand in 2030
- Green H2 supply potential**:** planned H2 projects already underway; access to adequate renewable resources including wind and sun; water and storage infrastructure
- Just transition alignment: ability to scale up within the hub and outside the hub; existence of political support; alignment with national roadmap; policy/strategic objectives such as job creation

Identifying hubs enabled us to map supply and demand sites within a given territory. Leveraging the map, we assessed the optimal transport mode and method from producer to off-taker (e.g., pipeline, liquified hydrogen transport by truck). We also calculated the additional cost of transporting hydrogen to various off-taker sites within the hub.

At the completion of this phase, we had identified catalytic hydrogen projects within each hub, sized corresponding hydrogen demand and assessed investment required to build H2 supply (offsite RES and electrolyzers) to meet this demand.

1 Hub identification

Each hub has its own demand and supply potential as well as drivers and barriers for localized green H_2 production

○ <15 kt ◐ 16-50 kt ● >51 kt 🟢 High 🟡 Medium 🔴 Low

	Hub / Filter criteria	① 2030 yearly H_2 demand potential	② H_2 supply potential	③ Just transition capability	Main drivers	Main barriers
A	Johannesburg (West Rand / Rustenburg)	●	🟢	🟢	Competitiveness to **replace feedstock / catalyst in H_2 based chemical** sectors (ammonia, methanol, peroxide) **Iron & Steel**, aluminum and cement industries account for >a third of hydrogen uptake Sasol's high ambition in Sasolburg	Competitiveness against **blue H_2** (with carbon capture) **Shrinking** of **oil refining** sector
B	Durban / Richards Bay	●	🟡	🟢	**H_2 FC trucks via N3 freight** route between Johannesburg-Durban Conversion of rail to H2 fueled **Fuel for port logistics** and potential export of H_2 and derivatives **Oil refining** feedstock substitution in near term	Competitiveness against **blue H_2** (with carbon capture) Competition with EV or rails **Shrinking** of **oil refining** sector
C	Mogalakwena / Limpopo	◐	🟢	🟢	H_2 fueled **mining trucks TCO** reaching breakeven vs. diesel **by 2030** Fuel cells drives development of **platinum economy**	**H_2 transportation from centralized production** to different mine off-takers (up to 300 km), requiring **more localized production sites** Access to **water infrastructure**

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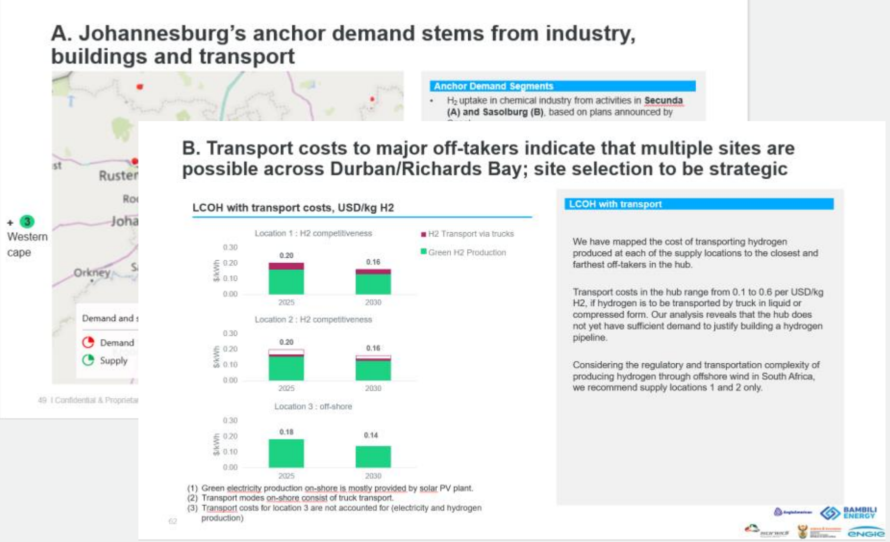
2 Mapping of demand and supply sites and assessment of transport options



A. Johannesburg's anchor demand stems from industry, buildings and transport

Anchor Demand Segments

- H_2 uptake in chemical industry from activities in Secunda **(A) and Sasolburg (B)**, based on plans announced by

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B. Transport costs to major off-takers indicate that multiple sites are possible across Durban/Richards Bay; site selection to be strategic

LCOH with transport costs, USD/kg H2

(1) Green electricity production on-shore is mostly provided by solar PV plant.
(2) Transport modes on-shore consist of truck transport.
(3) Transport costs for location 3 are not accounted for (electricity and hydrogen production)

LCOH with transport

We have mapped the cost of transporting hydrogen produced at each of the supply locations to the closest and farthest off-takers in the hub.

Transport costs in the hub range from 0.1 to 0.6 per USD/kg H2, if hydrogen is to be transported by truck in liquid or compressed form. Our analysis reveals that the hub does not yet have sufficient demand to justify building a hydrogen pipeline.

Considering the regulatory and transportation complexity of producing hydrogen through offshore wind in South Africa, we recommend supply locations 1 and 2 only.

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D Assess Macro Impacts

The goal of this phase was to understand the macroeconomic impacts of the hydrogen economy, based on the development of concrete projects identified for the Hydrogen Valley.

First, we provided a quantitative indication of the GDP, employment and tax revenues impacts so the projects identified for the Hydrogen Valley would materialize. We used the multiplier methodology, based on a Social Accounting matrix capturing the structure of an economy, and determined the direct and indirect effect of an expenditure in one sector on the other sectors. These multipliers are aligned with the National Hydrogen Society Roadmap.

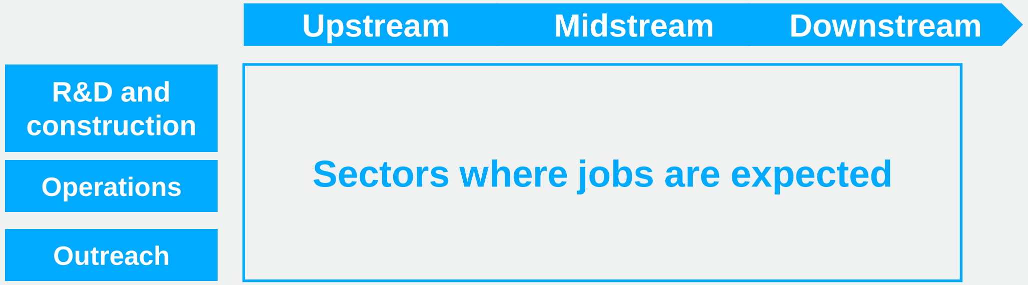
Second, we conducted an in-depth examination in employment effects by examining the sectors across the hydrogen value chain (e.g., resource, production, conversion, transport, storage and final applications) where jobs could be created based on our proposed hydrogen projects. We also conducted a qualitative assessment on the new, reinforced or converted jobs created by the pilot projects.

The intention of this exercise was not to forecast the socioeconomic impact, but rather to provide an order of magnitude impact of the contribution of hydrogen projects in the Valley should the full vision of the Hydrogen Valley be achieved.

1 Indication of quantitative effects of hydrogen investment and operation expenditures on:

- **GDP**
- **Tax revenue**
- **Employment**

2 Qualitative indication of employment impact along H2 value chain



E Identify Policy Enablers

The goal of this phase was to identify barriers that could hinder the launch of identified hydrogen and to provide corresponding policy and regulatory recommendations to unlock these barriers.

First, we identified current barriers to the development of hydrogen in South Africa, based on four elements: electricity, hydrogen production, hydrogen uptake and infrastructure.

The analysis of these barriers enabled us to synthetize the main guiding principles for policymaking that would encourage the development of hydrogen projects in the hub. These policy/regulatory instruments were both on the supply side (production of hydrogen) and demand side.

We developed a framework to map out all possible policy options to stimulate a hydrogen economy based on guidelines from international organizations and case studies/best practices from other countries. We also mapped existing regulation in South Africa to this framework to understand where progress had been made and where we could further develop the regulatory and policy environment to support the Hydrogen Valley.

Using the guiding principles as criteria, we selected the most pertinent policy and regulatory enablers required in the Hydrogen Valley. We provided a timeline recommendation with the different policy options and leveraged existing policies if applicable at the Hydrogen Valley and pilot project level ranging from quick-wins to longer-term enablers for scale up in the Valley.

1 Identify barriers to hydrogen project deployment and scale up, based on several dimensions

Electricity	H2 production	H2 demand	H2 production

Regulation and planning barriers

Cost barriers

2 Develop guiding principle for policy selection

Supply
- Ease deployment of RES and electrolyzers
- Make near-term CAPEX affordable

Demand
- Encourage H2 applications through financial incentives
- Create momentum for future demand
- Formalize hydrogen sector through standard and labels

3 Recommend a timeline of policy options, leveraging on existing policy if applicable, at hydrogen valley and pilot project level

Quick wins → Scaling up → Expansion

F

Identify Pilot Projects

The goal of this phase was to identify catalytic pilot projects within the selected hydrogen hubs to provide a concrete development roadmap.

We developed 3 criteria, vetted with stakeholders, for selecting catalytic pilot projects within the hydrogen hubs: the possibility to scale existing use cases, the total cost of ownership of the projects compared to the prevailing carbonized alternatives in the short to medium-term, and the relevance of a project to the strategic green hydrogen ambitions and just transition objectives of the Hydrogen Valley.

Based on these criteria, we built a list of pilot projects with priority projects selected for the short- and medium-term. Project phasing was based on two criteria: first, **a concrete momentum and willingness of actors** based on information shared during interviews and workshops; second, we considered whether projects could be **modular** or scaled up starting with a small pilot and then expanded in modules. This approach would allow for limited upfront capital investments in the pilot stage and gradual scaling-up of investments over time.

For each prioritized and near-term pilot project, we provided a project charter including the description of the project, the potential partners and players, the economic and competitiveness aspects to be considered, the just transition factors implied, the existing momentum, regulatory/policy enablers required and a roadmap of their deployment.

1 Selection of pilot projects based on three criteria vet by stakeholders

Existing use cases to be scaled

Total cost of ownership competitiveness

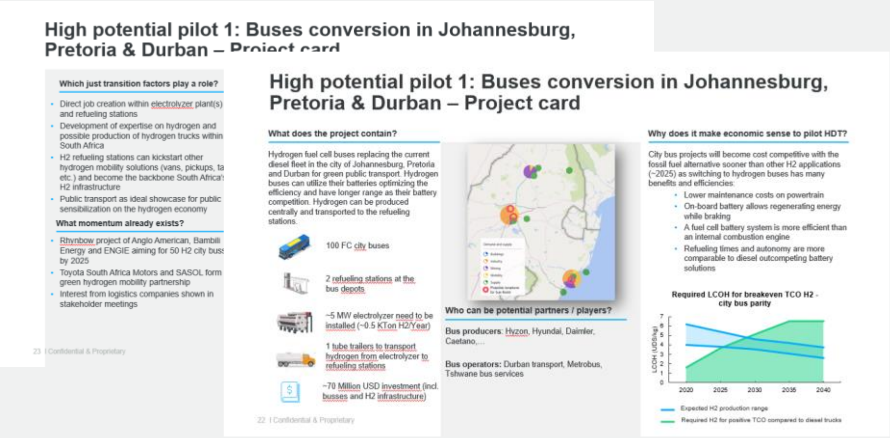
Just transition objectives

2 Prioritization of pilot projects

Concrete momentum and willing actors

Modularity of applications

3 Deep dive on development roadmap of prioritized pilot projects



High potential pilot 1: Buses conversion in Johannesburg, Pretoria & Durban – Project card

Which just transition factors play a role?

- Direct job creation within electrolyzer plant(s) and refueling stations
- Development of expertise on hydrogen and possible production of hydrogen trucks within South Africa
- H2 refueling stations can kickstart other hydrogen mobility solutions (vans, pickups, ta etc.) and become the backbone South Africa' H2 infrastructure
- Public transport as ideal showcase for public sensibilization on the hydrogen economy

What momentum already exists?

- Rhynbow project of Anglo American, Bambili Energy and ENGIE aiming for 50 H2 city buss by 2025
- Toyota South Africa Motors and SASOL form green hydrogen mobility partnership
- Interest from logistics companies shown in stakeholder meetings

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High potential pilot 1: Buses conversion in Johannesburg, Pretoria & Durban – Project card

What does the project contain?

Hydrogen fuel cell buses replacing the current diesel fleet in the city of Johannesburg, Pretoria and Durban for green public transport. Hydrogen buses can utilize their batteries optimizing the efficiency and have longer range as their battery competition. Hydrogen can be produced centrally and transported to the refueling stations.

100 FC city buses

2 refueling stations at the bus depots

~5 MW electrolyzer need to be installed (~0.5 KTon H2/Year)

1 tube trailers to transport hydrogen from electrolyzer to refueling stations

~70 Million USD investment (incl. busses and H2 infrastructure)

Who can be potential partners / players?

Bus producers: Hyzon, Hyundai, Daimler, Caetano,…

Bus operators: Durban transport, Metrobus, Tshwane bus services

Why does it make economic sense to pilot HDT?

City bus projects will become cost competitive with the fossil fuel alternative sooner than other H2 applications (~2025) as switching to hydrogen buses has many benefits and efficiencies:

- Lower maintenance costs on powertrain
- On-board battery allows regenerating energy while braking
- A fuel cell battery system is more efficient than an internal combustion engine
- Refueling times and autonomy are more comparable to diesel outcompeting battery solutions

Required LCOH for breakeven TCO H2 - city bus parity

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Throughout the project, we met with 20+ stakeholders one-on-one, including government actors, think tanks specializing in hydrogen, possible hydrogen producers and above all possible off-takers to test their appetite and willingness to pay

Stakeholder classification	Priority stakeholders
Data collection – quantitative contributor	• ESRG • Anglo-American • Limpopo LEDET • Gauteng Industrial Development zone • Sasol • Busmark
Data collection – qualitative contributor	• Tongaat Hulett • CIRE • Africa Climate Foundation • RMI • Bambili Energy • Africa H2 Project • HySa CoE • CAIA • GIFA • Dept of Public Works/Infrastructure • Transnet
Key stakeholder to be consulted	• KPMG & Hydrogen Society Roadmap team • Department of Trade, Industry & Competition (steel & chemicals desks) • Department of Transport

We held a workshop, attended by 60+ players, to collect insightful inputs and build momentum on the H2 Valley concept

Workshop attendees

Mobility	TRANSNET EST 1973 BUSMARK Volkswagen JOHANNESBURG METROBUS
Industry	SOUTH·AFRICAN·IRON·&·STEEL·INSTITUTE IDC Industrial Development Corporation the dtic Department: Trade, Industry and Competition REPUBLIC OF SOUTH AFRICA sasol GAUTENGIDZ INDUSTRIAL DEVELOPMENT ZONE ArcelorMittal CAIA Chemical & Allied Industries' Association Responsible Care ISONDO PRECIOUS METALS GAUTENG Infrastructure Financing Agency we are one Sibanye Stillwater PRO ROOF STEEL & TUBE
Buildings	- Limpopo Science and Technology Park
Enablers	HySA Infrastructure Hydrogen South Africa NEDBANK UNIVERSITY of the WESTERN CAPE KPMG ENERLEQ SULA GROUP
Consortium	AngloAmerican sanedi science & innovation Department: Science and Innovation REPUBLIC OF SOUTH AFRICA BAMBILI ENERGY engie

"**Rail will allow for a smaller number of fuelling stations** than that for buses and trucks"

"**Export is a sector for consideration** more in the Kwa-Zulu Natal Hub"

"Green steel supply for export markets, **SA could be ideal destination** to develop supply chains **for green steel**"

"**Significant investment** will be required for steel mills to transition"

"One need to **start with a small project**, **increase in phases**, for example, with small onsite H2 production for mobility application"

"**Opportunity** would lie in the **different business pricing models**"

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Chapter Summary

Based on hub selection criteria, the backbone of the Hydrogen Valley is structured around the convergence of three hydrogen hubs:

Hub A. Johannesburg (JHB as hub, with spoke extension to Rustenburg and Pretoria for select demand)

- **Demand.** There is the technical potential for sizable H2 demand in the Johannesburg hub, with up to74 kt H2 by 2030, including buses and public buildings. This hub also boasts a concentration of **industrial demand** thanks to pledges of key producers/off-takers (e.g., Sasol) for H2 applications that are not yet competitive by 2030. There is also high potential for demand in fuel cells for stationary power in buildings.
- **Supply.** There are potential H2 supply sites across Johannesburg and producing at **Western Cape** that do not reduce cost of producing hydrogen despite better RES potential.
- **Just transition.** A mobility transition to green H2 in Johannesburg serves wider population and improves **air quality.** Industrial clusters around Johannesburg could share H2 resources, leading to synergies and economies of scale in hydrogen production and multiplying the socioeconomic effect of these projects.

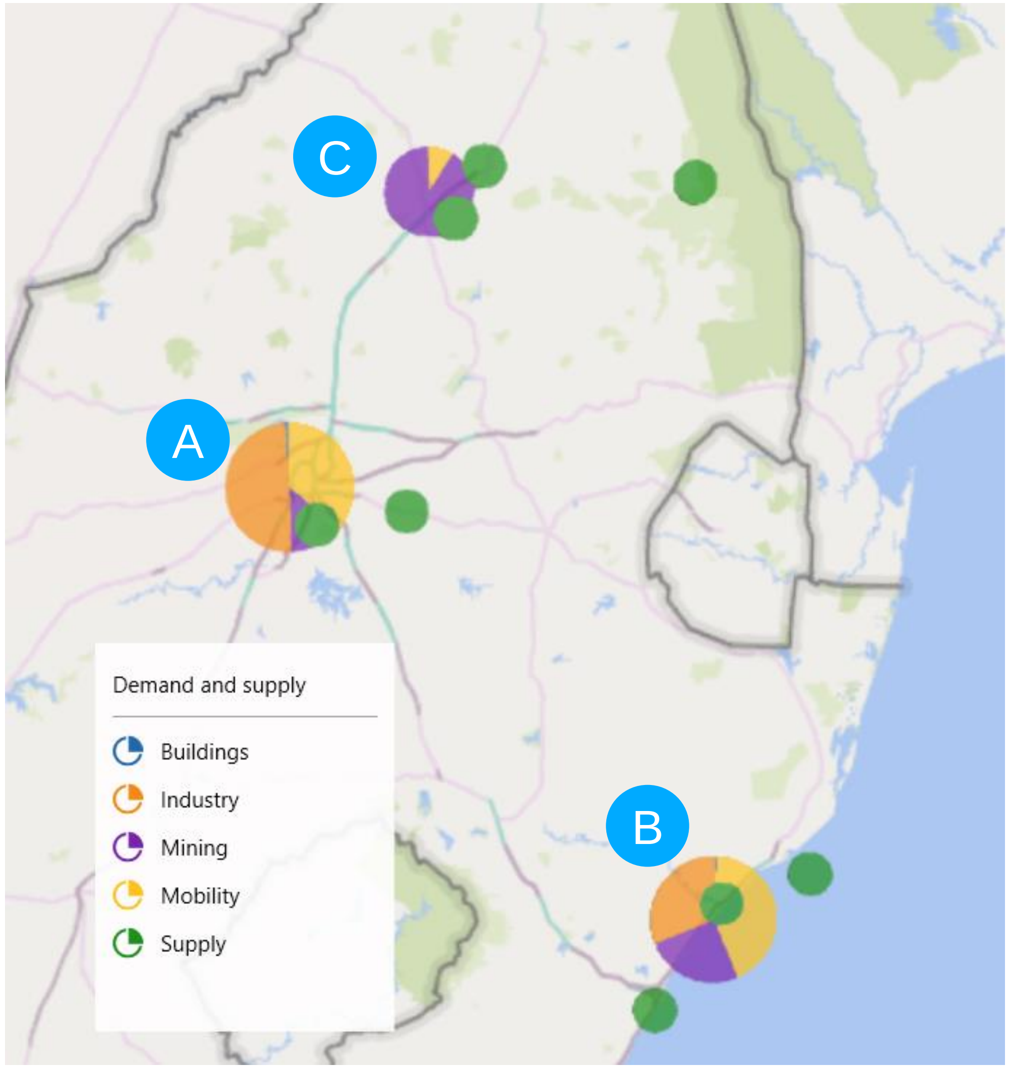
Hub B: Durban and Richards Bay

- **Demand.** Durban, similar in size to Johannesburg, is also a large demand hub and technical potential for hydrogen is seen in **heavy duty trucking** with positive business case, port operations and the addition of public buses and buildings.
- **Supply.** This hub sees strong solar PV potential and there are multiple sites for strategic placement of H2 supply (e.g., next to the N2, near the port of Durban, in Richards Bay). Offshore wind production for Richards Bay is possible, although solar PV installations are recommended as they lead to a more competitive LCOH in this region.
- **Just transition.** There is the possibility to develop **Richards Bay port** and help manage congestion at port of Durban. In addition, **marine bunkering using NH3** could have the potential to attract bulk carriers, containers, and general cargo into both Durban and Richards Bay ports that are planned for after 2030.
- **Export.** South Africa might also consider exporting H2 as ammonia from Richards Bay, although **other ports** have already been proposed as export hubs.

Hub C: Mogalakwena & Limpopo

- **Demand.** An analysis of technical potential reveals that demand may reach up to 40 kt by 2030 (high case), led by **mining trucks** TCO competitiveness.
- **Supply.** Hydrogen production costs are similar across different locations and therefore **site selection** must be based on strategic preference.
- **Just Transition.** This hub would reinforce the “green digital” strategy of the Limpopo Science and Technology Park. In addition, there are opportunities for **local job creation** from the hydrogen economy (e.g., O&M for electrolyzers and RES) and potential job development from transporting hydrogen via trucks.

The backbone of the Hydrogen Valley is structured around three hydrogen hubs



A **Johannesburg** (with expansion to Pretoria for select demand segments)

Driven by **H2-based sectors** switching from gray H2, feedstock substitution for **ethylene** production, fuel and catalyst for **iron & steel**, and **mining trucks fuel for diamond.** High potential in stationary power for buildings, and public mobility (e.g., buses)

B **Durban / Richards Bay**

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 gray H2, medium grade temperature heating, and **some export potential** (to be sized)

C **Mogalakwena/Limpopo**

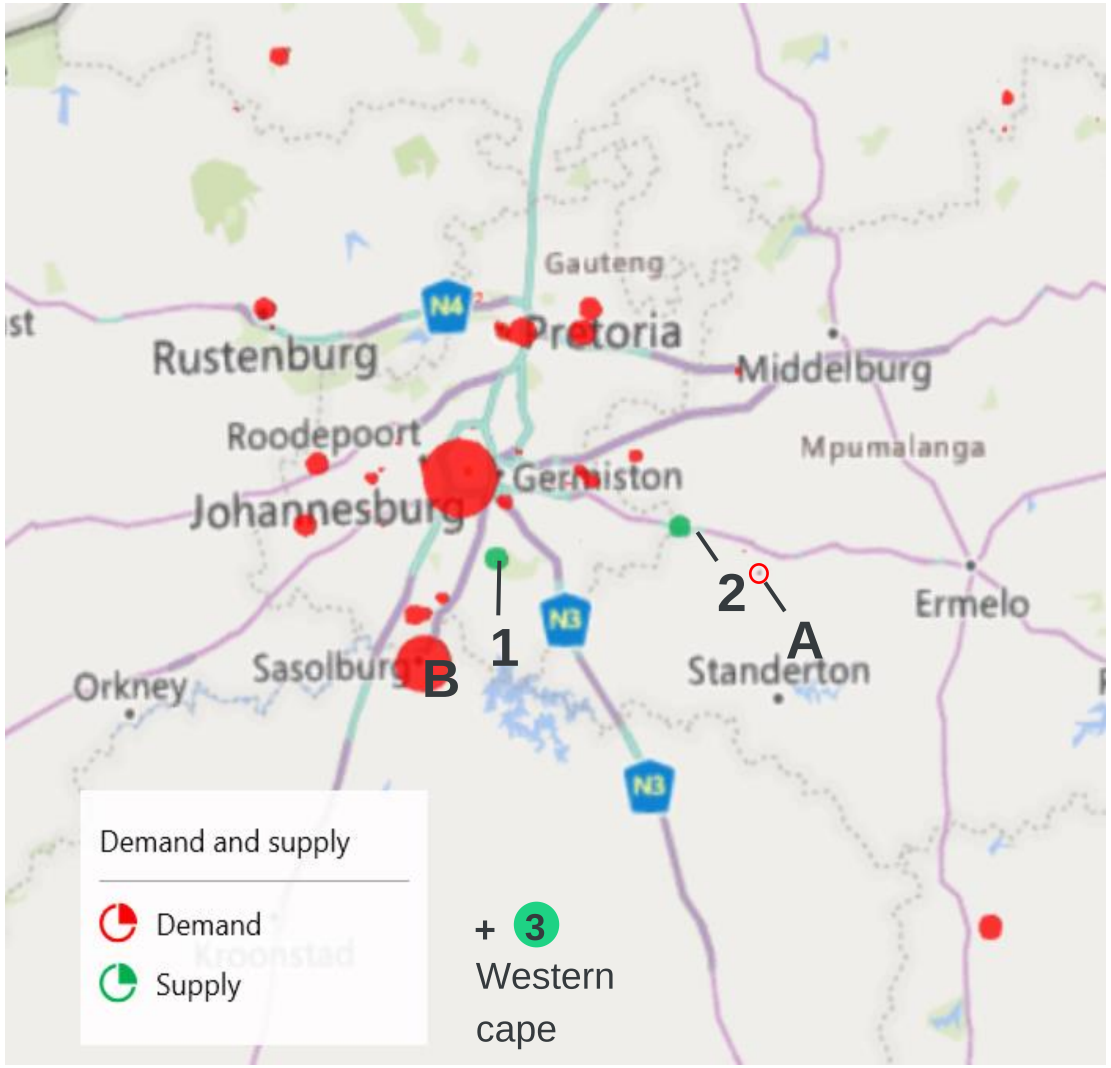
Driven by **mining trucks fuel for diamond, copper, titanium, and platinum** and some demand from heavy- and medium-duty **trucks via N1**

Each hub has its own demand and supply potential as well as drivers and barriers for localized green H2 production

○ <15 kt ◐ 16-50 kt ● >51 kt 🟢 High 🟠 Medium 🔴 Low

	Hub / Filter criteria	1 2030 yearly H2 demand potential	2 H2 supply potential	3 Just transition capability	Main drivers	Main barriers
A	Johannesburg (extension to Rustenburg/ Pretoria)	●	🟢	🟢	- Competitiveness to **replace feedstock / catalyst in H2 based chemical** sectors (ammonia, methanol, peroxide) - **Iron & Steel**, aluminum and cement industries account for >a third of hydrogen uptake - Sasol's stated ambition in Sasolburg (Sasol, 2020)	- Competitiveness against **blue H2** (with carbon capture) - **Shrinking** of **oil refining** sector
B	Durban / Richards Bay	●	🟠	🟢	- **H2 FC trucks via N3 freight** route between Johannesburg-Durban - Conversion of rail to H2 fueled - **Fuel for port logistics** and potential export of H2 and derivatives - **Oil refining** feedstock substitution in near term	- Competitiveness against **blue H2** (with carbon capture) - Competition with EV or rails - **Shrinking** of **oil refining** sector
C	Mogalakwena / Limpopo	◐	🟢	🟢	- H2 fueled **mining trucks TCO** reaching breakeven vs. diesel **by 2030** - Fuel cells have potential to enable **platinum demand** in electric mobility	- **H2 transportation from centralized production** to different mine off-takers (up to 300 km), requiring **more localized production sites** - Access to **water infrastructure**

A. Johannesburg's anchor demand stems from industry, buildings and transport



Anchor Demand Segments

- H2 uptake in chemical industry from activities in **Secunda (A) and Sasolburg (B)**, based on plans announced by Sasol
- Iron & Steel, aluminum and cement industries represent a significant share of hydrogen uptake
- Public-led H2 demand, including use in public buildings, buses and OR Tambo airport

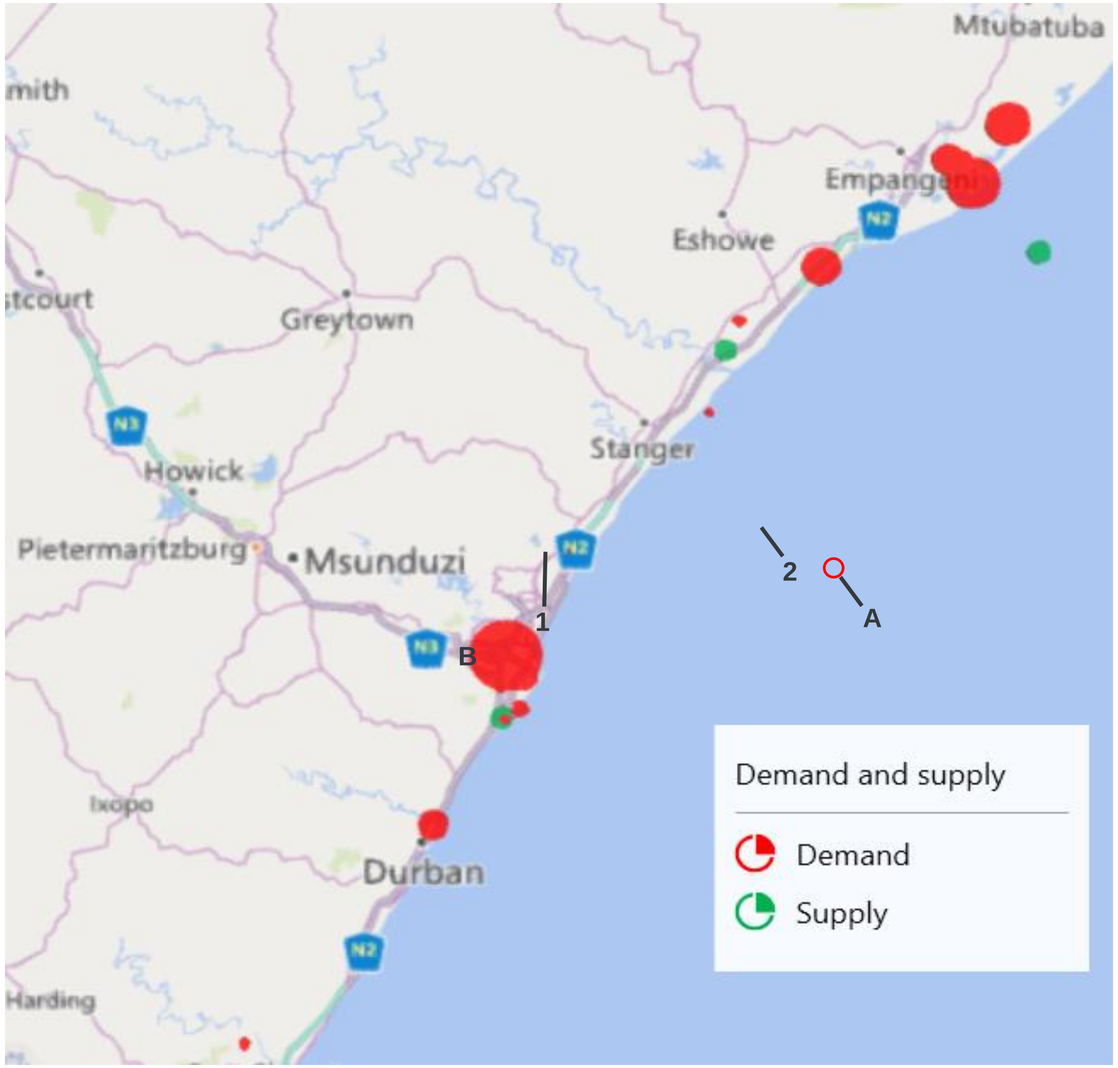
H2 supply locations

- **Location 1:** Between Sasolburg and N3, providing access to Sasolburg, filling stations along N3 and Johannesburg city
- **Location 2: Between Springs and Secunda,** also offering access to the N3 and large iron & steel off-takers
- **Location 3: Western Cape** where solar irradiation is higher

Just Transition Capability

- **Mobility** transition to green H2 in Johannesburg serves wider population and improves **air quality**
- **Industrial clusters around Johannesburg** could share H2 resources, leading to synergies and economies of scale

B. Durban hub is centered on mobility, with nearby N2 and maritime demand, although industrial demand is also notable



Anchor Demand Segments

- Growth of **H2 FC heavy- and medium-duty trucks** via N3 freight corridor
- Fuel switching in **port operations and cold ironing for ships**
- **H2 rail opportunity (long term)**
- Potential **export of H2 and its derivatives** to Europe/Asia
- **Mining and refining** sites

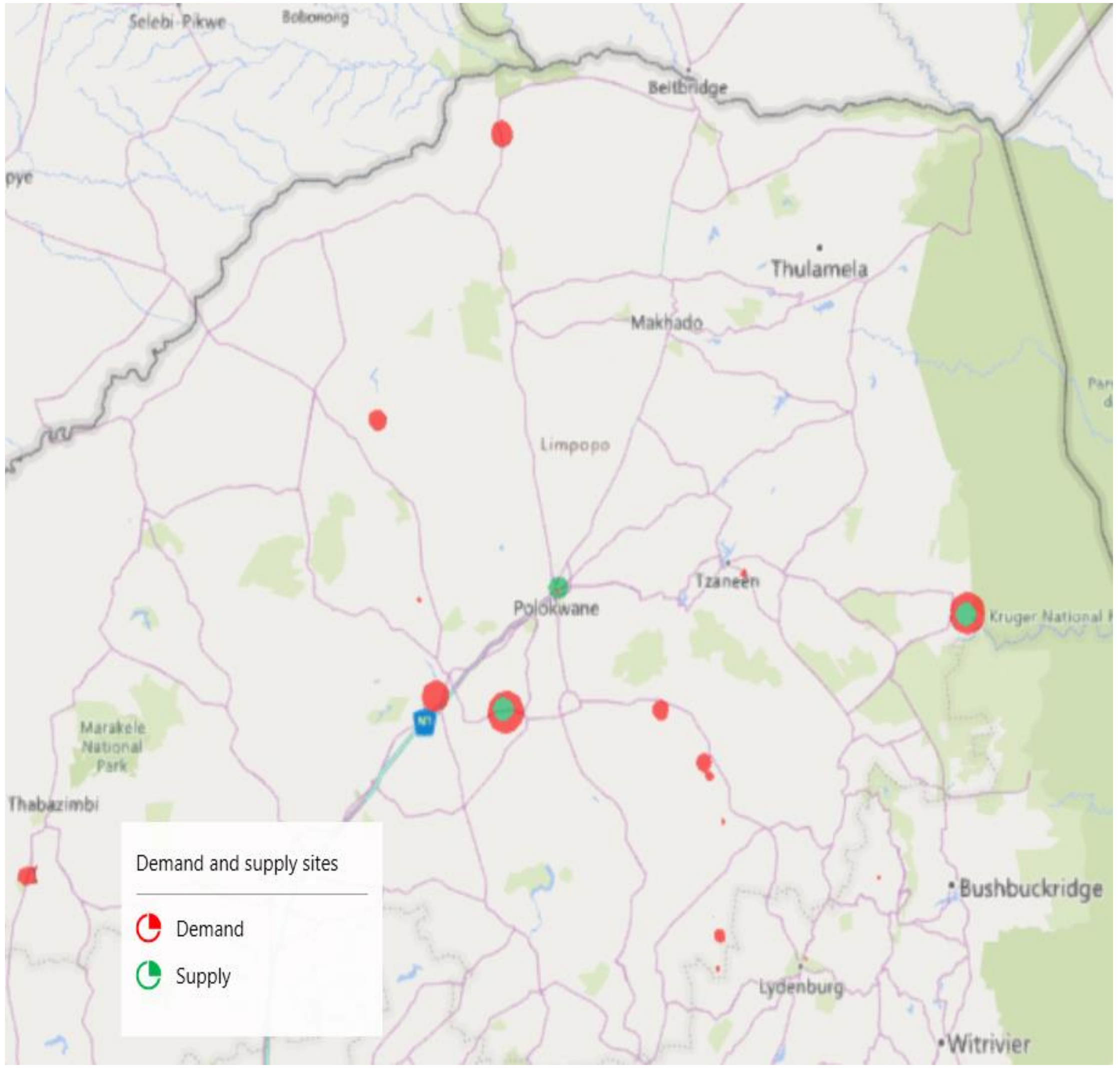
H2 supply locations

- **Location 1**: Near port of Durban to capitalize on demand from port operators, ships etc. with proximity to N3
- **Location 2**: Between, Durban and Richards Bay, to serve H2 off-takers in both port locations
- **Location 3**: Offshore wind turbines near Richards Bay

Just Transition Capability

- Potential development of **Richards Bay port**
- **Post 2030, marine bunkering using NH3** has the potential to attract bulk carriers, containers, and general cargo into both Durban and Richards Bay ports

C. Mogalakwena’s anchor demand is in the mining sector and hydrogen supply locations would be distributed across the hub



Anchor Demand Segments

- H2 fueled **mining trucks** competitiveness in near term
- **H2 FC heavy- and medium-duty trucks** via N1 freight corridor
- **Limpopo Science and Technology Park** expected to be major source of stationary power demand

H2 supply locations

- In Mogalakwena, the **distance between off-takers are significant**, therefore it is assumed that every off-taker produces its hydrogen **on-site.** The three green dots are largest off-taker locations based on which LCOH were calculated:
- Copper mine in East
- Diamond mine south of Polokwane
- Limpopo Science Park in Polokwane

Just Transition Capability

- **For Limpopo STP**, reinforcement of “green digital” strategy espoused by the park
- **Local job creation** from hydrogen economy, and potential job development from transporting hydrogen via truck

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Domestic demand per hub

Chapter Summary

Overall H2 demand for the H2 Valley could reach between 40% (low demand case) and 78% (high demand case) of expected national demand

Hub A. Johannesburg (extension to Rustenburg and Pretoria for select demand)

- Based on technical potential in the high uptake scenario, demand in Johannesburg could reach up to 74 kt by 2030
- Demand is driven by the industrial sector, with large H2 uptake in chemical industry (e.g., ammonia and ethylene)
    - In Johannesburg, chemical & refining demand has been informed by Sasol announcements, despite unfavorable LCOH for green H2
- Significant demand contribution from Heavy Duty vehicles along the N2 and public buses in both Johannesburg and Pretoria
- Opportunity to pilot hydrogen in buildings should public buildings in Pretoria and Johannesburg pilot fuel cells. There is a small opportunity at OR Tambo Airport and yet high potential for stationary fuel cell demand in private buildings such as corporate headquarters and data centres

Hub B: Durban and Richards Bay

- Based on technical potential in the high uptake scenario, demand in Durban/Richards Bay could reach up to 70 kt by 2030
- Demand primarily driven by growth of **H2 FC heavy- and medium-duty trucks via N3 freight corridor**, as heavy-duty trucks are expected to reach cost parity with diesel trucks by 2030
- Significant industrial demand, in particular from pulp and paper industries where interest in decarbonizing and refining through shrinking demand
- Opportunity to leverage port infrastructure, including port operational vehicles such as gurneys and cold ironing from fuel cells and marine bunkering in the long-term
    - As costs are high, but marine bunkering remains a strategic priority, our analysis reveals that that the Durban/Richards Bay hub may develop a pilot green ammonia ships by 2030
- The building sector may see uptake at OR Tambo airport alongside public buildings in Durban

Hub C: Mogalakwena & Limpopo

- Based on technical potential in the high uptake scenario, demand in Mogalakwena/Limpopo may reach 41 kt by 2030
- Demand driven by H2 mining trucks, as pilot projects already underway and proximity to heavy duty trucks along N3 corridor
- Limpopo Science and Technology Park also a possible key off-taker expecting to leverage H2 fuel cells as source of power in new industrial park

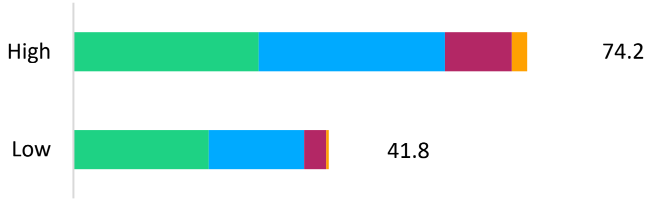
Each hub has its own demand potential of up to 74 kt H2 by 2030 and contributes to the just transition

Hub

Demand potential in 2030 per sector
kt H2/year 🟩 Industry 🟦 Mobility 🟥 Mining 🟧 Buildings

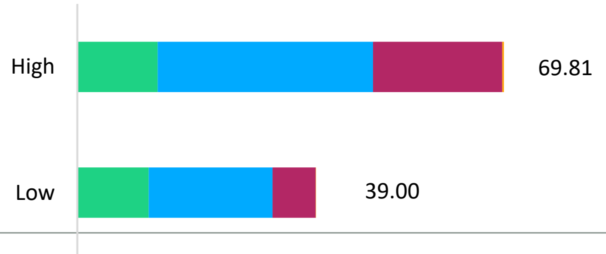
Just transition contributions

A Johannesburg



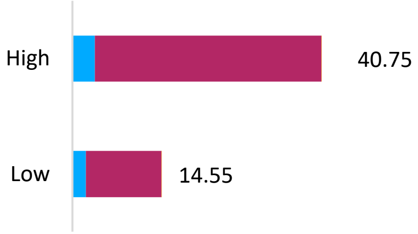
- Many **industrial clusters around Johannesburg** (Sasolburg, Springs) where **synergies** could be explored to boost the local economic tissue
- **Mobility** transition (e.g., public transport) to green H2 in Johannesburg serves wider population and improves **air quality**
- More reliable electricity supply in buildings through stationary fuel cells
- Government-led H2 development through public buildings and transport meant to create **economies of sale** and accelerated cost-down for private sector, and to improve **air quality** for citizens

B Durban/
Richards Bay



- **Richards Bay**, a nearby and less busy port than Durban port, has the **potential capacity to become the export port** from the east coast of SA. **Post 2030, marine bunkering using NH3** has the potential to attract bulk carriers, containers, and general cargo into both Durban and Richards Bay ports

C Mogalakwena/
Limpopo



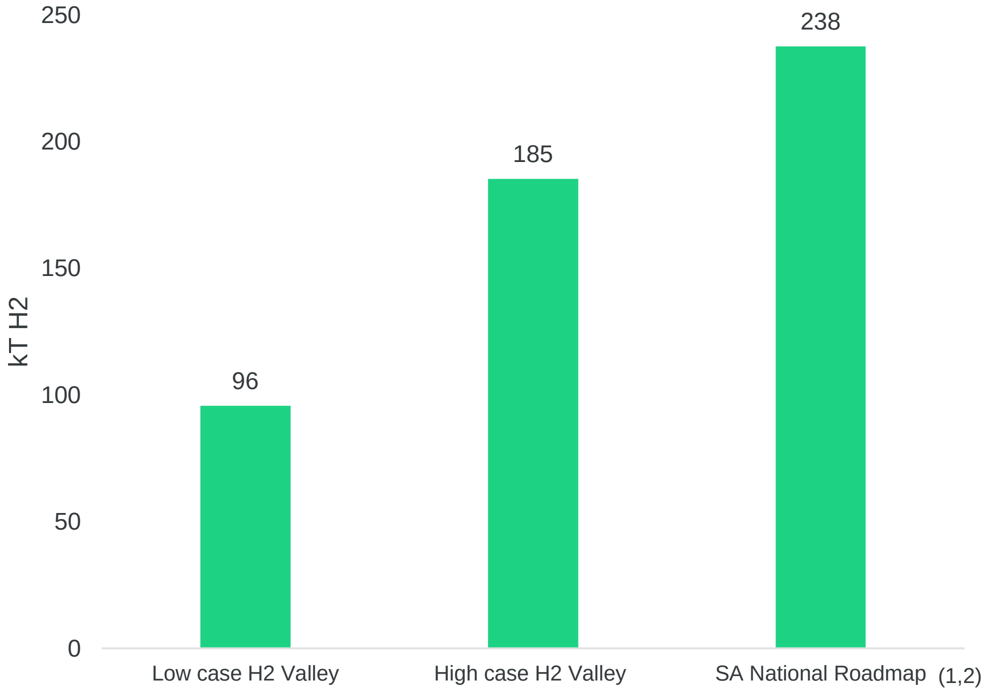
- Concentration of rare metals and gold mines in this zone with **future** (including for H2 asset manufacturing) **long-term potential demand of "green minerals“**
- **Positive impacts** from decarbonisation of mining sector to the **local communities** including reduced pollution, less environmental degradation and development of sustainable local jobs
- Opportunity to use **fuel cells for the data centres of the Limpopo Science Park**, as part of the "green digital" strategy supporting energy transition

Overall H2 demand for the H2 Valley could reach between 40%-78% of expected national demand

Hydrogen demand potential - benchmark in 2030

kt H2/Year

Export excluded

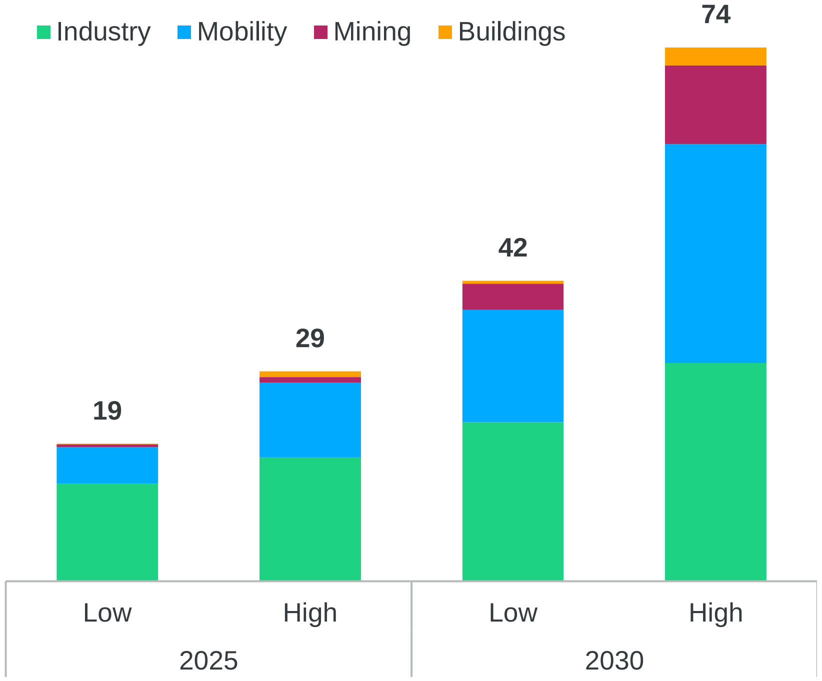


- The South African national hydrogen roadmap assumes that South Africa can produce an equivalent **of 2% of the world's green hydrogen** for local consumption and then **an additional 1% for potential hydrogen application including export opportunities.**
- In comparison to those national targets, the Hydrogen Valley area comes near to national production ambition for high-case demand hydrogen. Demand in the Hydrogen Valley is intended to amplify hydrogen demand throughout South Africa, which can leverage local supply chains developed in the Valley, learnings from hydrogen applications and tap into hydrogen supply Valley.
- As an order of magnitude, the high case estimated for green hydrogen demand for the Hydrogen Valley accounts for 2% of estimated Europe green hydrogen demand in 2030.

(1) [15] KPMG, 2020
(2) [11] IEA,2020: https://www.iea.org/reports/hydrogen

A. The potential demand in the Johannesburg hub ranges between a low-case of 41.8 and a high-case of 74.2 kT of hydrogen per year

Demand potential in 2030 per sector, kT H2/year



Not included in the demand: 1) Self-consumption by Sasol 2) 50,000 tons of aviation fuel 3) Demand from private buildings/data centres

☐ Detailed next

Key hypothesis

Anchor Demand Segments – Main hypothesis[3]

- H2 uptake in **oil refineries** (Natref, Sasol Secunda) assuming uptake **from gray to low-carbon H_2, even with shrinking production in the sector**
- H2 uptake in **ethylene and ammonia industries** assuming uptake **from gray to low-carbon H2**
- **Iron & Steel**, aluminum and cement industries account for more than a third of hydrogen uptake

- Growth of **H2 FC heavy- and medium-duty trucks via N3 and N1 freight corridor** with **3%[1] road shift towards rail in 2030** as part of the Green Transport Strategy
- Uptake of **public city and intercity buses** within Johannesburg, Pretoria and the wider the Gauteng region

- Fuel cell uptake for back up power (low case) or primary power (high case) in **public buildings** across Johannesburg and Pretoria (~60% public buildings in SA)
- Fuel cells to power **OR Tambo** airport as back up (low case) or primary power (high case)
- High potential for fuel cells to supply for **office buildings (back up supply) and data centres** (primary supply or back up, especially corporations with net-zero targets and an interest in improving electricity reliability[2]

Just transition capability

- Many **industrial clusters around Johannesburg** (Sasolburg, Springs) where **synergies** could be explored to boost the local economic tissue
- H2 **public transport** (e.g., buses), available to all citizens
- Government-led H2 development through public buildings and transport meant to create **economies of sale** and accelerated cost-down for private sector, and to improve **air quality** for citizens

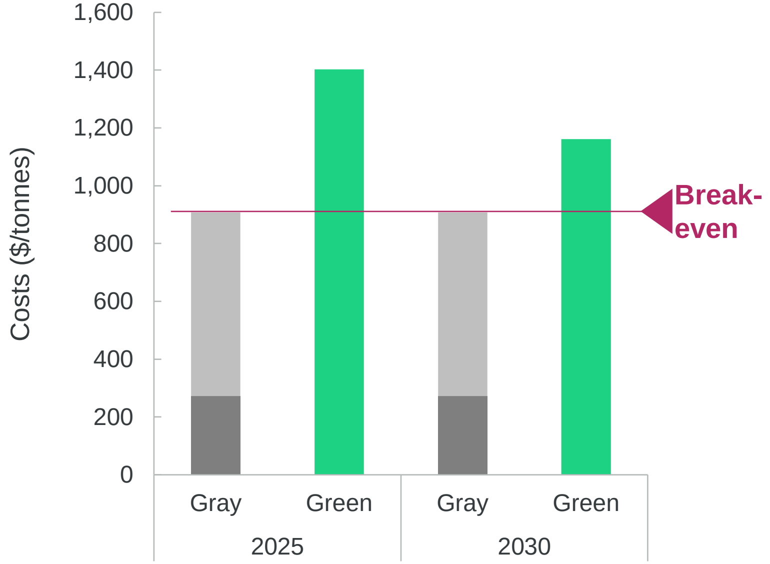
---

(1) H2 demand for rail has been considered however, it will only be feasible for non-electrified or new rails. Considering local conditions, H2 demand for rail will be minimal / negligible in the short term (by 2030)
(2) Private buildings/data centres not sized due to lack of data
(3) Further information on uptake curve available in annex

A. In Johannesburg, chemical & refining demand has been informed by Sasol announcements, despite unfavorable LCOH for green H2

Despite low competitiveness (LCOH) of green H2 derivatives

Ammonia cost, USD



… Sasol has made ambitious announcement on production in Sasolburg

Green hydrogen derivatives like ammonia production with green instead of gray hydrogen presents low competitiveness in terms of the Levelized Cost of Hydrogen. Nevertheless, Sasol has made an ambitious announcement on the production in Sasolburg (Sasol, 2020). There will be green ammonia production at Sasolburg facilities between 15 tonnes/day and 45 tonnes per day assumption: 15 today and 45 in 2030).

Although green ammonia sees a premium versus gray ammonia in 2030, Sasol will leverage existing electrolyzer capacity at Sasolburg to produce green ammonia for customers willing to pay this premium.

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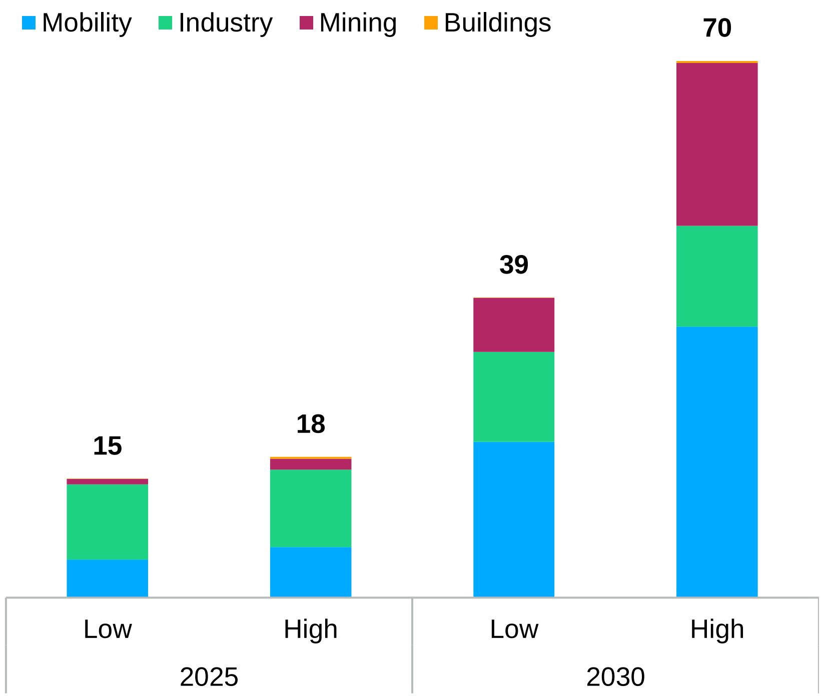
(1) Gray ammonia production costs were modelled using gray hydrogen price (that depends on fuel costs) ranging from 0.7 to 2.8 $/kg H2

B. The potential demand in the Durban/Richards Bay hub ranges between a low case of 39 and a high-case of 70 kT of hydrogen per year

Demand potential in 2030 per sector, kT H2/year



▭ Detailed next

Key hypothesis

Anchor Demand Segments – Main Hypothesis

- Growth of **H2 FC heavy- and medium-duty trucks via N3 freight corridor**
- Introduction of H2 trains following electrification of line from Durban to Richards[1]
- Uptake of public intercity buses on H2 along the N3 from Johannesburg to Durban
- **Fuel switching** for port's **equipment handling** and **electricity from vessel berthing, as well as uptake of ammonia marine bunkering as of 2030**
- Potential **export of H_2 and its derivatives** to key offtake markets (e.g., EU, Japan)
- **Oil refinery** (by Sapref) important uptake **but gradually shrinking over time**
- **Fuel for titanium mining trucks** by Richards Bay Mineral and Tronox KZN Sands
- Fuel cell uptake for back up power (low case) or primary power (high case) in **public buildings** across Durban (20% public buildings in SA)
- Fuel cells to power **King Shaka Tambo** airport as back up (low case) or primary power (high case)

Just transition capability

- **Durban port** is one of **the busiest ports** in South Africa, limiting the potential of exporting out of Durban. Meanwhile **Richards Bay**, a nearby port, has the **potential capacity to become be the export port** from the east coast of SA. However, competition with other South Africa ports for green H2 export should be taken into account
- **Post 2030, marine bunkering using NH3** has the potential to attract bulk carriers, containers, and general cargo into both Durban and Richards Bay ports

---

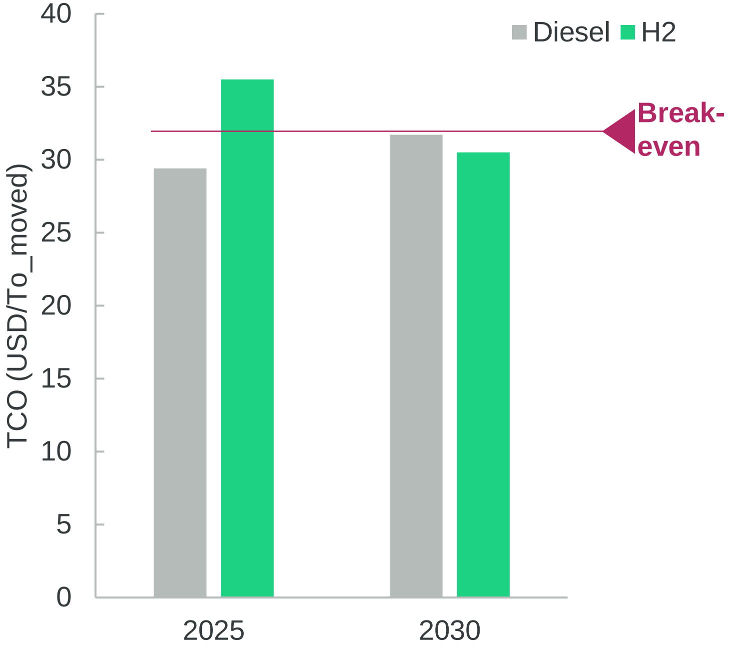
(1) H2 trains has been studied as a potential off-taker for H2. Given low appetite of Transnet by 2030, train will not be considered as an offtaker before 2030

(1) Further information on uptake curve available in annex

B. Hydrogen demand in Durban/Richards Bay hub is driven by fuel for heavy and medium-duty trucks via N3 freight corridor, a key opportunity considering the business case for H2 FC trucks and existing momentum

H2 Heavy-Duty Truck Total Cost of Ownership (TCO) is reaching break even vs. diesel in 2030

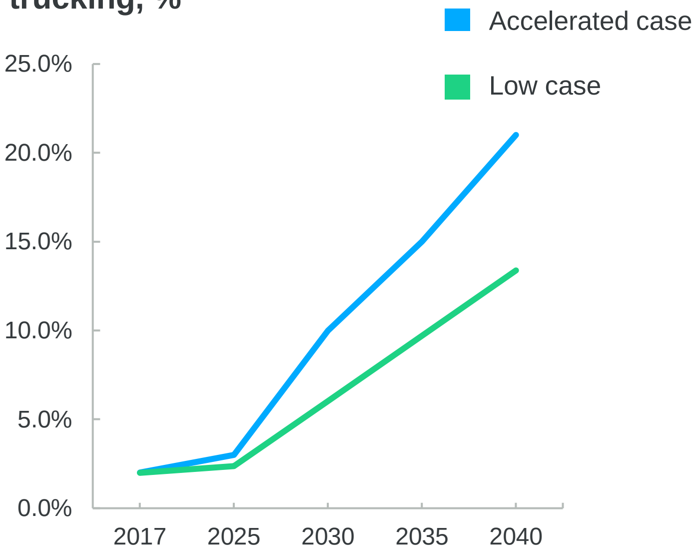
TCO of Diesel vs H2 trucks[1], USD



1 Analysis based on $4Ukg H2 LCOH

… leading to our projections for high uptake of H2 FC trucks especially beyond 2025.

H2 uptake curve in heavy duty trucking, %



High uptake: projecting slightly stronger growth than in the high case generic uptake curve for first adopters, given TCO outlook for FCEV HDT

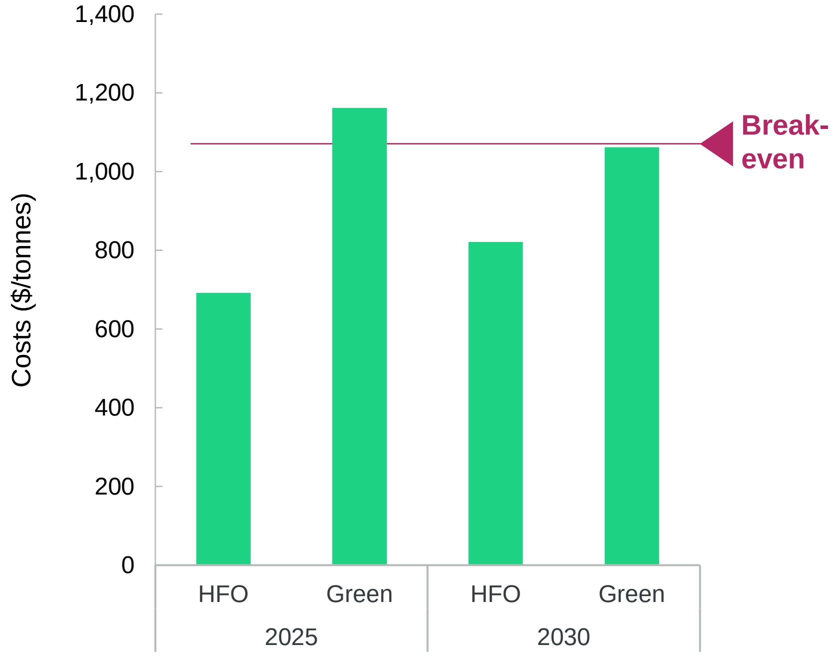
Low uptake: in line with the low case generic uptake curve for first adopters

Around 25% of hydrogen demand in Durban hub will be driven by the heavy-duty trucking industry. Fuel cells trucks are expected to reach competitiveness at a total cost of ownership (TCO) basis with diesel trucks before 2030. This TCO competitiveness informs the uptake of hydrogen fuel cell trucks, with up 20-25% of trucks in the Valley expected to be run on fuel cells by 2040.

B. While ammonia-fueled ships are not competitive in the near-term, they are a strategic priority for the Valley

There is still a green premium for ammonia as shipping fuel even when compared to heavy fuel oil (HFO) in 2030

Maritime fuel costs[1][2], USD



(1) Green ammonia is made from green hydrogen from off-shore wind
(2) HFO consists of heavy fuel oils projections (Enerdata database, 2021)

… yet SA has ambitions to develop a H2 bunkering sector

- After 2030, marine bunkering using NH3 has the potential to attract bulk carriers, containers and general cargo into both Durban and Richards Bay Ports.
- South Africa's abundance of renewable potential puts it in a strong position to produce zero carbon fuels for shipping]—Zero-Carbon shipping fuels in South Africa.
- South Africa is also a priority country for the P4G Getting to Zero Coalition Partnership, with a 2-year project to make zero emission vessels and fuels a reality.

Therefore, despite green premium of green ammonia versus heavy fuel oil, we expect pilot project ammonia ships bunkering by 2030 as hydrogen in the marine sector is a strategic priority. In the high uptake scenario, ammonia uptake in marine is in line with outlook for penetration of ammonia in global maritime fuel mix, not yet reaching commercial feasibility before 2025.

In the low uptake scenario, it is projected that around half of full potential could be expected in a low uptake case in the form of pilot projects.

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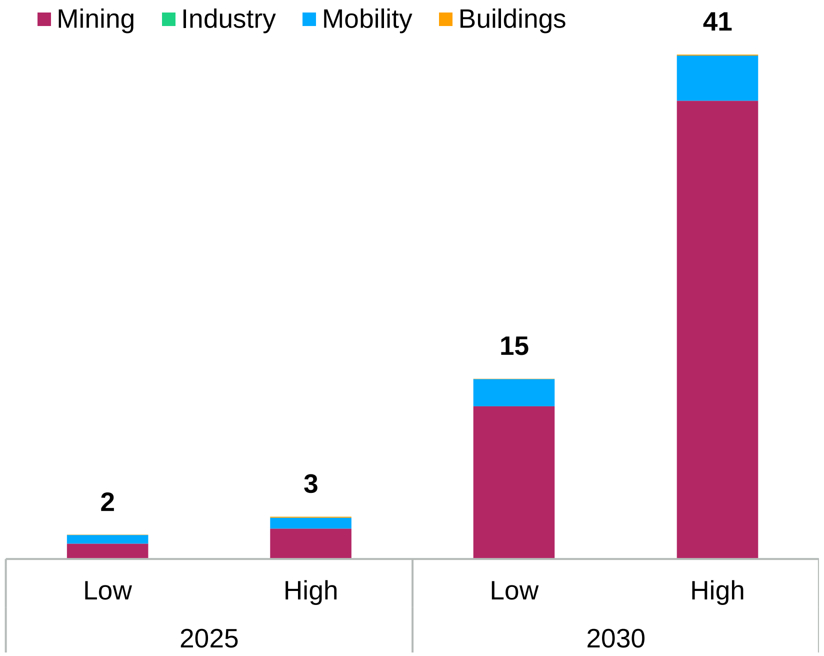
(1) P4G – Getting to Zero Coalition Partnership, "Zero carbon shipping fuels in South Africa", Ricardo – draft, 16/04/2021

C. Demand in Mogalakwena/Limpopo may reach 41 kt by 2030 in the high uptake scenario

Demand potential in 2030 per sector, kT H2/year



Further information on uptake curve available in annex

▭ Detailed next

Key hypothesis

Anchor Demand Segments – Main hypotheses

Fuel for mining trucks for:

- **Platinum** mining which is the key component for hydrogen equipment (electrolysers & Fuel Cells)
- Gold mining, with a 3% of the world mine pits in South Africa and being part of the Top 10 worldwide gold suppliers
- Titanium, Copper & Diamonds supports the mining sector on the North Zone

- **H2 FC heavy- and medium-duty trucks via N1 freight corridor**

- Fuel cell demand for back up power (low case) and primary power (high case) at the **Limpopo Science and Technology Park**

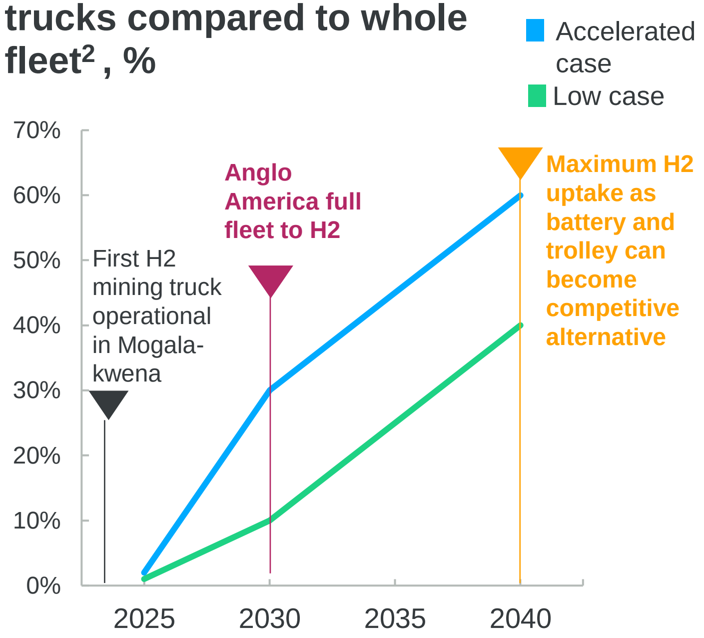
Just transition capability

- Concentration of rare metals and gold mines in this zone with **future long-term potential demand of "green minerals“** (including for H2 asset manufacturing)
- **Positive impacts** from decarbonisation of mining sector to the **local communities** including reduced pollution, less environmental degradation and development of sustainable local jobs
- Opportunity to use **fuel cells for the data centres of the Limpopo Science Park**, as part of the "green digital" strategy supporting energy transition, and contribute to economic development of the Limpopo region

C. Mogalakwena's primary off-taker are mining trucks due to their near-term competitiveness with traditional vehicles

Mining Trucks have a high uptake rate driven by Anglo America's 2030 commitment…

H2 uptake curve of mining trucks compared to whole fleet[2] , %

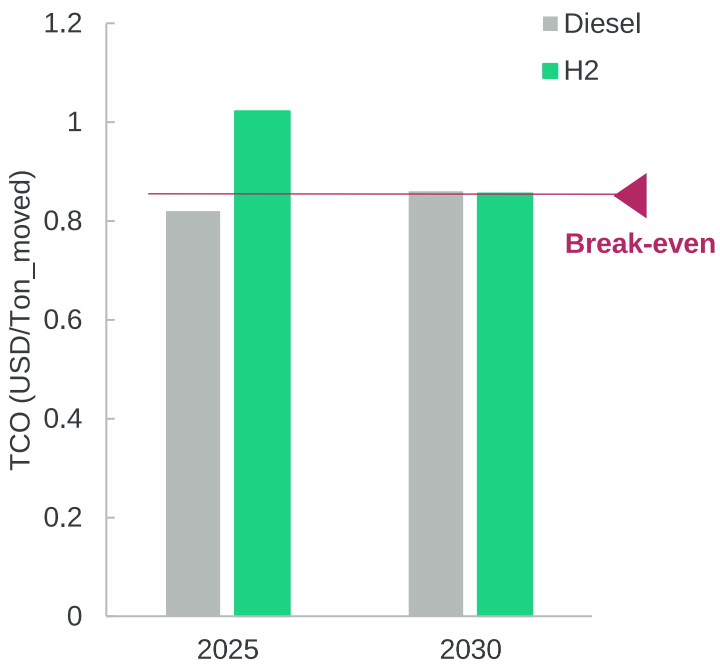


High uptake: Accelerated uptake to 2030, due to Anglo-American push

Low uptake: Slower uptake until cost parity reached in 2030, after which uptake accelerates

… and the H2 mining vehicles TCO reach breakeven vs. diesel in 2030

TCO of H2 and diesel mining trucks[1], USD



Consequently, mining trucks have a high uptake rate driven by an Anglo-American commitment to a full H2 fleet by 2030. By 2040, the Hydrogen Valley will have a maximum H2 uptake of 60% in the accelerated case and up to 40% in the low-case, as batteries and trolley can become a competitive alternative.

H2 mining trucks are **at par with diesel trucks** in terms of total cost of ownership as **of 2030**.

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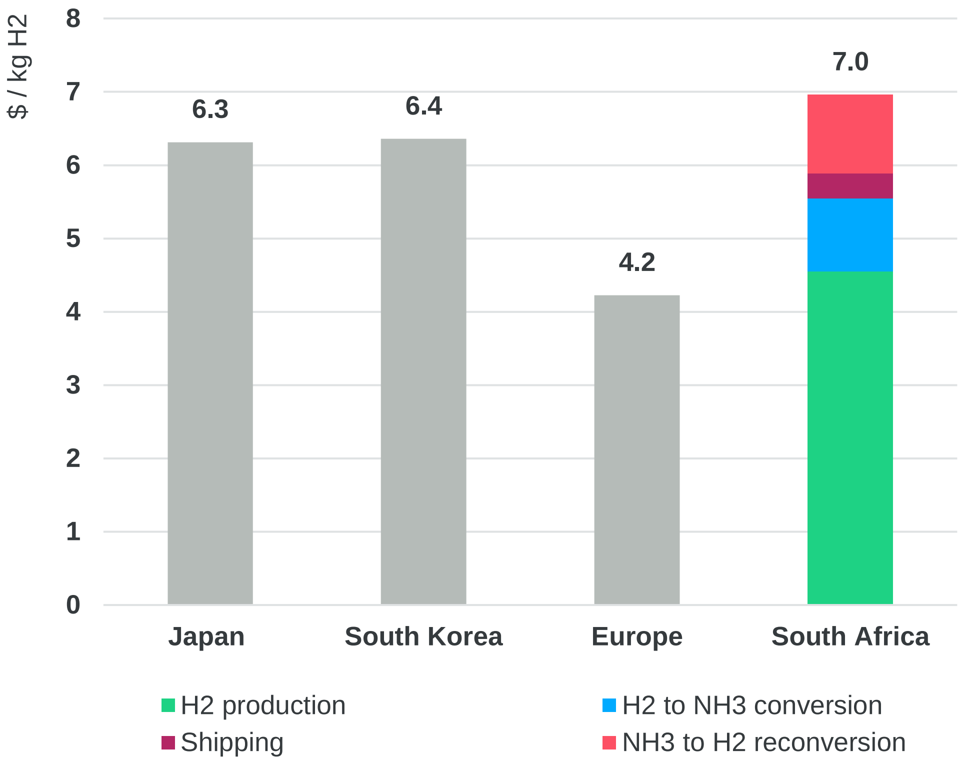
(1) H2 dispensed at 700 bar (2) Further information on uptake curve available in annex

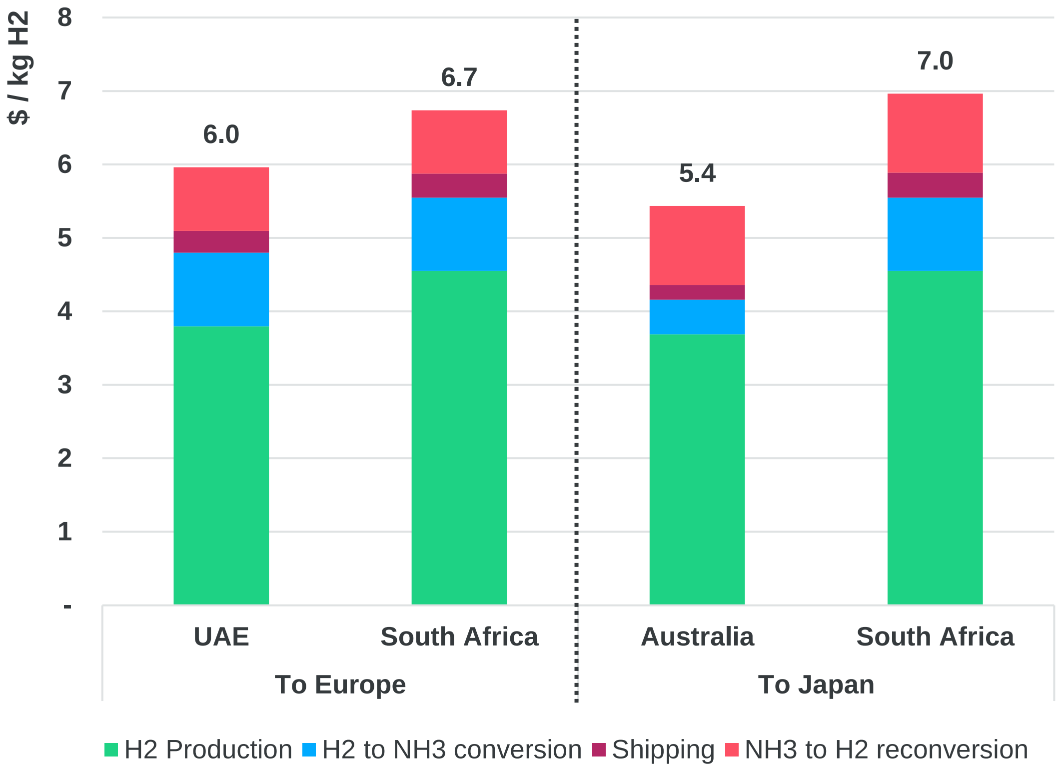
Hydrogen Export

South Africa has a national ambition to become a hydrogen exporter but must prepare for competition at the international level

In 2030, South Africa can approach competitiveness with domestic production in key offtake markets…



… but must prepare for competition from other hydrogen exporting countries such as UAE or Australia.



Today, ammonia (NH3) is considered to be the cheapest option to export hydrogen over a long distance

(1) [11] IEA Future of Hydrogen 2019, BNEF

Shipping costs in the left chart are based on the distance from South Africa to Europe

Richards Bay will also compete with other South African ports planning to become hydrogen export hubs

Port of Saldanha Bay

"Saldanha Bay presents itself as a ***great opportunity to create a hub not only for bunkering zero carbon vessels but also for export zero carbon fuels as a commodity*** *[…] It is located relatively close to South Africa's large solar PV potential, and north of Saldanha, holds significant fixed offshore wind potential as well as floating wind potential over a wider area surrounding the coast."* [1]

Port of Ngqura, Coega SEZ

"As an Industrial Development Zone, ***could establish itself as a hydrogen hub*** *for bunkering container and bulk vessels. If the renewable generation and zero carbon fuel production infrastructure can be oversized to accommodate, the port can also provide fuels for wider industry at and around the port, and the* ***fuel can be exported as a commodity****."* [1]

Boegoebaai Port

"The Boegoebaai port project is an initiative to develop a deep-see commercial hub that will allow transporting many of the Northern Cape commodities. The original plan envisioned dry and liquid bulk terminals and a multi-purpose container terminal. A further ***option under consideration would see the port having a liquid bulk terminal for green hydrogen and ammonia*** *which is linked to a bespoke production site using its renewable energy supply"* [2]

Hydrogen export could be a potential future source of demand. However, the Valley will face **competition from other hydrogen exporting countries** (e.g., Morocco, Australia) and from **other ports in South Africa**. We therefore **recommend that the Hydrogen Valley consolidate domestic demand and create economies of scale before embarking on ambitious export projects**, or to take an opportunistic stance (e.g., leverage international funds to develop export infrastructure).

The Hydrogen Valley will contribute to **readying South Africa for export** by ensuring a local supply chain, developing South African skills to support the sector, and ensuring security of hydrogen supply—benefits that will extend beyond the geographic boundaries of the region. In addition, the co-location of demand and supply gives synergies opportunities within the Valley that will help initiate and scale up pilot projects.

While hydrogen export has not been sized in the demand analysis, **export may become a source of demand for the Valley as opportunities emerge (e.g., international funds to develop export infrastructure), yet); nevertheless, consolidating domestic demand as recommended will remain as a key enabler.**

(1) Taken and reformatted from [9]"Zero carbon shipping fuels in South Africa", Ricardo – draft, 16/04/2021
(2) Taken and reformatted from [23]"Decarbonizing shipping: P4G – Getting to Zero Coalition Partnership, Mar 2021

Table of Contents

Chapter Summary

By 2030, green H2 LCOH production is expected to be ~$4 per kg H2 across hubs

By 2030, LCOH of green H2 produced with PEM electrolyzers is ~$4 per kg H2 across hubs, and is still more expensive than gray hydrogen, with a green premium of $1.6-$2.2.

- **All three hubs see similar costs of green hydrogen production**. Costs in 2030 are lower in Johannesburg (4.08-4.11 USD/kg H2)[1], compared to Durban (4.25-4.55 USD/kg H2) and Mogalakwena/Limpopo (4.10-4.27 USD/kg H2) due to slightly higher solar irradiation levels.
- SA H2 Valley LCOH estimates are higher than some other analyses, due to the use of PEM electrolyzers instead of alkaline electrolyzers, as well as conservative, yet significant (~60% between today and 2030), cost-down assumptions. We have taken a conservative approach in LCOH cost evolution and recognize that **further reductions are possible** depending on policy and technology evolution to 2030.
- Hubs see a **decrease in cost of hydrogen of ~25%** from 2025-2030, mainly driven by the capex decrease of PEM electroylzers.
- For all hubs, we recommend using primarily **solar PV** to power green hydrogen production, with some onshore wind (in Durban/Richards Bay) as the cost optimal supply mix.

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[1] Ranges dependent on location

We recommend co-locating hydrogen production in the hubs, close to supply sites.

- Although hydrogen can be produced at a slightly lower cost in other parts of South Africa (e.g., Northwest: 3.95 USD/kg H2 for production and ~1 USD/kg H2 for transport in 2030), **the transport costs** to bring hydrogen to the hub eliminate the relative cost advantage.
- In addition to production costs, transport costs range from up to 0.8 USD/kg H2 to bring hydrogen from supply locations to off-takers within the hubs. We recommend **transporting in the near term**, as greater demand is required to make the business case for building a pipeline.
- **Co-location** also provides benefits of bringing H2 know-how to the hub, finding synergies across projects and creating local economies of scale.

Each hub must anticipate infrastructure requirements and constraints in electricity supply, water supply, pipeline infrastructure and storage.

- For electricity supply, a dedicated RES supply (off-grid) is recommended to mitigate grid reliability risks and avoid network charges and taxes.
- Most hubs are vulnerable to water supply. In addition to seeking groundwater supply, hubs may also consider locating hydrogen supply next to existing water sources, desalination infrastructure, or dedicated water supply measures through water recycling or truck delivery.
- With no extensive H2 network in the region, existing gas pipelines could be leveraged for H2 transport and distribution in the longer term.
- While underground storage is not feasible before 2030, above ground storage can be leveraged to lower LCOH.

Hydrogen Supply

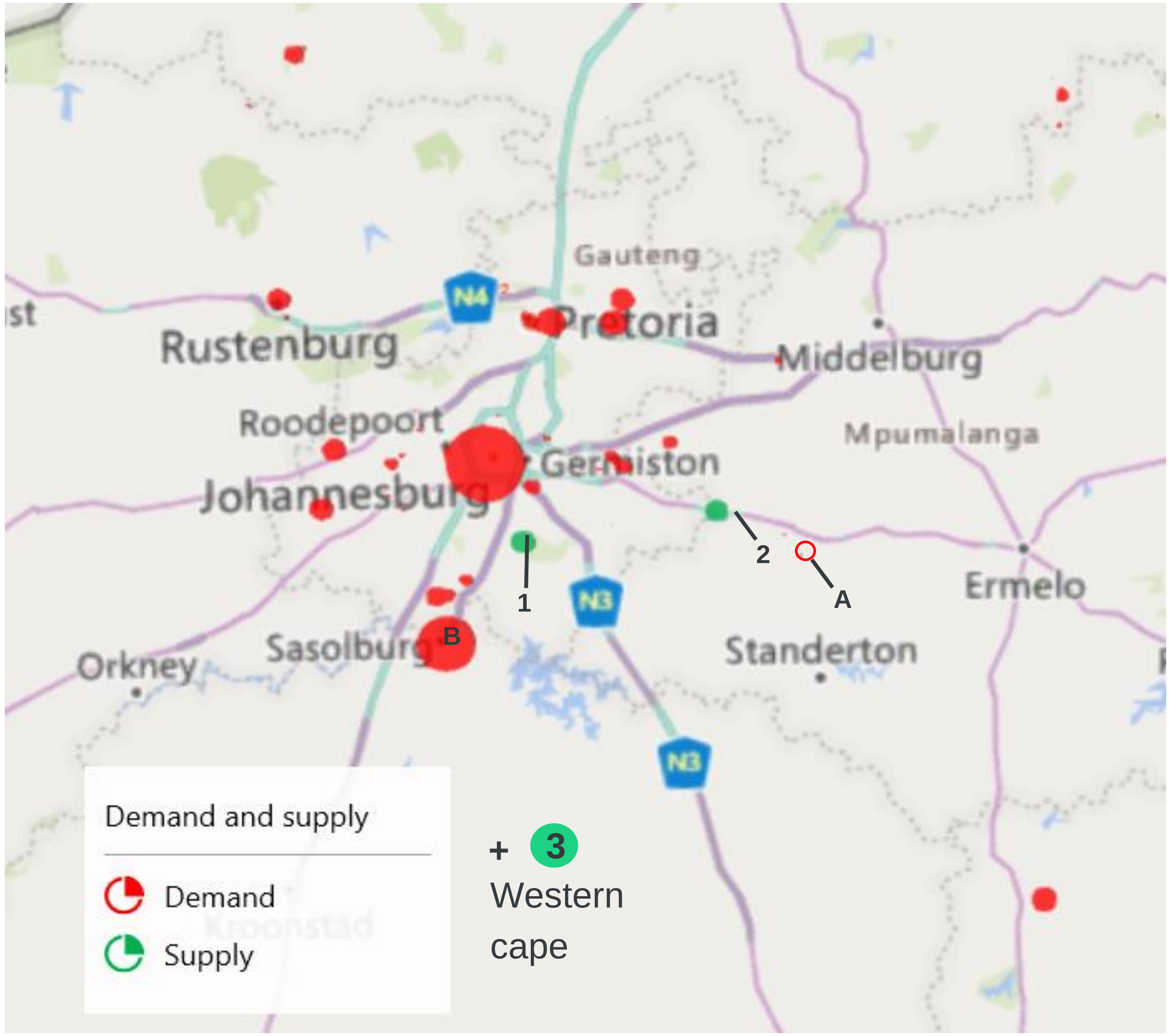
To meet this demand, we have explored possible locations to supply hydrogen in each hub

🟢 High 🟠 Medium 🔴 Low

	Hub / Filter criteria	H2 supply potential	LCOH Range[1]	Location
A	Johannesburg (West Rand/ Rustenburg)	🟢	2025: 5.41-5.48 USD/kg H2 2030: 4.06 – 4.11 USD/kg H2	Between Sasolburg and Johannesburg; between Springs and Secunda; further away in West
B	Durban/ Richards Bay	🟢	2025: 5.17-6.01 USD/kg H2 2030: 4.25 – 4.55 USD/kg H2	Durban area; between Durban and Richards Bay; off-shore
C	Mogalakwena/ Limpopo	🟠	2025: 5.44-5.49 USD/kg H2 2030: 4.10 – 4.27 USD/kg H2	In this hub, due to distances between the off-takers, most of the H2 production will have to be decentralised. Renewable potential will be constrained by site location.

(1) LCOH calculate for off-grid, behind the meter solutions only; range based on location

A. Johannesburg: Multiple sites are possible for green hydrogen production, based on RES quality and proximity to demand-off-takers



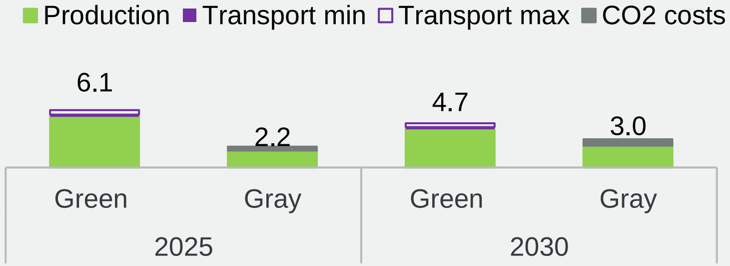
H2 supply locations

- **Location1:** Between Sasolburg and N3, providing access to Sasolburg, filling stations along N3 and Johannesburg city
- **Location 2: Between Springs and Secunda,** also offering access to the N3 and large iron & steel off-takers
- **Location 3: Western Cape** where solar irradiation is higher *(not selected)*

LCOH

LCOH in Johannesburg USD/kg H2

- **Western Cape location not selected,** as transport costs increase exceeded the savings on production costs (which is only 3%) despite better irradiation profile

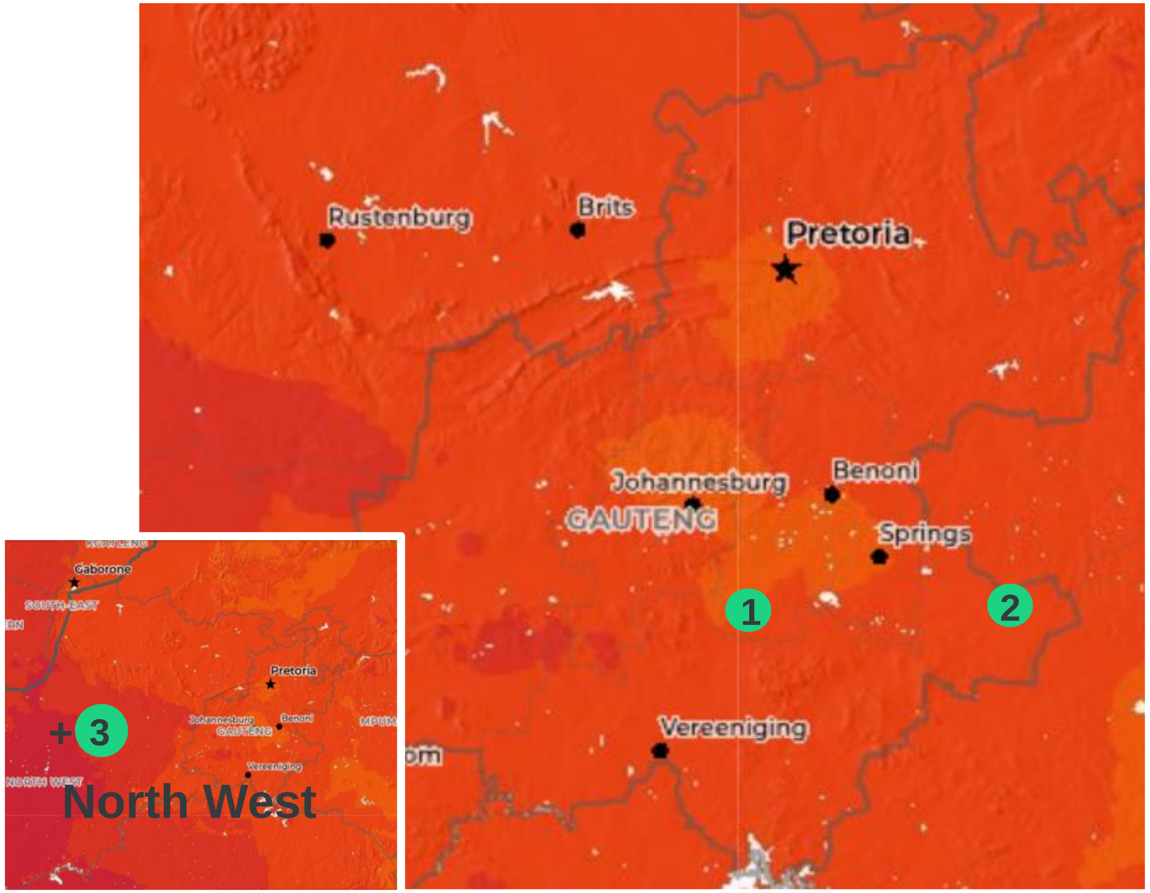


Planned H2 Projects

- Several projects planned for fuel cells in mobility and buildings sector
- Sasol to produce green hydrogen at sites in hub

A. Analysis reveals that multiple sites are possible for green hydrogen production, based on RES quality and proximity to demand off-takers

Supply sites in Johannesburg



H2 supply locations

Three supply locations have been selected to calculate the levelized cost of hydrogen (LCOH). These locations have been strategically selected as they are in close proximity to potential hydrogen demand in the hub and have access to renewable energy sources such as sun or wind. We have also selected one site in the Northwest and tested the cost of transporting electricity or hydrogen to the hub to capitalize on the high solar irradiation available in the nation’s best solar region.

Most of Johannesburg sees strong solar PV irradiation and therefore supply sites within Johannesburg were heavily influenced by the location of possible off-takers.

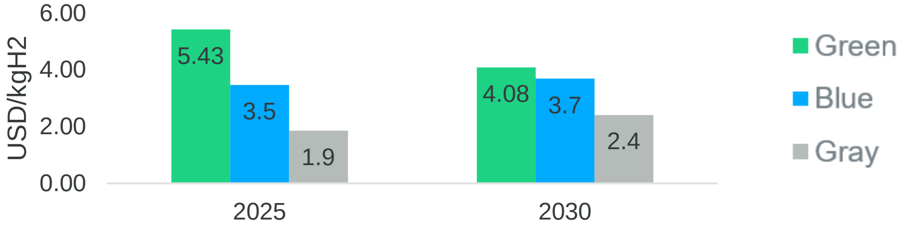
We have tested three supply sites for hydrogen production:

- **Location1: Between Sasolburg and N3**, providing access to Sasolburg, filling stations along N3 and Johannesburg city
- **Location 2: Between Springs and Secunda,** also offering access to the N3 and large iron & steel off-takers
- **Location 3: Western Cape** where solar irradiation is higher

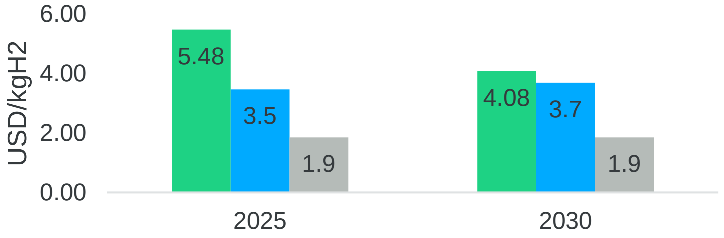
A. A green premium between green and gray hydrogen is expected across all hubs in 2030

….all have a green premium, including in Western Cape[1234]

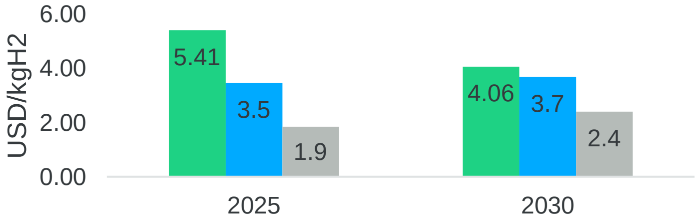
Hydrogen production costs – location 1 *USD/kgH2*



Hydrogen production costs – location 2 *USD/kgH2*



Hydrogen production costs – location 3 *USD/kgH2*



LCOH

The cost of producing hydrogen in the Johannesburg hub ranges from 4.06-4.08 USD/kgH2 by 2030 (depending on the location), which averages to a ~25% decrease from the cost in 2025.

Nevertheless, all three locations still see a green premium between gray and green hydrogen, ranging from ~1.70-2.20USD/kgH2.

Locations 1 and 2 calculate hydrogen production costs using large-scale solar PV within Johannesburg, whereas location 3 tests producing hydrogen in the Northwest. Despite the strong solar irradiation in the Northwest, the cost differential compared to producing hydrogen in Johannesburg is still limited, as Johannesburg still sees strong solar irradiation, though marginally less than the Northwest.

SA H2 Valley LCOH estimates are higher than some other analyses for two reasons:

- Our assumptions on electrolyzer cost-down are less aggressive than some other reports based on observations about the limited impact of economies of scale in electrolyzer installations above 10 MW, since electrolyzer installations are modular
- We have also taken a conservative approach in LCOH cost evolution and recognize that f**urther reductions are possible** depending on policy and technology evolution to 2030

---

(1) Demand is assumed to be flexible to ensure best synergies with RES potential

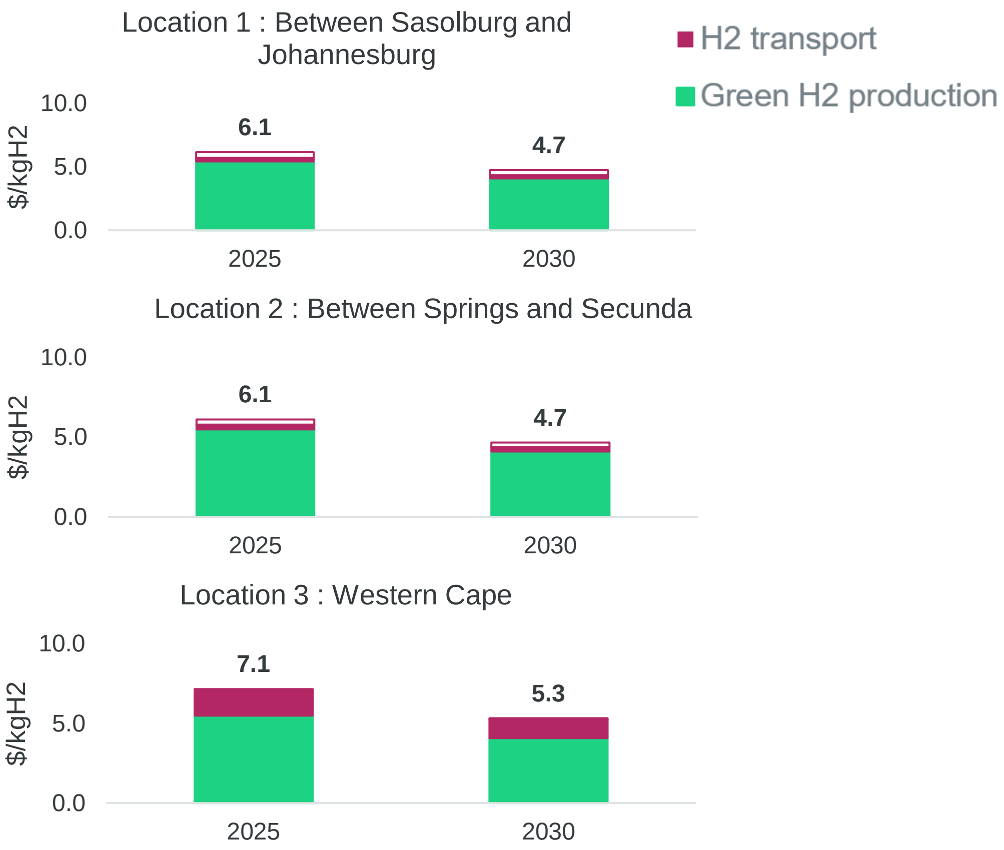
(2) Gray hydrogen number consists of the average of hydrogen costs from SMR coal gasification, considering future fuel prices. Source for gray H2 costs: Bloomberg 2020 Hydrogen Economy Outlook: will hydrogen be the molecule to power a clean economy?, BloombergNEF. Source for SA fuel costs evolutions: ENERDATA.

(3) Green H2 LCOH includes RES (solar and wind) + electrolyzer + water treatment. Transports costs are not accounted for on this slide.

(4) Considering current CO2 tax levels in SA, assuming no more taxes allowances by 2025-2030, and a yearly growth of 10%, CO2 taxes amounts in 2025 to 0.03 or 0.06 USD/kgH2 for SMR and coal gasification respectively, and in 2030 to 0.06 or 0.1 USD/kgH2 for SMR and coal gasification respectively

A. When considering transport costs to major off-takers indicate that locations 1 and 2 are most competitive for producing green hydrogen

LCOH with transport costs, USD/kgH2



LCOH

We have mapped the cost of transporting hydrogen produced at each of the supply locations to the closest and farthest off-takers in the hub.

If hydrogen is to be transported by truck in liquid or compressed form, transport costs in the hub range from 0.5 within the hub to 1 USD/kg H2 in Western Cape. Our analysis reveals that the hub does not have sufficient demand to justify building a hydrogen pipeline.

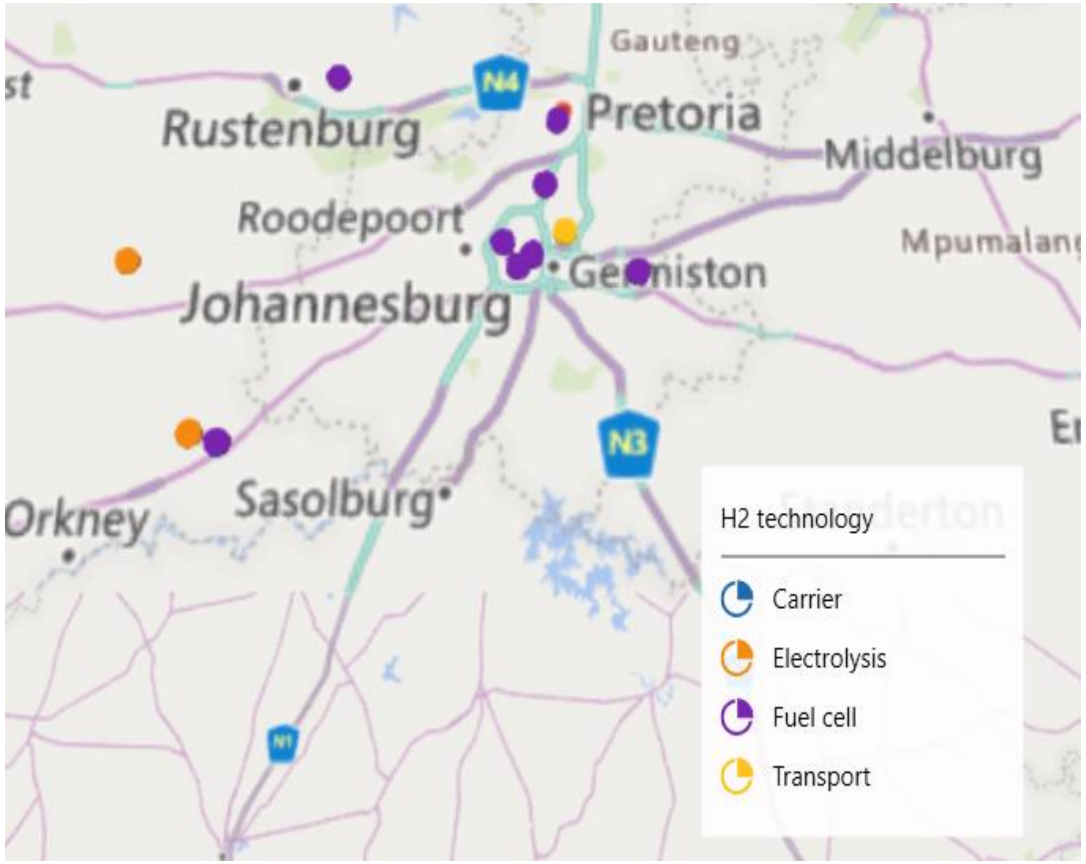
When accounting for the cost of transporting hydrogen from the Northwest (location 3) to the Johannesburg hub (location 1), the slight cost advantage of producing hydrogen in the Northwest is erased. Therefore, we recommend production at sites 1 and 2.

---

(1) Transport modes are optimized based on demand per hour and distance of transport: hydrogen from location 1 & 2 will be transported by truck or pipeline; hydrogen from Western Cape would be transported by liquid truck

A. Johannesburg: there are many ongoing and existing hydrogen demonstration sites within the hub

Existing hydrogen demonstration projects



Existing Projects Description

- HySA/UWC demonstrates three electric scooters with fuel cell range extenders and hydrogen refueling infrastructure
- Bambili Energy, in conjunction with HySA (NWU and UCT) deploy seven fuel cell systems at One Military hospital in Pretoria
- HySA at NWU develops and demonstrates a locally built hydrogen generator for laboratory hydrogen supply
- HySA/NWU establishes a 55kW solar farm to produce and store green hydrogen
- LOHC pilot plant built at NWU HySA in collaboration with Framatome
- HySA developed a 2.5 kW fuel cell system with renewable hydrogen production and storage at Poelano Secondary School in Ventersdorp
- Impala Platinium invested into HySA Systems for fuel cell prototype for mining applications
- 100 kW platinum-based hydrogen fuel cell unit is installed at Minerals Council's building
- Vodacom use fuel cells to power some of its stations
- Clean Energy investments, Anglo/DST and Air Products installed a 5kW fuel cell back up unit in Randburg, Gauteng
- Anglo Platinum demonstrates underground fuel cell mining locomotive at Khomanani mine
- Sasol has committed to developing ammonia and jet fuels from green hydrogen

(1) [5] Department of Science and Innovation & NWU, 2020, Hydrogen Society Baseline Assessment Report, Version 2.0

B. Durban hub is centered on mobility, with nearby N2 and maritime demand, although industrial demand is also notable

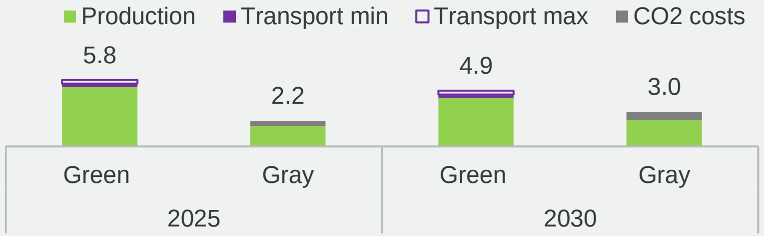
H2 supply locations

- **Location 1:** Near port of Durban to capitalize on demand from port operators, ships etc. with proximity to N3
- **Location 2:** Between, Durban and Richards Bay, to serve H2 off-takers in both port locations
- **Location 3:** Offshore wind turbines near Richards Bay

LCOH

- Electricity sourcing is mainly coming from **wind farms**. Off-shore wind implies higher LCOH than on-shore, adding to transmission lines challenges

LCOH in Durban (inland) USD/kg H2

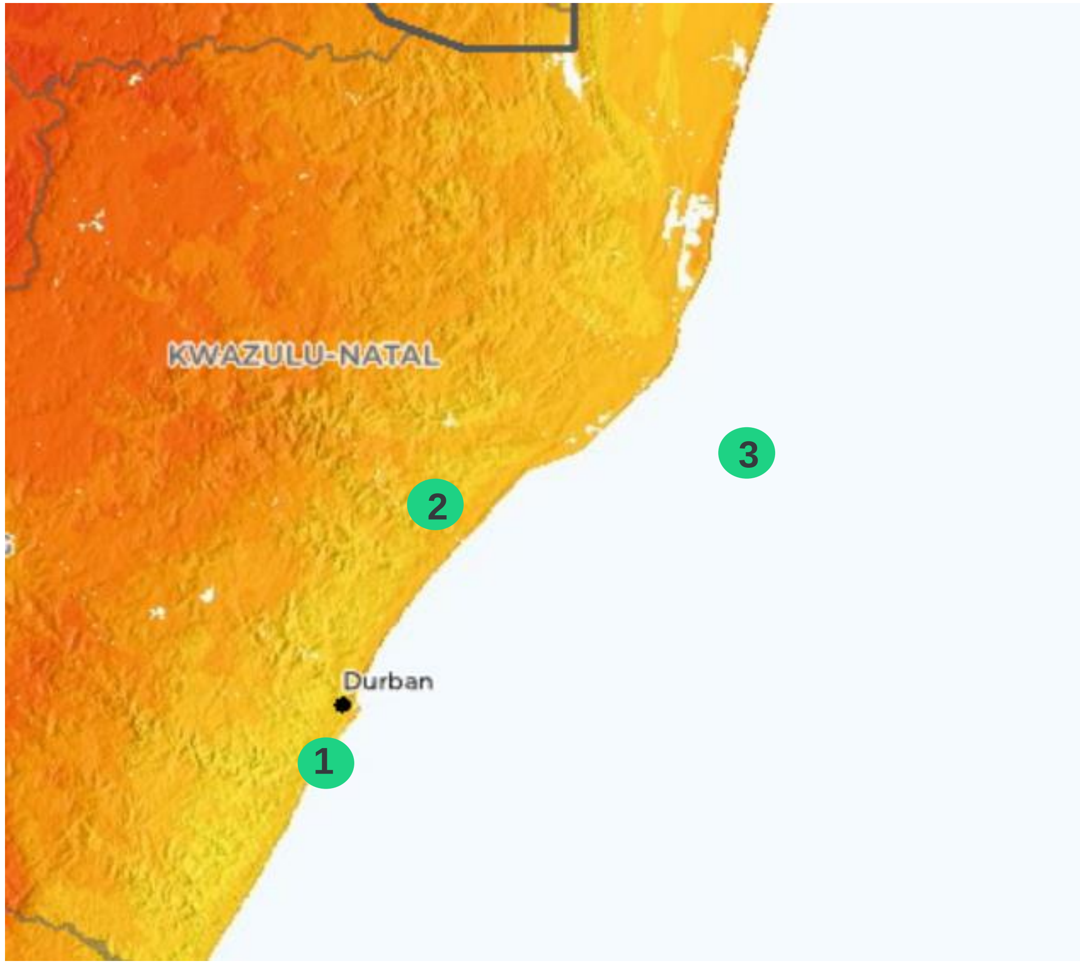


Planned H2 Projects

- Government Project Phoenix in Durban starts the manufacturing of a solid oxide fuel cell factory as part of major infrastructure projects in SA
- Interest from sugar processors in producing H2

B. We have selected three possible sites for hydrogen production in Durban

Supply sites in Durban/Richards Bay



H2 supply locations

Three supply locations have been selected to calculate the levelized cost of hydrogen (LCOH). These locations have been strategically selected to be in close proximity to potential hydrogen demand in the hub and with access to renewable energy sources such as sun or wind.

In the case of Durban, the best solar PV locations were far inland and far from potential demand off-takers along the coast. Therefore, supply sites were heavily influenced by the location of possible off-takers.

We have tested three supply sites for hydrogen production:

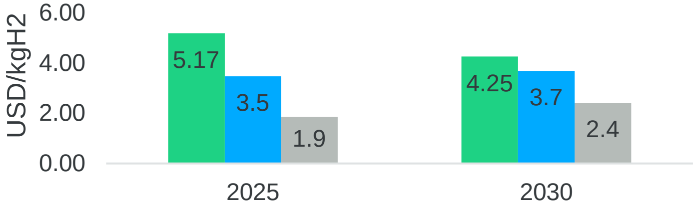
- Location 1: Near port of Durban to capitalize on demand from port operators, ships etc. with proximity to N3
- Location 2: Between, Durban and Richards Bay, to serve H2 off-takers in both port locations
- Location 3: Offshore wind turbines near Richards Bay

B. Analysis reveals that the green premium for producing green H2 still exists in 2030 across all tested sites

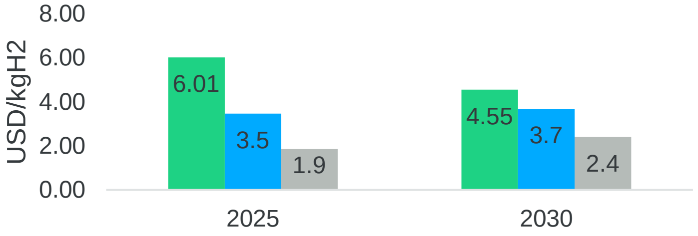
Hubs with solar PV may be the most competitive green LCOH option[1,2,3]

Hydrogen production costs – location 1 *USD/kgH2*

Hydrogen production costs – location 2 *USD/kgH2*



Hydrogen production costs – location 3 *USD/kgH2*



LCOH

The cost of producing hydrogen in the Durban hub ranges from 4.25-4.55 USD/kg H2 by 2030 (depending on the location), which in some locations is an up to 25% decrease from the cost in 2025.

Nevertheless, all three locations will still see a green premium between gray and green hydrogen, ranging from 1.90-2.10 USD/kg H2.

Locations 1 and 2 calculate hydrogen production costs using large-scale solar PV, whereas location 3 uses offshore wind. The LCOH of producing hydrogen with offshore wind is still more expensive than producing through solar PV, even in 2030.

SA H2 Valley LCOH estimates are higher than some other analyses for two reasons:

- Our assumptions on electrolyzer cost-down are less aggressive than some other reports, as we have used figures for PEM electroylzers (as opposed to less-costly alkaline electrolyers) due to their high platinum content and response to demand flexibility. Our electrolyzer capex costs also include full cost of installation
- We have also taken a conservative approach in LCOH cost evolution and recognize that f**urther reductions are possible** depending on policy and technology evolution to 2030.

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(1) Gray hydrogen number consists of the average of hydrogen costs from SMR coal gasification, considering future fuel prices. Source for gray H2 costs: Bloomberg 2020 Hydrogen Economy Outlook: will hydrogen be the molecule to power a clean economy?, BloombergNEF. Source for SA fuel costs evolutions: ENERDATA.

(2) Green H2 LCOH includes RES (solar and wind) + electrolyzer + water treatment + storage

(3) Considering current CO2 tax levels in SA, assuming no more taxes allowances by 2025-2030, and a yearly growth of 10%, CO2 taxes amounts in 2025 to 0.03 or 0.06 USD/kgH2 for SMR and coal gasification respectively, and in 2030 to 0.06 or 0.1 USD/kgH2 for SMR and coal gasification respectively

B. Transport costs to major off-takers indicate that multiple sites are possible across Durban/Richards Bay; site selection to be strategic

LCOH with transport costs, USD/kgH2

LCOH with transport

We have mapped the cost of transporting hydrogen produced at each of the supply locations to the closest and farthest off-takers in the hub.

Transport costs in the hub range from 0.1 to 0.6 per USD/kg H2, if hydrogen is to be transported by truck in liquid or compressed form. Our analysis reveals that the hub does not yet have sufficient demand to justify building a hydrogen pipeline.

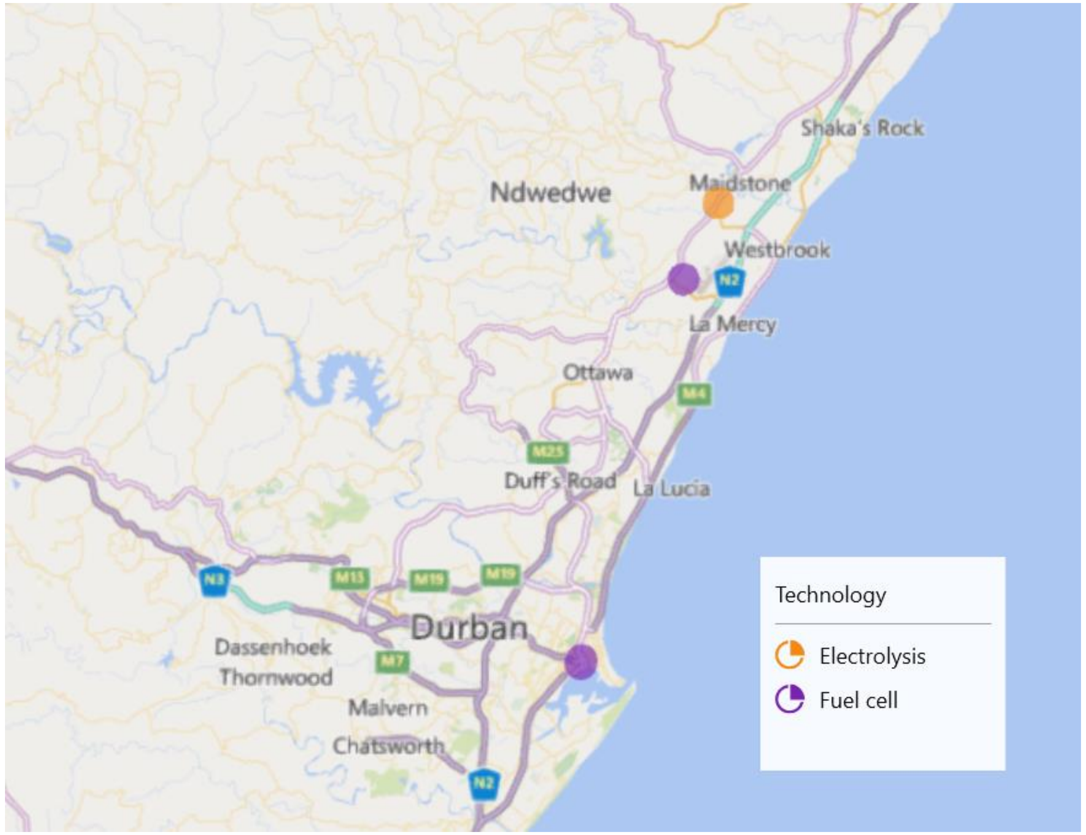
Considering the regulatory and transportation complexity of producing hydrogen through offshore wind in South Africa, we recommend supply locations 1 and 2 only.

---

(1) Green electricity production on-shore is mostly provided by solar PV plant.
(2) Transport modes on-shore consist of truck transport.
(3) Transport costs for location 3 are not accounted for (electricity and hydrogen production)

B. There are a few existing hydrogen projects planned within the Durban hub

Existing hydrogen demonstration projects



Existing Projects Description

There are only a few existing hydrogen projects planned within the Durban hub:

- Government Project Phoenix in Durban starts the manufacturing of a solid oxide fuel cell factory as part of major infrastructure projects in South Africa
- Interest from sugar processors in producing H2; processors have excess water/electricity to leverage for green hydrogen production
- Early-stage planning by Hewlett Tongaat to produce H2 using excess water and electricity from sugar operations

In addition, no operational PV farms reported according to our research. Therefore, the majority of the Durban hub must be served by new RES and hydrogen projects to be developed within the Valley initiative.

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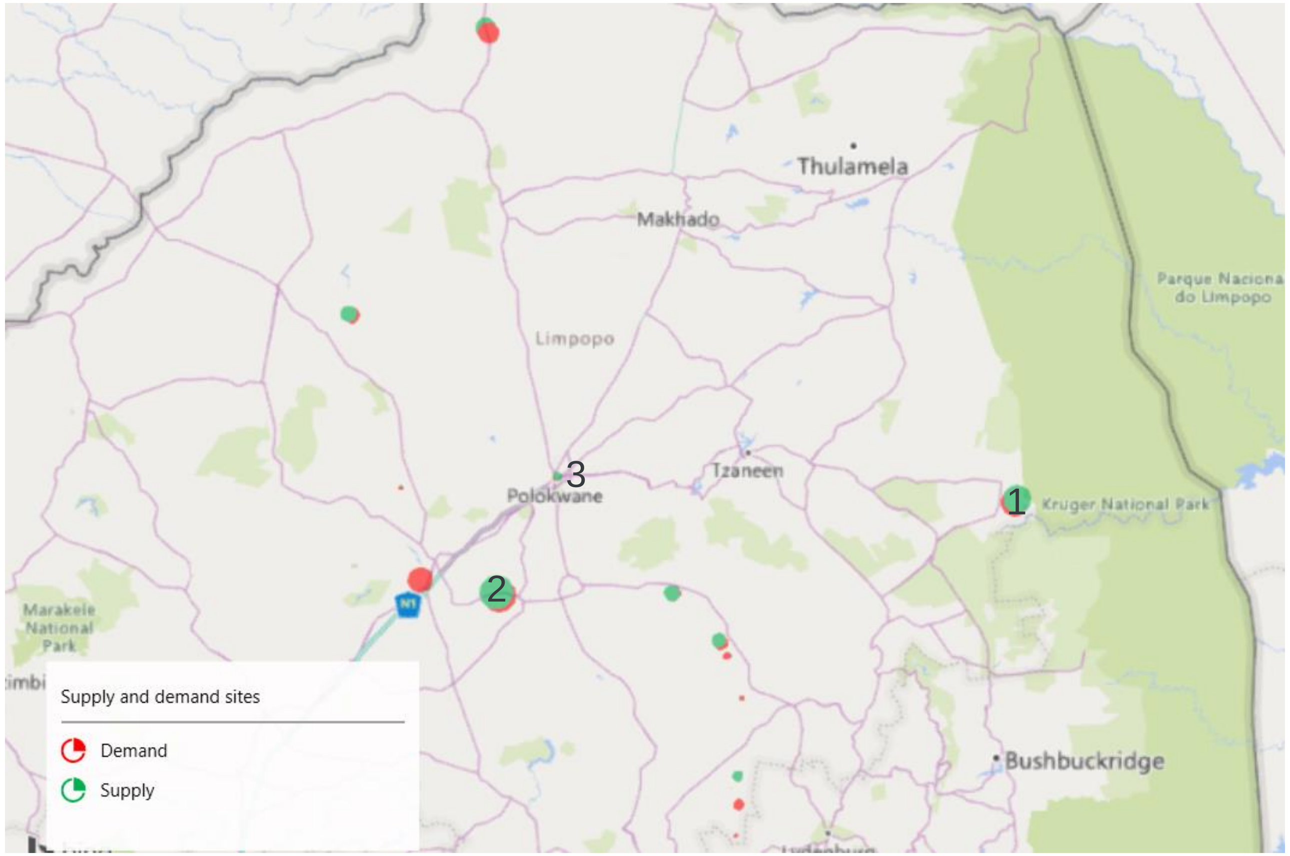
(1) [5] Department of Science and Innovation & NWU, 2020, Hydrogen Society Baseline Assessment Report, Version 2.0

C. In Mogalakwena/Limpopo, it is optimal to have decentralized hydrogen supply in most of the locations



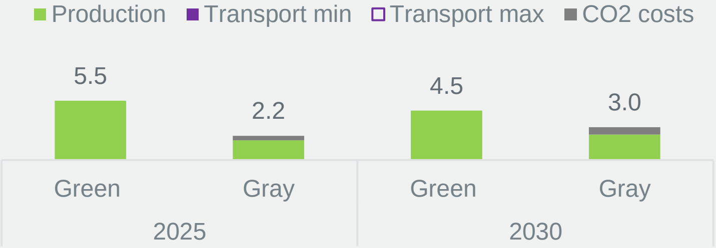
H2 supply locations

- In Mogalakwena, the **distance between off-takers are significant**, therefore it is assumed that **every large off-taker produces its hydrogen on-site.**
- LCOH for supply locations indicated by green dots numbered 1, 2 and 3 were calculated. They represent supply sites that are co-located with largest off-taker locations:
  1. Copper mine in East
  2. Diamond mine south of Polokwane
  3. Limpopo Science Park in Polokwane

In addition, more locations (indicated by unnumbered green dots) have been identified southwest of Polokwane, to address multiple small sites that could possibly serve the N1 (transport is required)

LCOH

LCOH in Mogalakwena* USD/kgH2



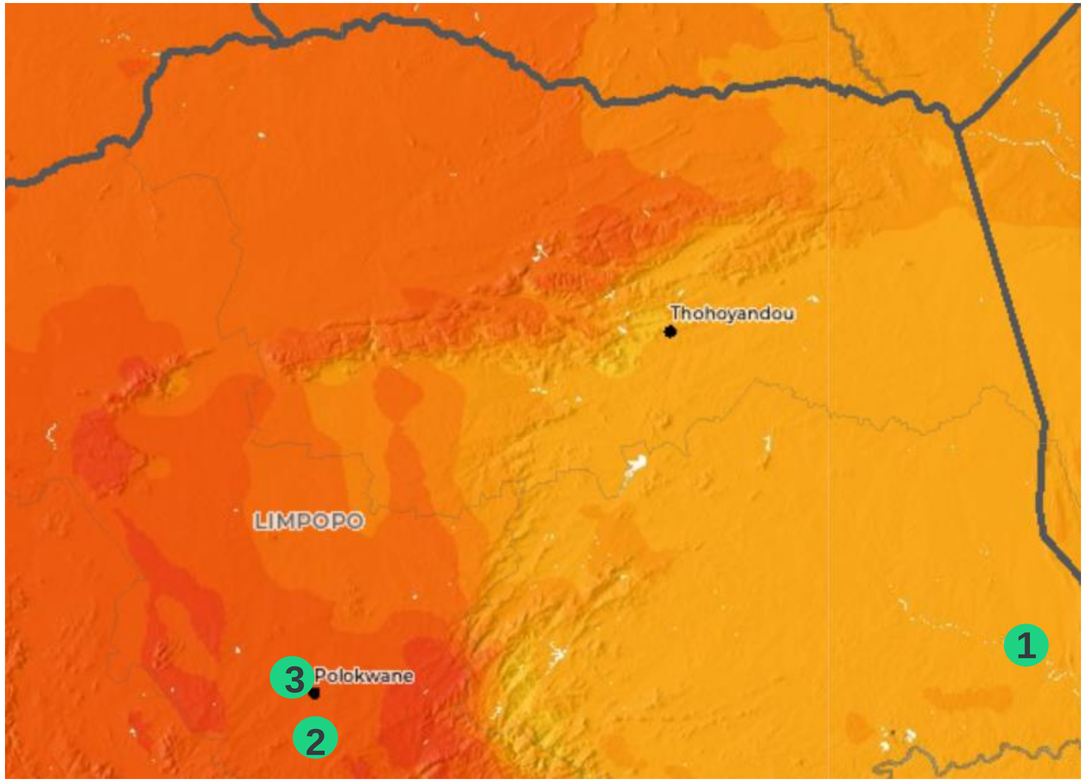
Planned H2 Projects

- Few hydrogen demonstration projects ongoing in Mogalakwena hub, yet a total of 119 MW of solar farms installed in the hub:
- Anglo American is investing in hydrogen-powered fuel cell mine haul trucks (3.5 MW installed today)

*Average of all supply locations, without transport costs

C. Analysis reveals that multiple sites are possible for green hydrogen production despite high LCOH

Supply sites in Mogalakwena…



H2 supply locations

Three supply locations have been selected to calculate the levelized cost of hydrogen (LCOH). These locations have been strategically selected to be in close proximity to potential hydrogen demand in the hub and have access to a renewable energy source such as sun or wind.

In Mogalakwena, the distance between off-takers is significant and therefore it is assumed that every large off-taker produces its hydrogen on-site.

Additionally, more locations have been identified southwest of Polokwane, to address multiple small sites and possibly reach vehicles on the N1, though transport is required.

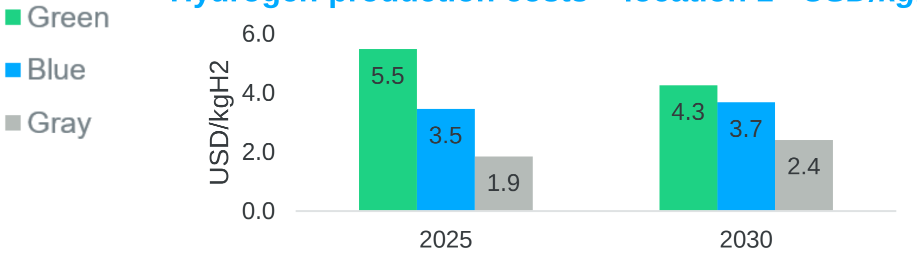
The three green dots are largest off-taker locations based on which LCOH were calculated:

- Copper mine in East
- Diamond mine south of Polokwane
- Limpopo Science Park in Polokwane

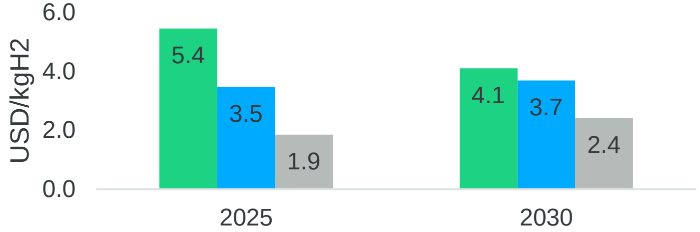
C. Cost of hydrogen production is similar across the Mogalakwena/Limpopo hub, with a green premium at each site

….all see a green premium compared to gray LCOH[1234]

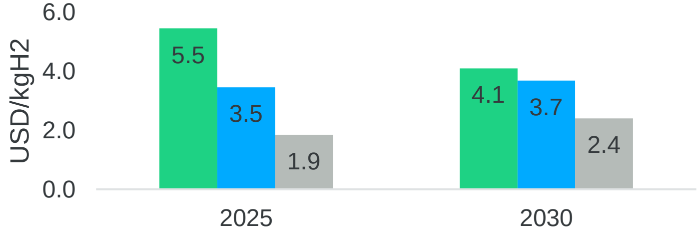
Hydrogen production costs – location 1 - *USD/kgH2*



Hydrogen production costs – location 2 - *USD/kgH2*



Hydrogen production costs – location 3 - *USD/kgH2*



LCOH

The cost of producing hydrogen in the Mogalakwena/Limpopo hub ranges from 4.10-4.30 USD/kg H2 by 2030 (depending on the location), which in some locations is a ~25% decrease from the cost in 2025.

Nevertheless, all three locations still see a green premium between gray and green hydrogen, ranging from 1.70-2.00 USD/kg H2.

As there is no particular cost advantage to producing hydrogen at a specific site within the hub, we recommend producing hydrogen near these large off-takers. This will minimize transport costs for the direct off-takers.

To diversify risk, we also recommend smaller hydrogen supply sites to the Southeast of Polokwane, in order to capture demand from the N2 and smaller mines.

SA H2 Valley LCOH estimates are higher than some other analyses for two reasons:

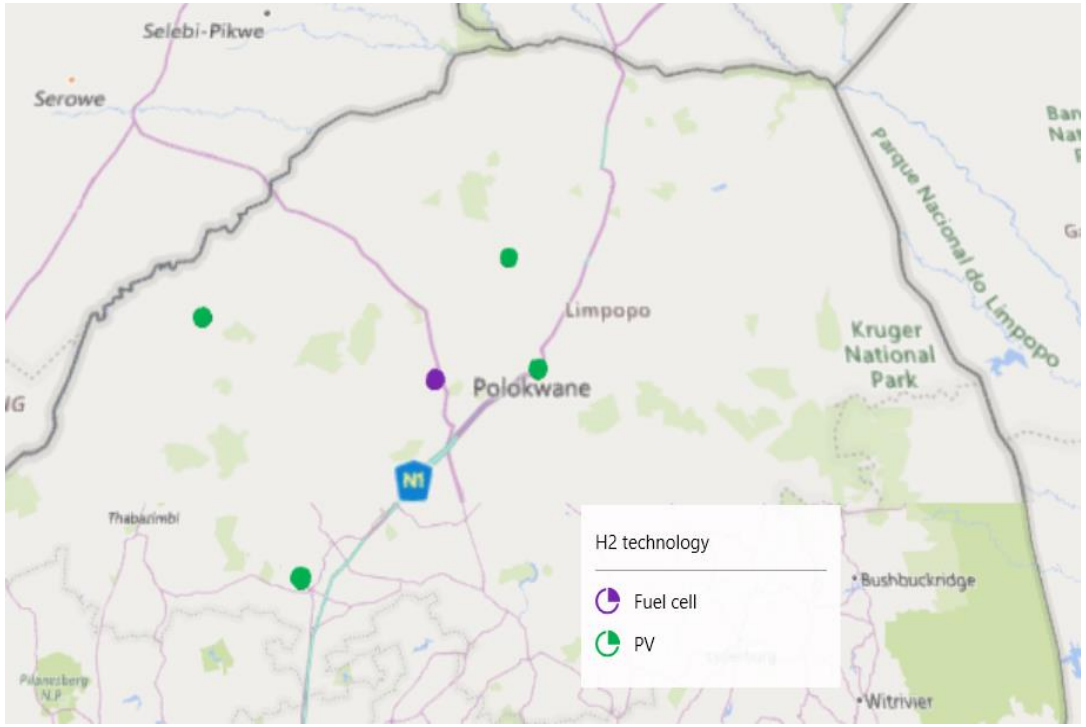
- Our assumptions on electrolyzer cost-down are less aggressive than some other reports, as we have used figures for PEM electroylzers (as opposed to less-costly alkaline electrolyers) due to their high platinum content and response to demand flexibility. Our electrolyzer capex costs also include full cost of installation
- We have also taken a conservative approach in LCOH cost evolution and recognize that f**urther reductions are possible** depending on policy and technology evolution to 2030.

---

(1) In Mogalagkwena, off-taker sites are located far away from each other. It is assumed that every off-taker produces its hydrogen on-site. The three green dots are large/strategic off-taker locations based on which LCOH were calculated.
(2) Source for gray H2 average: [1] Bloomberg 2020 Hydrogen Economy Outlook: will hydrogen be the molecule to power a clean economy?, BloombergNEF; with natural gas prices range from $1.1-10.3/MMBtu, coal from $30-116/t
(3) Green H2 LCOH includes RES (solar and wind) + electrolyzer + water treatment. Transports costs are not accounted for on this slide.
(4) Considering current CO2 tax levels in SA, assuming no more taxes allowances by 2025-2030, and a yearly growth of 10%, CO2 taxes amounts in 2025 to 0.03 or 0.06 USD/kgH2 for SMR and coal gasification respectively, and in 2030 to 0.06 or 0.1 USD/kgH2 for SMR and coal gasification respectively

C. Mogalakwena/Limpopo: there are few hydrogen demonstration projects ongoing in hub

Existing hydrogen demonstration projects



Existing Projects

- There are few hydrogen demonstration projects ongoing in Mogalakwena hub, yet a total of 119 MW of solar farms installed in the hub:
    - Soutpan Solar park (28 MW)
    - Tom Burke Solar Park (60 MW)
    - Witkop Solar Park (30 MW)
    - Bella Mall (1MW)
- Anglo American is investing in renewable hydrogen production technology at its Mogalakwena PGMs mine and in the development of hydrogen-powered fuel cell mine haul trucks (3.5 MW installed today).

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(1) Renewable Energy IPP Procurement Programme Database

Hydrogen Infrastructure & Transport

We investigated infrastructure availability for each of the selected supply site

Upstream

A. Electricity

- Given falling costs of RES, **a dedicated RES supply (off-grid) is recommended** to mitigate grid reliability risks and avoid network charges and taxes
- However, longer term, wheeling might be required to scale up the H2 economy
- Having **flexible H2 demand that is correlated to off-grid RES profile** is important to **keep LCOH down**

B. Water

- **Accessibility of water supply varies** throughout the hub
- Water supply is mostly **at risk** in remote locations
- By strategically repositioning specific supply sites, potential future water insecurity can be **anticipated and mitigated**

Downstream

C. Transport

- Where possible, **position green H2 supply sites in the hubs close to existing gas pipelines**, keeping open the option of **future possible injection**
- **In the short-term** investments in **H2 pipelines** in the hubs do **not** seem **competitive.** Given the limited H2 volume at play in the first phase, the **use of trucks for H2 transport** is preferred

D. Storage

- Opportunities **for long-term underground storage** are limited in the Valley in the short and mid-term
- Short-term above ground storage options can be leveraged to match fluctuating demand, yet **do not impose any location-specific constraints** that require repositioning of supply hubs

Investments

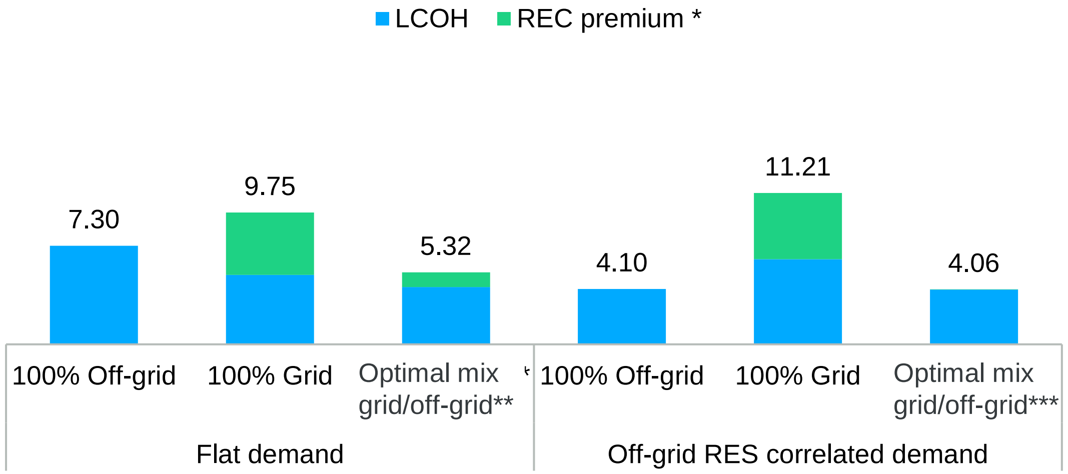
E. Infrastructure Investments

By 2030, meeting the potential H2 demand in the hubs would correspond to **total investments of 3 to 6 billion USD**

A. Despite higher LCOH, off-grid electricity will provide better availability and reliability with less regulatory roadblock

A mix of off-grid and on-grid electricity supply presents the cheapest option for producing hydrogen…

LCOH for Location 1 in Johannesburg (between Sasolburg and Johannesburg) in 2030, USD/kgH2



Renewable Energy Certificate (REC) premium :Eskom is launching the Renewable Energy Tariff pilot programme that will allow all customers to source up to 100% of their electricity from Eskom's renewable sources > enable to certify renewable energy via Renewable Energy Certificates (RECs)
** With **flat demand**, optimal mix consists of **40%** (without REC) to **95%** (with REC) RES share
*** **With RES correlated demand**, optimal mix consists of **99% RES share**
*** As **economies of scale for electrolyzers**' costs level off as from **100 MW**, LCOH of **low and high case** are similar

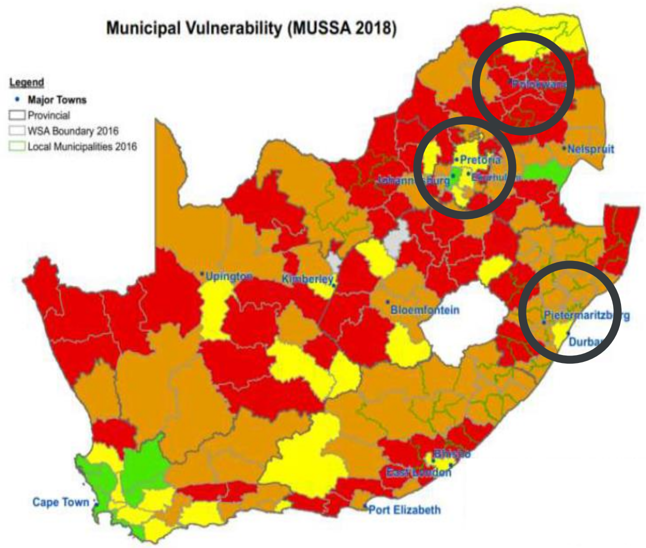
… yet we recommend supplying through off-grid electricity, which presents fewer drawbacks

Sourcing	Pros	Cons
Off-grid	For RES correlated demand (flexible demand), solutions are cheaper than on-grid	For flat demand, more expensive than on-grid
On-grid	Low reliability risk For flat demand, cheaper than off-grid	For RES correlated demand, more expensive than off-grid High reliability risk of grid electricity supply Highly carbonized electricity Regulatory roadblock remains, even with unbundling of ESKOM

To claim for green H2, REC via Eskom can be purchased yet will increase LCOH by up to 90% (see green bars "REC premium" in graph)

B. Investments in water infrastructure could mitigate prevailing supply risks while contributing to a just transition

We observed vulnerability as assessed by local water authorities…



🟥 Extreme vulnerability

🟧 High vulnerability

🟨 Moderate vulnerability

🟩 Low vulnerability

… and identify water supply risks as the result of local water infrastructure at several locations across hubs, especially in more remote and rural areas

Hub	Overview of water security	Recommended action
Johannes-burg	Moderate vulnerability - **Reserves in South and South-East support water supply, yet there remain province-wide concerns** of **water security** by 2030 - **Sufficient infrastructrure** near **metropolitan area** and Sasolburg, yet there is **increased risk** nearby Mpumalanga	- **Locate supply site near Nigel** to enhance security of supply while remaining sufficiently close to key off-takers
Durban	High vulnerability - **Reserves in North-West** of Kwazulu-Natal support supply, yet **overall concerns** of **water security** and **droughts** are still foreseen in the assessment - **Well-developed infrastructure** in **Durban port** and the **metropolitan area, yet high risks in rural areas** remain along the coast due to **poor infrastructure** and weak financial position	- While high vulnerability, **no option for increased water security** by relocating coastal supply sites - Consider **possibility of leveraging or building desalination infrastructure** in mid-term to mitigate water risk
Mogala-kwena	Extreme vulnerability - **Province-wide water shortages**, **poor infrastructure**, weak financial position and technical capabilities, however, plans for **Musina Dam Project** could enhance water security - While little **surface water availability**, **ground water reserves** could be levered via dedicated infrastructure	- Consider **dedicated supply** measures **through water recycling, truck delivery or** investments in infrastructure for **ground water extraction**

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(1) [21] Municipal Water Services Authority Business Health: National Executive Summary Report 2018 Municipal Strategic Self-Assessment

C. Installing hydrogen pipelines in 2025 would require significant hydrogen demand per off-taker to outcompete gaseous and liquid hydrogen trucking

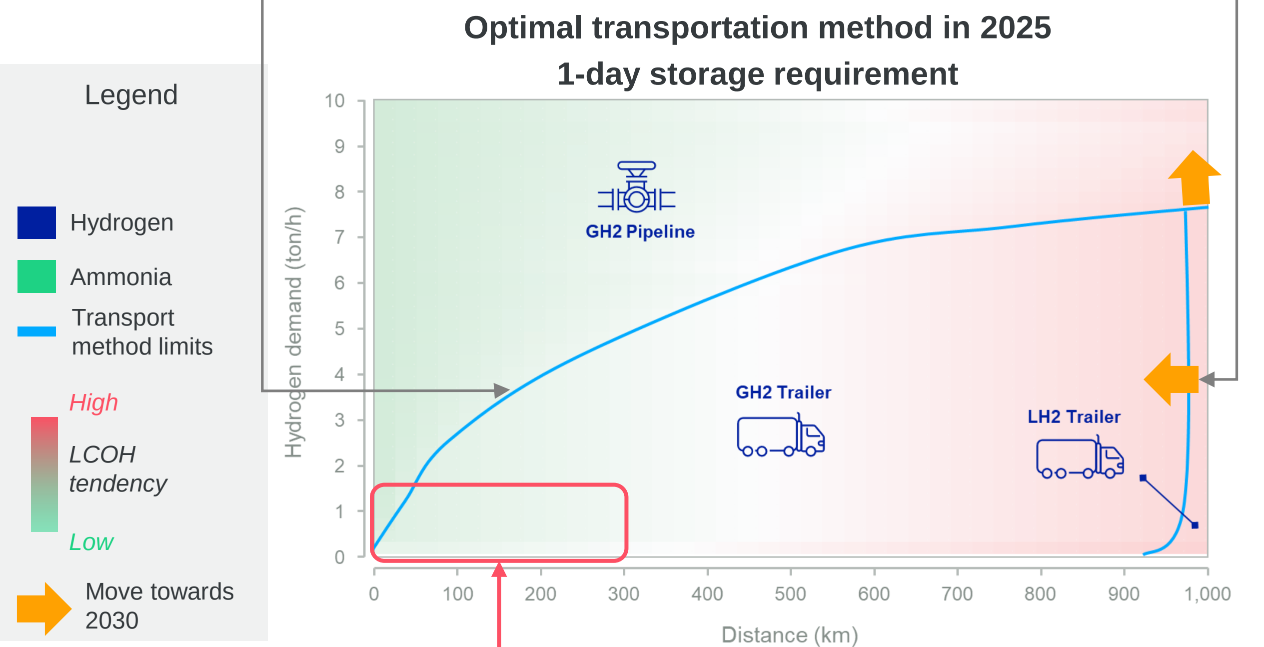
Pipelines require **significant hydrogen demand** to make economic sense:

- 100 km -> 2.8 Ton/h H2 required
- 200 km -> 4 Ton/h H2 required
- 500 km -> 6.2 Ton/h H2 required

Significant **technology improvements** are expected in the **liquefaction process** towards 2030 :

- Decreased CAPEX
- Efficiency gain

These evolutions will improve overall competitiveness of LH2 trailers



Optimal transportation method in 2025
1-day storage requirement

Demand range within the valley

We therefore recommend transportation through trucks:

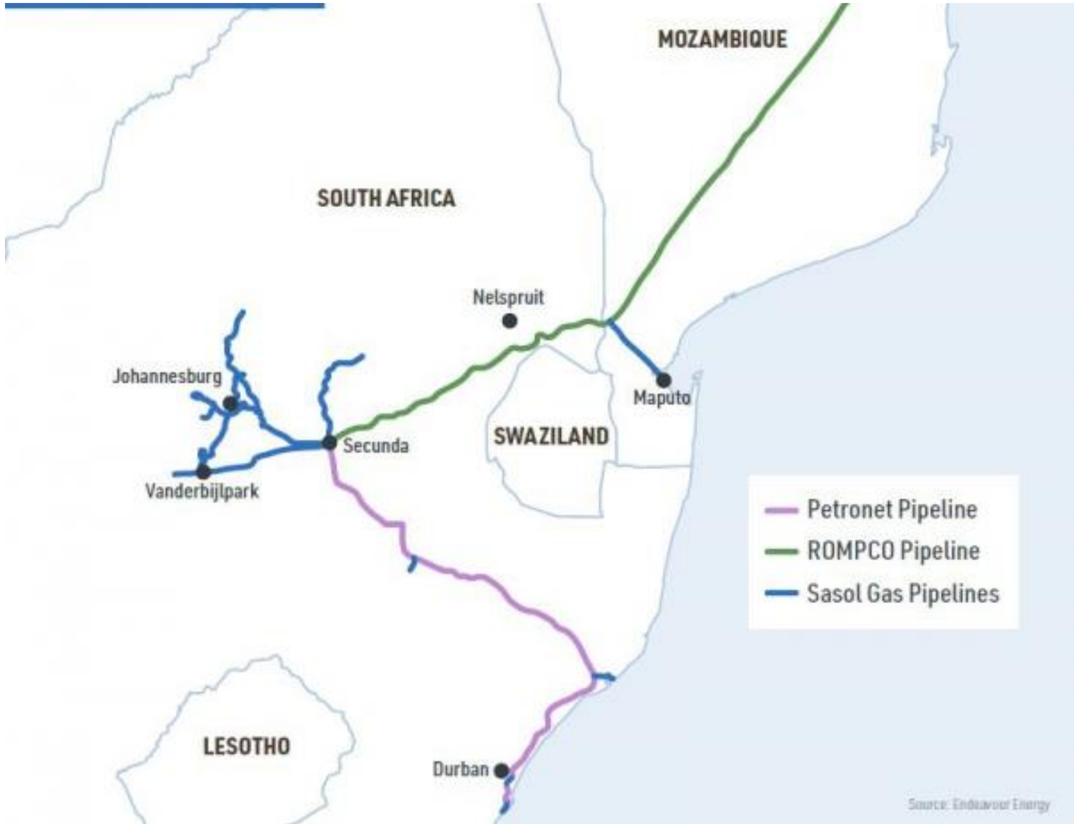
- Transporting hydrogen in compressed or liquid form by truck is the cost optimal option while demand is still low
- Transporting through truck also allows for rapid scale out without the need to build or rehabilitate pipeline and await regulation for hydrogen blending

The current vision of the Hydrogen Valley does not yet include enough H2 demand **for pipelines to be financially viable**:

- Demand within the Valley is expected at around 1 ton H2/hour produced, with transport required at far less than 300 km
- Pipelines would become cost competitive at more than 3 tons H2/hour for the same distance expected for the Valley

C. With no extensive H2 network in the region, existing gas pipelines could be leveraged for H2 transport in the long term

Gas pipelines are present both in the region of Johannesburg and along the coast of KwaZulu Natal…



Source: Endeavour Energy

… driving strategic positioning of supply sites near pipelines to allow for options of H2 blending in the future

Hub	Proximity of gas pipeline infrastructure	Recommended action
Johannes-burg	• **Extensive gas distribution network** (incl H2 pipeline from Vanderbijlpark to Springs) that could be considered for H2 distribution with minimal technical upgrades	• **Locate supply site near Randvaal** to allow connection to pipeline to Sasolburg along R59 • **Locate supply site near Nigel** to allow connection to pipeline to Secunda
Durban	• **One transmission pipeline along the coast,** that could be considered for H2 transport after technical upgrade	• Coastal supply sites are located already **close to pipeline**
Mogala-kwena	• **No gas pipelines in the Limpopo province today**	• **Consider technical requirements** of any future pipelines for H2 transport or blending

D. While underground storage is not feasible before 2030, above ground storage can be leveraged to lower LCOH

Opportunities for long-term underground storage in the Valley are limited in short and mid-term:

- **Salt caverns**, which are today the **most mature and cost-efficient** hydrogen storage, **are not present** in the H2 valley nor in South Africa
- **Other geographical options are available** that could theoretically be used **for long-term underground H2 storage** include**:**
  - **Depleted oil and gas fields**: Durban and Zululands fields near- and off-shore
  - **Underground rock caverns:** Underground coal mines in the area of Mpumalanga and Kwazulu Natal

These long-term storage technologies are **not yet technically and economically proven** and will likely not reach commercial maturity before 2030.

Key identified demands will likely require relatively stable supply without seasonality required for other H2 applications like heating. Therefore, **long-term storage is unlikely to play a key role in the valley on the short- and mid-terms.**

… existing above-the-ground technologies* for short-term storage can be leveraged to match fluctuating demand

Smaller volumes
Short-term application

Pressurized containers

Taken into account in LCOH calculations

- **Very mature** technology, ideally suited to **buffer daily demand fluctuations** between pickup in case of transportation under compressed form by tube trailers
- Volume requirements limit large volume applications

Liquified hydrogen tanks

- Requires a **significant cost** for liquifaction that is not economic unless required for transport
- Mostly suited to **buffer daily or weekly demand fluctuations** for large volumes or distances of transportation, where transport under liquified format is most economic

Ammonia storage tanks

- Allows to **buffer demand fluctuations up to weeks and months**, but not suited for hydrogen offtakers as **reconversion of ammonia is not economic** today
- Suited only in case of usage of **ammonia as a final product** (and transportation in that form)

Large volumes
Long-term application

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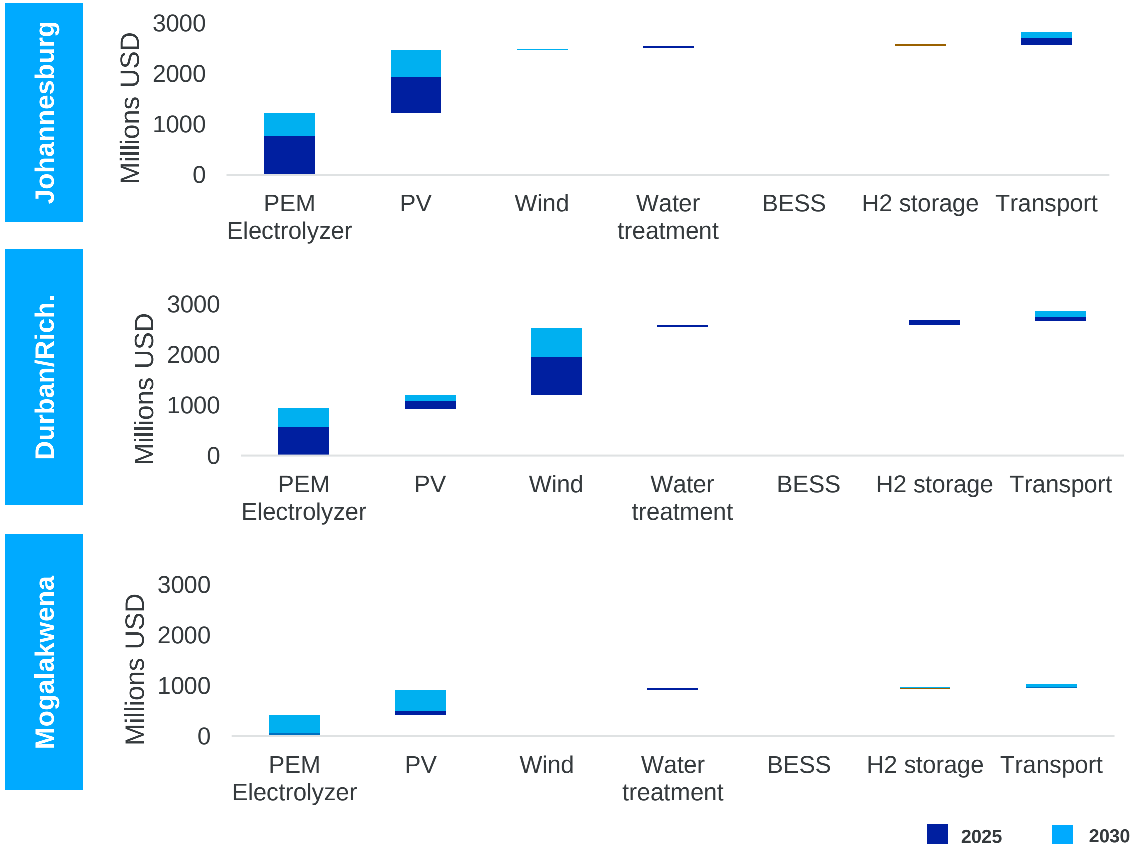
*Liquid Organic Hydrogen Carriers are not considered as a viable means of stationary storage due to outlook of poorer economic feasibility than alternatives

E. To meet potential hydrogen demand in the hubs, by 2030 investments in hydrogen equipment would correspond to up to 3 to 6 billion USD

By 2030, electricity sourcing is the first source of costs in green hydrogen production

Waterfall charts of investments (high case) 2025 and 2030, Million USD

High case



Insights

- Investments corresponding to hydrogen equipment are estimated to be 3 billion USD in the low case, and 6 billion USD in the high case, across hubs
- Investments in 2030 are made to satisfy additional demand that cannot be met by 2025 investments
- In 2025, electrolyzer costs make up for half of production investments costs. Electricity sourcing amounts to 45% of the investments in 2030, due to a decrease of electrolyzer costs more aggressive than decrease of RES costs, electricity sourcing amounts for more than half of the investment's costs
- In addition to electrolyzer and RES, water treatment amounts to just 2% of investment costs. Due to flexible demand, electric and hydrogen storage are not extensively used and represent neglectable costs. Depending on distance and demand volume, transport can amount up to 10% of total costs.

Note 1: investments in required installations **for planned project** are not accounted for.
Note 2: this analysis is intended as a **vision to guide short term initiatives**, rather than a forecast of what will materialize

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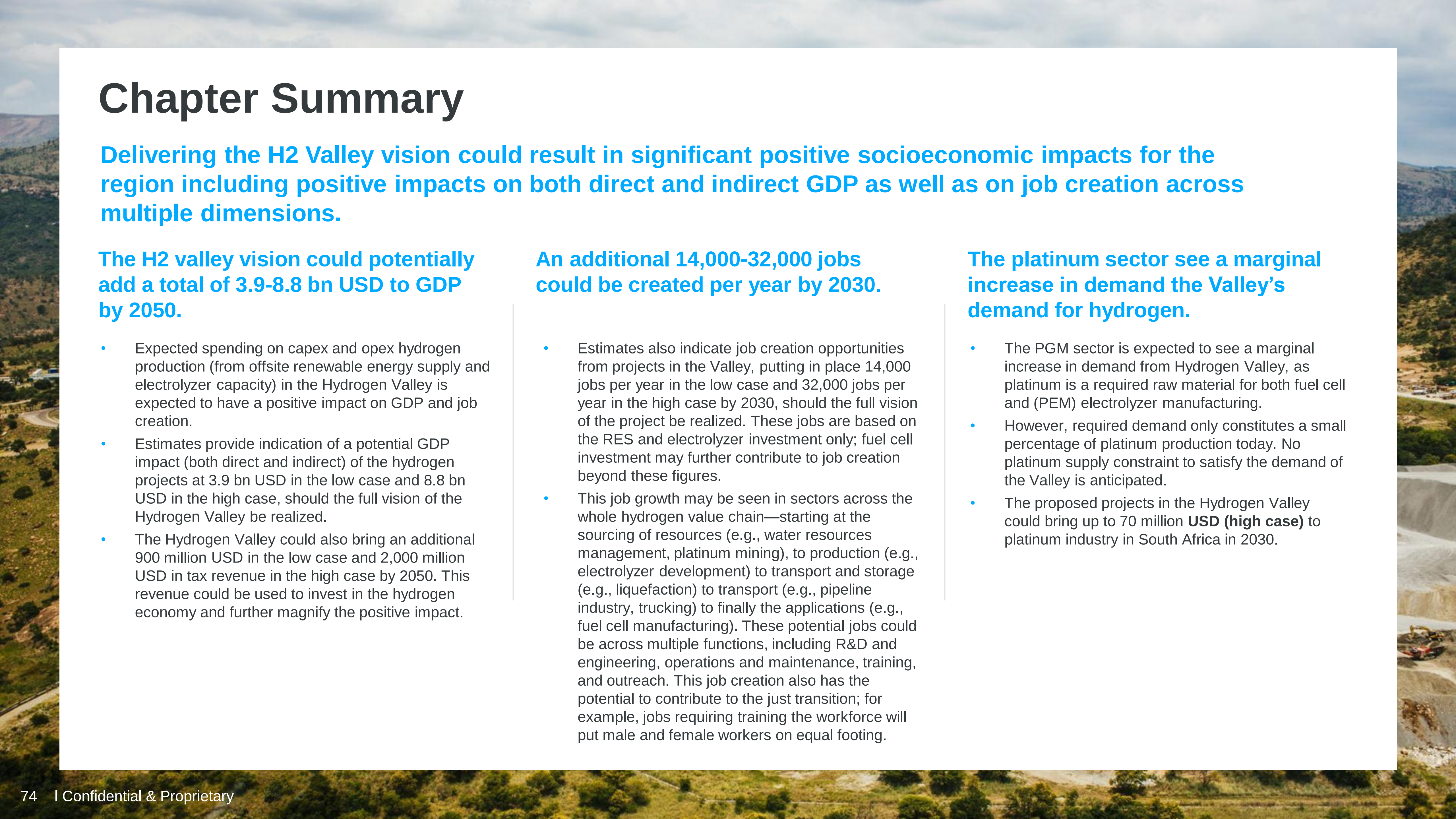


Chapter Summary

Delivering the H2 Valley vision could result in significant positive socioeconomic impacts for the region including positive impacts on both direct and indirect GDP as well as on job creation across multiple dimensions.

The H2 valley vision could potentially add a total of 3.9-8.8 bn USD to GDP by 2050.

- Expected spending on capex and opex hydrogen production (from offsite renewable energy supply and electrolyzer capacity) in the Hydrogen Valley is expected to have a positive impact on GDP and job creation.
- Estimates provide indication of a potential GDP impact (both direct and indirect) of the hydrogen projects at 3.9 bn USD in the low case and 8.8 bn USD in the high case, should the full vision of the Hydrogen Valley be realized.
- The Hydrogen Valley could also bring an additional 900 million USD in the low case and 2,000 million USD in tax revenue in the high case by 2050. This revenue could be used to invest in the hydrogen economy and further magnify the positive impact.

An additional 14,000-32,000 jobs could be created per year by 2030.

- Estimates also indicate job creation opportunities from projects in the Valley, putting in place 14,000 jobs per year in the low case and 32,000 jobs per year in the high case by 2030, should the full vision of the project be realized. These jobs are based on the RES and electrolyzer investment only; fuel cell investment may further contribute to job creation beyond these figures.
- This job growth may be seen in sectors across the whole hydrogen value chain—starting at the sourcing of resources (e.g., water resources management, platinum mining), to production (e.g., electrolyzer development) to transport and storage (e.g., liquefaction) to transport (e.g., pipeline industry, trucking) to finally the applications (e.g., fuel cell manufacturing). These potential jobs could be across multiple functions, including R&D and engineering, operations and maintenance, training, and outreach. This job creation also has the potential to contribute to the just transition; for example, jobs requiring training the workforce will put male and female workers on equal footing.

The platinum sector see a marginal increase in demand the Valley's demand for hydrogen.

- The PGM sector is expected to see a marginal increase in demand from Hydrogen Valley, as platinum is a required raw material for both fuel cell and (PEM) electrolyzer manufacturing.
- However, required demand only constitutes a small percentage of platinum production today. No platinum supply constraint to satisfy the demand of the Valley is anticipated.
- The proposed projects in the Hydrogen Valley could bring up to 70 million **USD (high case)** to platinum industry in South Africa in 2030.

We have examined socioeconomic impact from the Hydrogen Valley project across multiple dimensions

Socioeconomic effects considered	Outcomes
- Indication of potential **socioeconomic benefits** of the H2 Valley project in terms of : - GDP - Job - Tax revenue	- Total Contribution to **GDP**: 3.9 billion USD (low case) to 8.8 billion USD (high case) by 2050 - **Jobs**: additional 14 000 jobs per year (low case) to 32 000 jobs per year (high case) based on RES and electrolyzers - **Tax Revenue**: additional 900 million USD (low case) to 2,000 million USD (high case) by 2050
- **Qualitative** insights on jobs from a **sectoral** and **community** perspective	- Creation of **new** jobs, **preserving** of existing jobs and **conversion** from high to low carbon activities' jobs
- Indication of potential benefits of moving towards a H2 economy in terms of **platinum production**	- If electrolyzer and fuel cell investment materializes, the PGM sector will see a **marginal increase in demand** for platinum, generating up to 70 million US in revenue to the sector in 2030 in the high case scenario - Nevertheless, the demand from the Hydrogen Valley would remain small compared to production levels today. **No platinum supply constraints** are anticipated to satisfy the demand of the Valley

H2 Valley expenditures could have substantial positive socioeconomic impacts in terms of GDP, jobs, Tax revenues

Ranges based on Low and High Demand Cases

Multiplier methodology

- **GDP:** the multiplier is the additional economic impact that results from the new increased expenditure (1)
  - **Direct impact**: concerns the construction or operational activity
  - **Indirect:** concerns additional businesses impacted along the supply chain that would need to increase their production and employment
  - **Induced**: will benefit the employees of the suppliers affected
  - **Employment:** number of additional employment opportunities that could be created from the additional demand that results from the new or added expenditures (1)
  - **Tax revenue:** growth of a hydrogen economy in South Africa will lead to increased tax revenues accruing to the State resulting from the additional economic activity

Multipliers (2)	CAPEX	OPEX
GDP	1.291	1.388
Employment	4.745	3.952
Tax revenue	0.297	0.312

(1) Expenditure considered related the **CAPEX and OPEX of Electrolyzer and RES assets**

(2) Multiplier selected from [15]KPMG, 2020, Hydrogen Society Baseline Assessment Report

Potential effect indication of H2 Valley on GDP, billion USD

Hub	Range 2025	Range 2030
Johannesburg	• 1-2.1	• 0.6-1.5
Durban	• 1-2.1	• 0.7-1.6
Mogalakwena	• 0.1-0.2	• 0.3-1.2

Total of 3.9 to 8.8 billion USD by 2050

Potential effect indication of H2 Valley on employment, k jobs/year

Hub	Range 2025	Range 2030
Johannesburg	• 3.8-7.9	• 2.3-5.4
Durban	• 3.8-7.6	• 2.9-5.8
Mogalakwena	• 0.4-0.7	• 1.3-4.3

Additional 14,500-31,800 employment opportunities per year for RES and electrolyzers

Potential effect indication of H2 Valley on Tax revenues, Million USD

Hub	Range 2025	Range 2030
Johannesburg	• 240-510	• 140-350
Durban	• 250-490	• 190-370
Mogalakwena	• 20-50	• 80-280

Additional 900-2,000 million USD by 2050

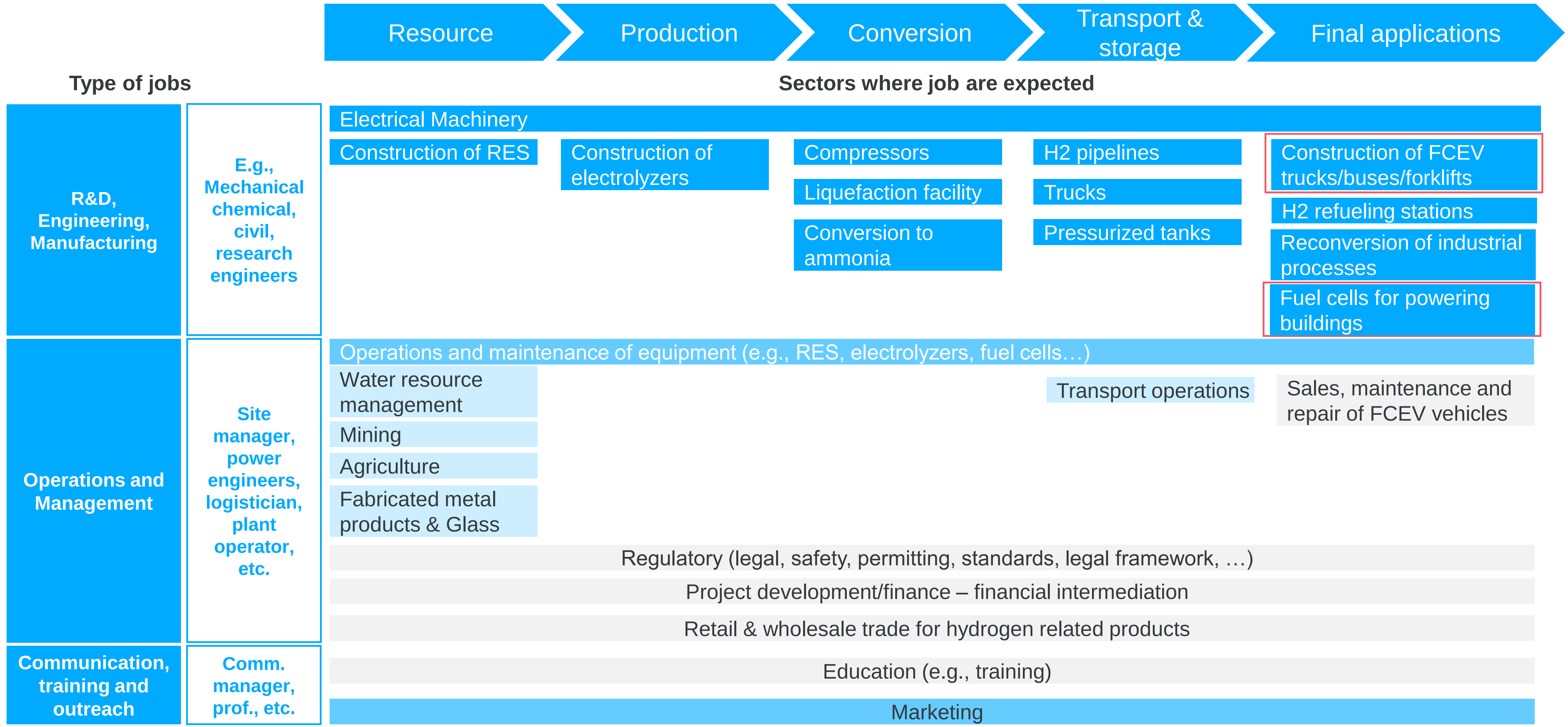
Note 1: Effects are considered for the whole duration of the project:
- Range 2025=2025-2045 duration
- Range 2030: 2030-2050 with effects of 2025 duration deduced

Note 2: Range = range between low and high demand cases

The Hydrogen Valley could contribute to job creation across the hydrogen value chain

🟦 High skills
▦ Medium skills
▢ Low skills
░ Mixed skills
☐ Detailed next

NON EXHAUSTIVE



Resource → Production → Conversion → Transport & storage → Final applications

Type of jobs

Sectors where job are expected

R&D, Engineering, Manufacturing

E.g., Mechanical chemical, civil, research engineers

Electrical Machinery

Construction of RES

Construction of electrolyzers

Compressors

Liquefaction facility

Conversion to ammonia

H2 pipelines

Trucks

Pressurized tanks

Construction of FCEV trucks/buses/forklifts

H2 refueling stations

Reconversion of industrial processes

Fuel cells for powering buildings

Operations and Management

Site manager, power engineers, logistician, plant operator, etc.

Operations and maintenance of equipment (e.g., RES, electrolyzers, fuel cells…)

Water resource management

Mining

Agriculture

Fabricated metal products & Glass

Transport operations

Sales, maintenance and repair of FCEV vehicles

Regulatory (legal, safety, permitting, standards, legal framework, …)

Project development/finance – financial intermediation

Retail & wholesale trade for hydrogen related products

Communication, training and outreach

Comm. manager, prof., etc.

Education (e.g., training)

Marketing

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(1) [20] Navigant, 2019, Gas for Climate – Job creation by scaling up renewable gas in Europe & KMPG, 2020, KPMG Economics

There is also notable opportunity for the H2 Valley to open opportunities for direct and indirect jobs related to local manufacturing of H2 equipment like fuel cells

ILLUSTRATIVE - BAMBILI ENERGY CASE STUDY

FC value chain	Material Management	Hydrogen Generator Floor	Fuel Cell Stack Floor	Quality Assurance	Final applications
Type of jobs	• Mechanical engineer • Electrical engineer	• Computer numerical control • Hydrogen general system assembly • PSA assembly • Welding	• Stacking assembly	• System testing and calibration	

Bambili Energy alone estimates contributing to the creation of ~30 000 jobs (direct, indirect, induced) across the hydrogen value chain from fuel cell-based activities

Many of these jobs will be new and the Hydrogen Valley will also provide the chance to preserve and reconvert existing jobs

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		Description	Communities affected
1	**New jobs**	- Creation of jobs in the hydrogen sector based on three areas (energy sourcing, O&M and CAPEX) - A major part of green hydrogen economy jobs will be related to the construction of renewable electricity and H2 infrastructure	▨ Majority of medium-skilled workers in these sectors ■ High-skilled jobs related to the manufacturing, installation and operation of the plants 🍃 New jobs in rural areas (with RES) where job opportunities are scarcer ♀ Women: New jobs imply that all workers must be trained; levels the playing field for entrants to the workforce
2	**Preserving jobs**	- Green H2 makes some sectors resilient to climate transition, as these jobs are required in the new H2 economy	░ Majority of low and semi-skilled workers in these sectors 🎯 Required materials sourced locally, positively impacting workers in the upstream H2 value chain
3	**Reconverting jobs**	- Other sectors will witness transition of workers from carbon intensive activities to H2 activities - This reconversion argues for a need for policy schemes (e.g., training) to facilitate the transition of workers from carbon intensive sectors	■ High skilled workers required in H2 economy, these sectors need to increase their related R&D capabilities □ Conversion of low-skilled workers as well 🏭 Communities working in “dirty energy” ♀ Women: job conversion implies that all workers must be trained; levels the playing field

■ High skills
▨ Medium skills
□ Low skills
░ Mixed skills

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(1) [20] Navigant, 2019, Gas for Climate – Job creation by scaling up renewable gas in Europe & KMPG, 2020, KPMG Economics

As the project emphasizes using PEM electrolyzers (with a higher platinum content than alkaline electrolyzers), the H2 Valley could create new demand for the South Africa platinum industry to meet H2 equipment manufacturing requirement

Driver | **Features** | **Insights**

Electrolyzers

- Required Pt:
  - **0.44 [gPt/kW]**[1]
- Annual Operation
  - **350 [days/years]**
- Plan to fulfill H2 demand
  - **2025: 1-2%**
  - **2030: 10-30%**

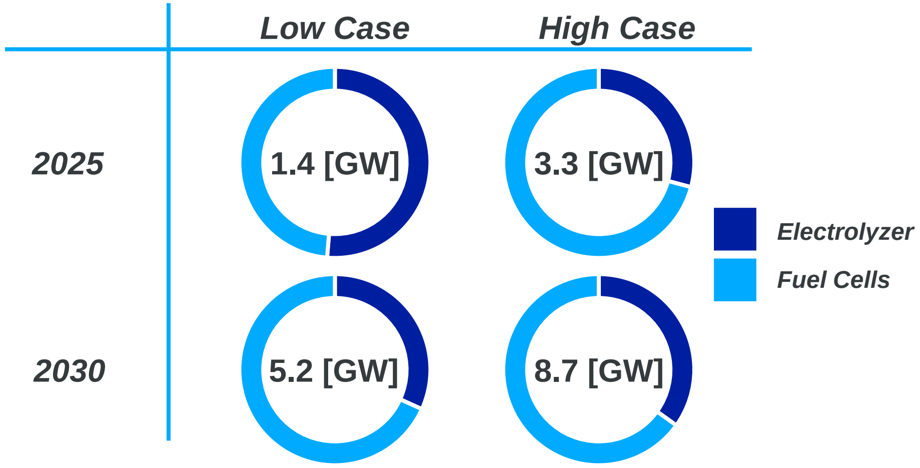
- SA to deploy PEM electrolyzers, which use higher share of Platinum

Fuel Cells

- Required Pt:
  - **0.125 [gPt/kW]**[2]
- Annual Operation
  - **Internal data**
- Required Power Per Mining Truck:
  - **1.4 [MW]**

- Fuel Cell as shows a high share of the market, due the amount of vehicle replacement on mining & mobility
- These estimations could be bigger if calculated for all type of vehicles in SA, and extra chemical demand, such as methanol, biofuels, etc.

Hydrogen Electrolyzers & Fuel Cell requirements



Heavy duty FCEV Fleet such as mining trucks are the major drivers causing both electrolyzer and fuel cell demand, with Johannesburg capturing 62% of the projected share demand of fuel cells.

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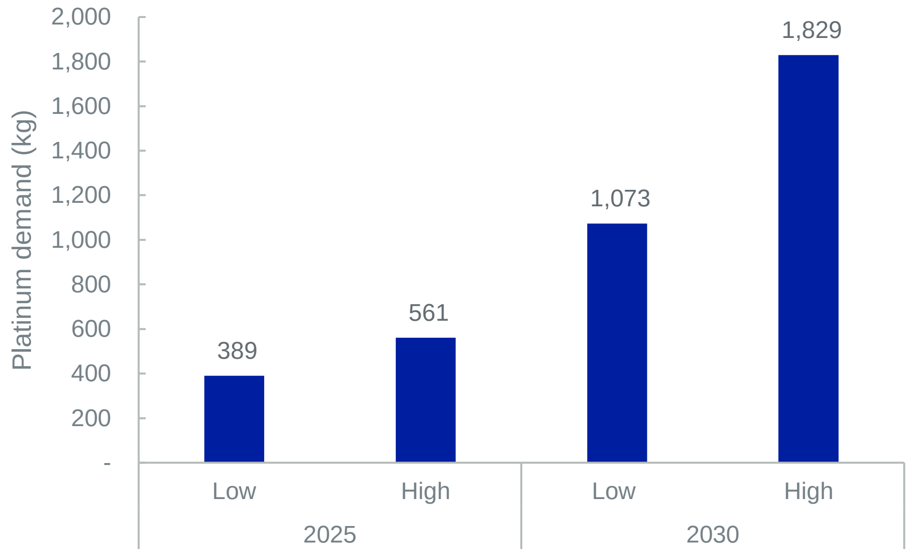
(1) [25] NREL, 2019, Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. 11 g/m$_2$ of membrane and 0.04m$_2$/kW result in 0.44 gPT/kW
(2) [25] DOE, 2015, DOE Technical Targets for Polymer Electrolyte Membrane Fuel Cell Components. Platinum group metal content 0.125 g/kW

This demand for platinum is marginal compared to production volumes today, but could generate up to 71 million USD in revenue to the sector in 2030

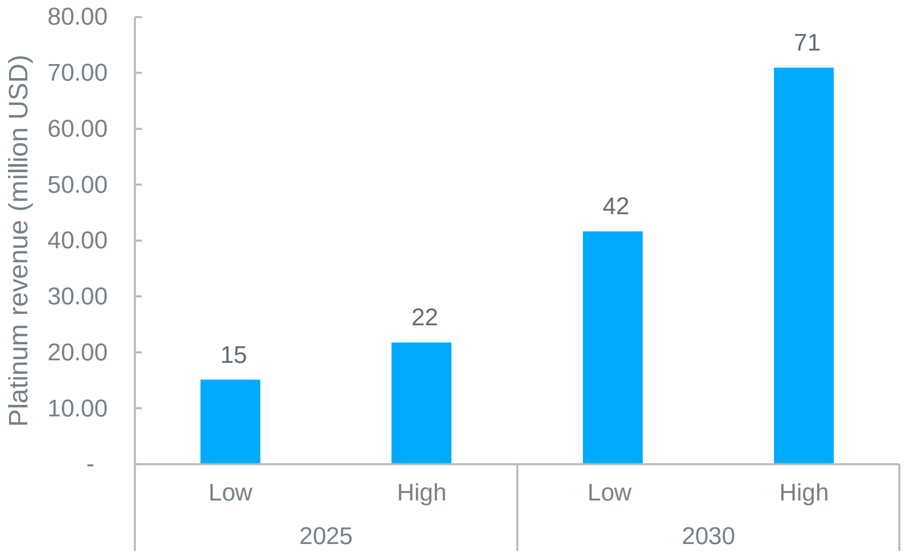
High Case

Platinum in H2 Valley, kg



- The total amount of Platinum required to fulfill the equipment (PEM electrolyzers & fuel cells) demand **marginally increases the annual production** in South Africa **by 1800 kg by 2030.**
- This is the equivalent of **1-2% of platinum production today**. Therefore, a platinum supply constraint is not anticipated.

Platinum revenues, million USD



- Each Oz of platinum has a market price **1,240 USD/oz** (38,800 USD/kg), and annual production fluctuates between 150 and 200 Tons per year.
- By 2030, demand from the Hydrogen Valley could generate between **42 and 71 million USD** in revenue for platinum alone (without other rare metals as iridium), depending on the evolution of platinum ratios in electrolyzes and fuel cells

Iridium, another PGM, is also a vital catalyst for hydrogen production in a PEM electrolyzer that will also see a marginal increase in demand

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Chapter Summary

Regulatory and policy enablers are required to kickstart the hydrogen economy.

While South Africa has already put in place many policies that can nurture the hydrogen economy, multiple barriers still exist to scale up hydrogen in the Valley.

- South Africa has already put in place many policies to kickstart the hydrogen economy, including policies to promote renewable electricity, electroyzer development, hydrogen demand and hydrogen transport infrastructure.
- Multiple barriers still exist to scale up hydrogen in the Valley. These **relate to sourcing green electricity** (limited green electricity on grid), **electrolyzer scale up** (high costs), **hydrogen demand** (lack of clear targets and strategies at the sector level) and **infrastructure** (e.g., missing hydrogen transport and storage regulation).

We identified policy and regulatory enablers to address these barriers.

Across each of these categories, we recommend a suite of policy and regulatory instruments:

- To ease deployment of RES and electrolyzers, we recommend offering financial incentives to lower capex cost and fast track RES deployment through simplified permitting procedures.
- To make near-term capex affordable for hydrogen supply infrastructure, we recommend a mix of direct financial support, financial incentives and CO2 taxes.
- In order to create momentum for future demand, it is important to put in place sector planning to provide transparency on future off-take and encourage technology partnerships between suppliers and off-takers to share risk of new projects.
- Finally, standards and labels are required to harmonize technology specifications and guarantee safety of hydrogen production, transport and of applications.

To kickstart the hydrogen economy, a few of these policies should be rolled out in the near term.

- A few key policies are required to support the deployment of projects identified by the study:
- Create, clarify and fasten permitting procedures for authorities and project developers.
- Enable low interest funding for H2 mobility projects.
- Introduce carbon taxes for fossil fuel-based production.
- Expand on DTIC grant programme to incorporate H2 applications.
- Establish green gases targets.
- Leverage on IPAP to provide incentives to manufacturers to retrofit/invest in H2 compatible plant.
- Government to lead the way as a key off-taker of green H2 powered buildings for resiliency purposes.

South Africa has already put in place many policies that can nurture the hydrogen economy and that can catalyze the H2 Valley across the value chain

NON EXHAUSTIVE

	Electricity	Electrolyzer	Demand	Hydrogen Transport Infrastructure
Planning & Regulation	• **RES sourcing:** REIPPP Programs[1] where independent producers can participate in tenders. Electricity is to be sold to Eskom. • **Wheeling:** Amendment of the Electricity Regulations on New Generation Capacity aims at moving beyond the single buyer model which will enable wheeling on a larger scale than what is currently operational in SA. • **IRP[2]:** An electricity capacity plan with how electricity demand is to be addressed. • **Permitting:** Generation projects up to 100MW exempt of NERSA licensing requirements.	Few existing policies are observed.	• High-level hydrogen demand target in **National Roadmap Strategy.** • The **Industrial Policy Action Plan (IPAP)** provides financial incentives for manufacturers within the clean energy sector in SA . • **Green Transport Strategy** (DoT) aims at identifying opportunities for the deployment of fuel cells in the public transportation sector.	• **Study** on the future use of **Transnet Pipelines** for the development of inland **natural gas** transmission. • **Critical Infrastructure Programme (CIP)** could be used to advance the investments in hydrogen infrastructure.
Financial support	• **REDZ[3]:** Where wind and solar PV development can occur in concentrated zones, creating priority areas for investment in the electricity grid. • **CAPEX subsidy:** SA Accelerated Depreciation Allowance implies a 28% discount on the price of solar system.	• **Project funding:** The SA National Energy Development Institute (SANEDI) funds projects through HySA. • **Incentives:** Innovation. Possibility of tax incentive to advance R&D within H2 landscape such as the Income Tax Act, Support Programme for Industrial	• **Carbon Tax:** Emissions from the use of petrol and diesel (excl. aviation and maritime) are subject to a carbon tax with tax-free allowances. • **Special Economic Zones (SEZ):** Benefit from reduced corporate tax rate and accelerated tax allowance on buildings of companies operating in designated SEZ.	• **Infrastructure project funding:** HySA programme, under the DSI, with specific mandate of HySA Infrastructure centers on hydrogen generation, storage, transport and codes and standards.

(1) Renewable Energy Independent Power Producers Procurement
(2) Integrated Resources Plan
(3) Renewable Energy Deployment zones

Nevertheless, multiple barriers challenge the scale up of the hydrogen economy in Hydrogen Valley

NON EXHAUSTIVE

	Electricity	H2 Production	Hydrogen Demand	Hydrogen Transport Infrastructure
Planning & Regulation	• **Limited green electricity on national grid:** electricity of national grid produced by a highly carbonized mix. • **Challenges related to grid access of Green RES:** uncertainty around green electricity solutions such as wheeling/tenders transiting through the grid. • **Need to align policies** to ensure that electricity regulations enable H2 development.	• **Manufacturing deployment required:** there is a need for higher electrolyzer manufacturing capacity to rapidly scale the H2 economy. • **Challenges in permitting due to lack of H2 experience,** creating a lack of clarity on the permitting procedure and lengthy existing regulations including EIA. • **Missing H2 regulation** around technical standard for the electrolyzer. • **Challenges with water access and licenses:** difficult and lengthy process.	• **Lack of clear targets** and strategies at sector level, implying a lack of guarantees for future demand for green hydrogen/products and prevent deployment of H2 at gigawatt scale. • **Missing H2 technical and safety regulations** in downstream applications.	• **Missing H2 transport and storage regulation,** around technical, safety and commercial standards to address hydrogen transport and storage hazards. • **Barriers to achieve transport at scale:** installing hydrogen pipelines in 2025 requires significant hydrogen demand per off-taker to outcompete gaseous and liquid hydrogen trucking.

Financial support	• **High electricity CAPEX for new RES:** despite solar energy reducing by around 30% in 2030, green electricity production remains capital intensive and comprises 50% of hydrogen production costs in the South African Hydrogen Valley.	• **High electrolyzer costs:** The PEM electrolyzers costs will decrease by 60% between today and 2030 and yet their cost remains high with production costs of green hydrogen heavily depending on the investment cost of the electrolyzers.	• **Cost competitiveness of H2**
			  • Cost of green H2 will remain higher than grey H2: **green premium** of green compared to grey ranges between 3 and 1.6 USD/kg H2 (2025-2030).
			  • Only a few H2 applications competitive today on a TCO basis; investment in these applications required before TCO competitiveness is achieved.	

[15] KPMG, 2020, Hydrogen Society Baseline Assessment Report
[13] IRENA, 2021, Green Hydrogen Supply: a guide to policy making
[8] FCH JU funded studies, 2021, Hydrogen Valleys: insights into the emerging hydrogen economies around the world

We have identified five guiding principles to overcome these barriers that will constitute criteria to prioritize regulatory and policy enablers

Supply guiding principles

Electricity

Electrolyzer

Ease deployment of RES and electrolyzers to expedite roll out

Make near-term CAPEX affordable for hydrogen supply infrastructure (RES, electrolyzers)

Demand guiding principles

Demand

Infrastructure

Encourage H2 applications through financial incentives

Create momentum for future demand in target, planning and government purchases to scale up the hydrogen economy

Formalize hydrogen sector through standard and labels including safety standards, technical standards

Regulatory and policy enablers are required to unlock barriers in green electricity production, roll out electrolyzers, incentivize off-takers and build H2 infrastructure

Overview of primary regulatory and policy enablers

NON EXHAUSTIVE

<table>
<tr><th>Electricity</th><th>Electrolyzer</th><th>Green H2 Uptake</th><th>Infrastructure</th></tr>
<tr><td colspan="4">Planning</td></tr>
<tr><td colspan="4">Fiscal/financial incentives</td></tr>
<tr><td colspan="4">Targets</td></tr>
<tr><td colspan="4">Research and Development</td></tr>
<tr><td colspan="4">Guarantees of origin</td></tr>
<tr><td>Sustainability assurance measures</td><td>Manufacturing capacity support</td><td>Non-financial incentives (privileged access, …)</td><td>Creation of standards for transport and storage</td></tr>
<tr><td>Fast tracking RES deployment</td><td>Encourage technology partnerships between suppliers and off takers</td><td>Creation of standards (specifications, safety, ..)</td><td>Regulation to access and operate infrastructure</td></tr>
<tr><td>Clarifying wheeling opportunities</td><td>Direct financial support</td><td>International agreements</td><td></td></tr>
<tr><td colspan="2">Ancillary market participation</td><td>Hydrogen market</td><td></td></tr>
<tr><td></td><td></td><td>Carbon price</td><td></td></tr>
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[15] KPMG, 2020, Hydrogen Society Baseline Assessment Report
[13] IRENA, 2021, Green Hydrogen Supply: a guide to policy making
[8] FCH JU funded studies, 2021, Hydrogen Valleys: insights into the emerging hydrogen economies around the world

Leveraging this framework and guiding principles, we identified specific policy requirements for the Hydrogen Valley

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Guiding principles	Policy enablers	Specific policy requirements for SA H2 Valley	Relevant entity
Ease deployment of RES and electrolyzers to expedite roll out	Financial incentives Fast tracking RES deployment	• Exemption from taxes and levies on electricity grid • Investment subsidies for electrolyzers • Creation, clarification and fastening of **permitting procedures** for authorities and project developers (e.g., through task force) – exemption for projects > 100 MW in the long term • Ease wheeling for independent producers	DSI, DMRE, ESKOM, Environmental Affairs, Municipalities (land permitting), NERSA, etc.
Make near-term CAPEX affordable for hydrogen supply infrastructure	Direct financial support Financial incentives	• **CAPEX subsidy** or state tax exemption for manufacturing, R&D and sales of electrolyzers • **Exemption from** electrolyzers connected to the grid **from taxes and fees** normally levied on large consumers. • Leverage international climate funds like the Green Climate fund, and Innovation fund	DSI, DMRE, DTIC, DoF, NERSA, SEZs
Encourage H2 applications through financial incentives	Direct financial support Financial incentives Carbon pricing	• **CAPEX subsidy** or **state tax exemption** for final applications • **Environmental regulation:** applying additional taxes and levies to grey hydrogen and other fossil fuels and quotas. **Repurpose subsidies** for diesel trucks into H2 trucks	DSI, SEZs, DoT, DTIC, Dept of Public Works, DMRE
Create momentum for future demand in order to scale up the hydrogen economy	Planning Encourage technology partnerships between suppliers and off-takers Carbon pricing	• **Strategic roadmap and planning** to establish demand certainty across sectors with green gas and vehicle targets • **Special Economic Zones** to incentivize targeted economic activities • **Government purchases** to stimulate the growth of the domestic H2 related industry • Policy makers **connecting** project developers and local off-takers • **CO_2 taxes** to disincentivize non green applications	DSI, SEZs, DoT, DTIC, Dept of Public Works, DMRE
Formalize hydrogen sector through standard and labels	Creation of standards Regulations to access and operate infrastructure	• **Harmonized codes and standards** including safety and commercial specs • **Regulatory framework** for **hydrogen injection** such as retrofitted or newly-built gas grids and H2 pipelines and the operation of a H2 **storage** facility	SABS, DoT, DTIC, Dept of Public Works, DMRE

Aside transversal supply policy enablers, demand policy enablers can be further specified by sector and pilot projects

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	Mobility	Chemicals	Powering offices
Catalytic pilot projects	**Buses** **Mining trucks** **Forklifts (ports)** **Heavy duty trucks**	**Ethylene in Sasolburg** **Ammonia in Sasolburg**	**LSTP power** **Office buildings - Rustenburg**
Encourage H2 applications through **financial incentives**	• **CAPEX subsidy** or **state tax exemption** for FCEV and refueling stations • Low **interest funding** for H2 mobility projects • **Repurpose subsidies** for diesel trucks into H2 trucks	• Application of **taxes/quotas** to grey hydrogen use • **Premiums** for green hydrogen use in industry • **Carbon price** for fossil fuel-based production	• Applying **taxes/quotas** to fossil fuel use in building sector
Create momentum for future demand in order to scale up the hydrogen economy	• % **target** for FCEV vehicle target • Government to **lead the way** with own fleets (e.g., buses) to build economies of scale • **Leverage on green Transport strategy** to further deploy fuel cell in public transportation sector	• Expand on DTIC **grant programme** to incorporate H2 applications • Leverage existing **SEZ** to be eligible for incentives and update rules to support non-export green H2 industries • Establish **green gases targets** • Provide incentives to **manufacturers** to retrofit H2 compatible plants • Encourage **technology partnering**	• Government to **lead the way** as a key off-taker of green H2 powered buildings for resiliency purposes

Formalize hydrogen sector through standard and labels	• H2 safety and quality **standards** e.g.:
	  • H2 pressure in vehicles
	  • H2 pressure in charging station
		• Commercial mixed (green/grey) products **standards**
		• **Blending** mandates for fuel for heat
			• Safety **standards** to ensure transport and storage to populated areas

These enablers should be further assessed and detailed at the national level (see national Hydrogen Society Roadmap)

[15] KPMG, 2020, Hydrogen Society Baseline Assessment Report
[13] IRENA, 2021, Green Hydrogen Supply: a guide to policy making
[8] FCH JU funded studies, 2021, Hydrogen Valleys: insights into the emerging hydrogen economies around the world

To kickstart the hydrogen economy, we recommend starting with quick wins to deploy some of these enablers

NON EXHAUSTIVE

	Cross cutting enablers	Mobility	Chemicals	Powering offices
	All	**Buses** **Mining trucks** **Forklifts (ports)** **Heavy duty trucks**	**Ethylene in Sasolburg** **Ammonia in Sasolburg**	**LSTP power** **Office buildings - Rustenburg**
Near term (pilots, quick wins)	• Ease wheeling for independent producers • Create, clarify and fasten **permitting procedures** for authorities and project developers	• Establish target for FCEV vehicle target • Enable low interest funding for H2 mobility projects • Government to lead the way with own fleets (e.g., buses) to build economies of scale • Repurpose subsidies for diesel trucks into H2 trucks	• Introduce higher carbon price for fossil fuel-based production • Expand on DTIC grant programme to incorporate H2 applications • Establish green gases targets • Leverage on IPAP to provide incentives to manufacturers to retrofit/invest in H2 compatible plant	• Government to lead the way as a key off-taker of green H2 powered buildings for resiliency purposes
Medium term (scaling up)	• Introduce CAPEX subsidy or state tax exemption for manufacturing, R&D and sales of electrolyzers • Exempt electrolyzers connected to the grid from taxes and fees	• Develop H2 safety and quality standards e.g., pressure in vehicles and in charging stations • Introduce CAPEX subsidy or state tax exemption for FCEV and refueling stations	• Introduce taxes/quotas to grey hydrogen use • Encourage technology partnering • Develop commercial standards for mixed (green/grey) products • Develop blending mandates for fuel for heat	• Develop safety standards to ensure transport and storage to populated areas
Long term (expansion)	• Introduce feed-in schemes to compensate storage solution when producing during long low-RES periods • Introduce auction mechanisms	• Leverage on green Transport strategy to further deploy fuel cell in public transportation sector	• Introduce premiums for green hydrogen use in industry	• Introduce taxes/quotas to fossil fuel use in building sector

These enablers should be further assessed and detailed at the national level (see national Hydrogen Society Roadmap)

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[13] IRENA, 2021, Green Hydrogen Supply: a guide to policy making
[8] FCH JU funded studies, 2021, Hydrogen Valleys: insights into the emerging hydrogen economies around the world

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Chapter Summary

Nine catalytic projects across the mobility, industrial and buildings sectors have been selected to kickstart the hydrogen economy in the Valley.

Across Johannesburg, Durban/Richards Bay and Mogalakwena/Limpopo, we have identified around 15 projects, 9 of which are pilot projects that should be the near-term focus.

One of the main advantages of Hydrogen Valley is its ability to quickly deploy projects. Following the hub and Spokane concept, these projects will begin in the hubs and then scale to the whole Valley.

We have selected and prioritised projects to kick off hydrogen economy using multiple selection criteria:

- Existing use cases that can be scaled
- Total cost of ownership (TCO) competitiveness compared to conventional alternatives
- Importance to strategic green hydrogen ambitions and just transition objectives
- Concrete momentum and willing stakeholders
- Modularity of application to limit initial investment and later scale-up

In the mobility sector, there is already momentum in place for multiple projects and new opportunities.

- There is already momentum in place to deploy mining trucks (e.g., project Rhyno in Mogalakwena) and heavy-duty trucks along the N3 corridor.
- We recommend piloting mobility applications like forklifts in the Durban and Richards Bay port environment, public buses in metropoles and berthing activities in the port of Durban powered by fuel cells.
- A longer-term activity, marine bunkering for ammonia could be deployed as hydrogen in the maritime sector is a strategic priority though not yet cost competitive.
- A fuel cell train between Durban and Richards Bay could be interesting once the technology is further developed.

In the industrial sector, the Hydrogen Valley should support existing projects in the near term.

The industrial sector already sees many pilot projects underway that could be supported by this project. Sasol has committed to developing Ammonia from green hydrogen. Ethylene could also be an opportunity for Sasol. Green steel is a national priority, and there could be an opportunity to pilot green steel production with Arcelor Mittal at one of its sites near Johannesburg. The government is interested in reducing emissions in the paper and pulp sector, presenting an opportunity for Durban-based paper mills to switch from natural gas fuel to hydrogen.

In the buildings sector, the Limpopo Science and technology park, as well as Anglo-American corporate office buildings in Rustenburg have already planned to install fuel cells for power.

Other interesting opportunities include public office buildings in metropoles and airport buildings at OR Tambo & King Shaka airport1. Though not the focus of the pilot projects, there is also significant future potential in fuel cells for backup power in corporate headquarters (e.g., Anglo-American), as well as in data centres beyond Limpopo. Corporate headquarters are increasingly interested in hydrogen fuel cells to provide backup power while also helping the corporation achieve net-zero or either sustainability targets. Data centres may also use hydrogen as primary or backup power to achieve higher levels of tier ratings and are especially interested in guaranteeing secure and reliable electricity supply, an important factor that may outweigh the green premium for some actors. Fuel cells in buildings is rapidly changing landscape in South Africa and the impact on the Hydrogen Valley could be exponential.

(1) Alternatively, airports may integrate fuel cells through mobility applications (e.g., buses, operational vehicles). For the purposes of this report, we assumed that airports will pilot hydrogen through one type of application first (here, buildings) before scaling.

We have selected and prioritised projects to kick off hydrogen economy using multiple selection criteria

Projects are selected based on three criteria…

Existing use cases that can be scaled up and are most relevant to the Valley's local economic context

Total cost of ownership (TCO) competitiveness with prevailing carbonized alternatives in the short to medium term

Importance to the strategic green hydrogen ambitions and just transition objectives of the Valley and South Africa as a nation

…we further prioritized them into short- and medium-term opportunities based on three characteristics

Concrete momentum and willing stakeholders as identified during the stakeholder interviews and workshop

Modularity of application to limit upfront initial investment and later scale-up

We have identified promising concrete projects that could progressively be deployed to kickstart the hubs

NON-EXHAUSTIVE

🟢 Johannesburg 🔵 Durban / Richards Bay 🟣 Mogalakwena ☐ Sample project card provided ☐ High potential pilots

kton H2 / year

	Hubs	Projects	Launch of Pilots	Scaling-up	Expansion across sectors
Mobility	🟢 🔵	Buses conversion in Johannesburg, Pretoria & Durban	Up to 1	1 – 4	4 – 8
	🟣 🔵	Mining trucks	Up to 8	8 – 25	25 – 50
	🔵	Retrofitted port logistics in Durban and Richards Bay ports	Up to 1	1 – 2	2 – 4
	🟢	Forklifts in logistics centers in Rustenburg/Johannesburg	Up to 0.2	Up to 0.5	0.5 – 5
	🟢 🔵	Heavy duty trucks conversion with refueling stations	Up to 5	6 – 9	12 - 26
	🔵	Freight Trains between Durban & Richards Bay			0.3 – 0.7
	🔵	Marine bunkering for ammonia powered bulk carriers			5 – 10
	🔵	Berthing activities powered by H2 FC			0.3 – 0.5
Industry*	🟢	Ethylene in Sasolburg	Up to 2	2 – 4	8 – 13
	🟢	Ammonia in Sasolburg	5 – 16	5 – 16	5 – 16
	🟢	Iron & steel with ArcelorMittal (e.g. Vereeniging & Vanderbijlpark)		1 – 2	1 – 3
	🔵	Durban paper mills converting natural gas to H2		2 – 5	4 – 7
Buildings	🟣	Data center in Limpopo Science & Technology Park power supply	Up to 0.1	Up to 2	
	🟢	Anglo American corporate office buildings in Rustenburg	Up to 0.1	0.2 – 1	1 – 2
	🟢 🔵	Public offices in Johannesburg, Pretoria and Durban		Up to 1	1 – 2
	🟢 🔵	Buildings in OR Tambo & King Shaka International Airport**		Up to 0.2	0.2 – 0.4

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* *Sasol project to produce 50 000 tons jet fuel/year not included as partners already identified

** Instead of buildings FC demand, hydrogen demand for airport mobility applications (buses, operational vehicles) could also be considered.

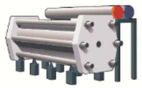
Proposed Pilot 1: Buses Conversion in Johannesburg, Pretoria & Durban

What does the project contain?

Hydrogen fuel cell buses replacing the current diesel fleet in the city of Johannesburg, Pretoria and Durban for green public transport. Hydrogen buses can utilize their batteries optimizing the efficiency and have longer range as their battery competition. Hydrogen can be produced centrally and transported to the refueling stations.

100 FC city buses

2 refueling stations at the bus depots



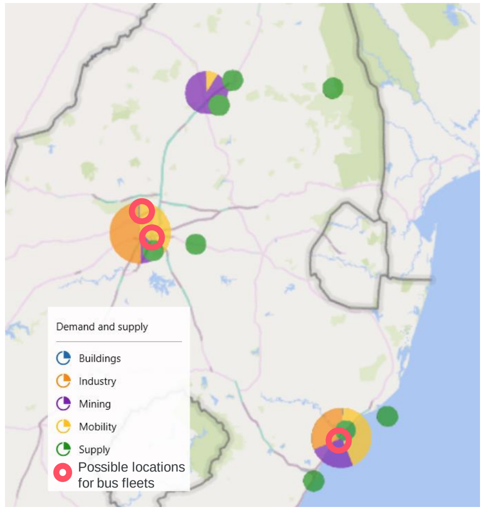
~5 MW electrolyzer needs to be installed (~0.5 KTon H2/Year)

1 tube trailers to transport hydrogen from electrolyzer to refueling stations

~57.5 million USD investment for buses

~12.5 million USD investment for H2 infrastructure (incl. transport and refueling stations)

How does the project contribute to the hub?



Potential to share investment of refueling stations with heavy duty truck and forklift pilots

Who can be potential partners / players?

Bus producers: Hyzon, Hyundai, Daimler, Caetano, etc.

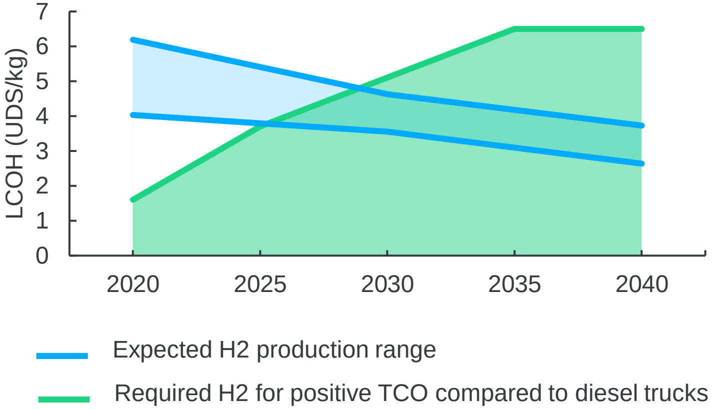
Bus operators: Durban transport, Metrobus, Tshwane bus services

Why does it make economic sense to pilot HDT?

City bus projects will become cost competitive with the fossil fuel alternative sooner than other H2 applications (~2025) as switching to hydrogen buses has many benefits and efficiencies:

- Lower maintenance costs on powertrain
- On-board battery allows regenerating energy while braking
- A fuel cell battery system is more efficient than an internal combustion engine
- Refueling times and autonomy are more comparable to diesel outcompeting battery solutions

Required LCOH for breakeven TCO H2 - city bus parity



Proposed Pilot 1: Buses Conversion in Johannesburg, Pretoria & Durban

Which just transition factors play a role?

- Direct job creation within electrolyzer plant(s) and refueling stations
- Development of expertise on hydrogen and possible production of hydrogen trucks within South Africa
- H2 refueling stations can kickstart other hydrogen mobility solutions (vans, pickups, taxis, etc.) and become the backbone South Africa’s H2 infrastructure
- Public transport as ideal showcase for public sensibilization on the hydrogen economy

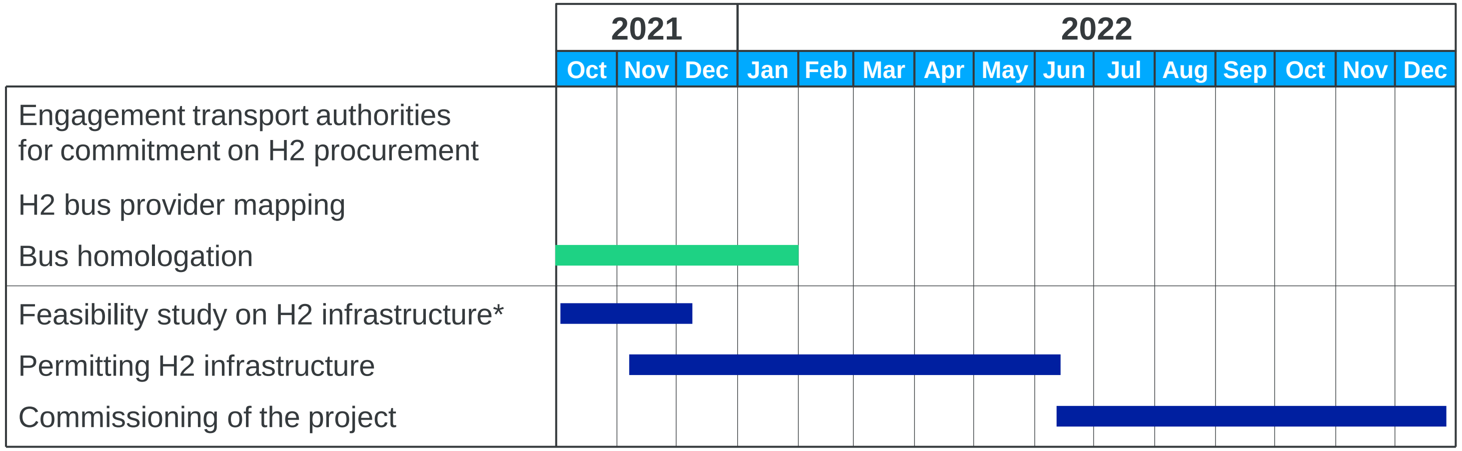
What momentum already exists?

- Rhynbow project of Anglo American, Bambili Energy and ENGIE aiming for 50 H2 city buses by 2025
- Toyota South Africa Motors and SASOL form a green hydrogen mobility partnership
- Interest from logistics companies shown in stakeholder meetings

What regulatory/policy enablers are required?

- **Financial incentives:**
    - CAPEX subsidy or state tax exemption for FCEV and refueling stations
    - Low interest funding for H2 buses projects
- **Future demand:**
    - % target for fuel cell buses in private and public transport
    - Government to lead the way with own fleets (e.g., buses) to build economies of scale
    - Non-financial incentives such as carpool lanes for FCEV
- **Regulation:**
    - Standards for H2 pressure in buses and related charging stations

Recommended next steps (to be validated with stakeholders)



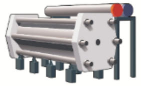
*H2 infrastructure includes H2 production location (electrolyzer, storage and compressing) and refueling stations

Proposed Pilot 2: Mining Trucks in Open Pit Copper / PGM / Diamond Mines

What does the project contain?

Fuel cell, battery powered mining trucks of a payload bigger than 200 tons for open pit copper / PGM / diamond mines. Because of H2 demand on-site green hydrogen production is considered. The first pilot is being developed at Anglo American's Mogalakwena platinum mine.

~10 to 50 trucks per open pit mine with a powertrain of ~2MW



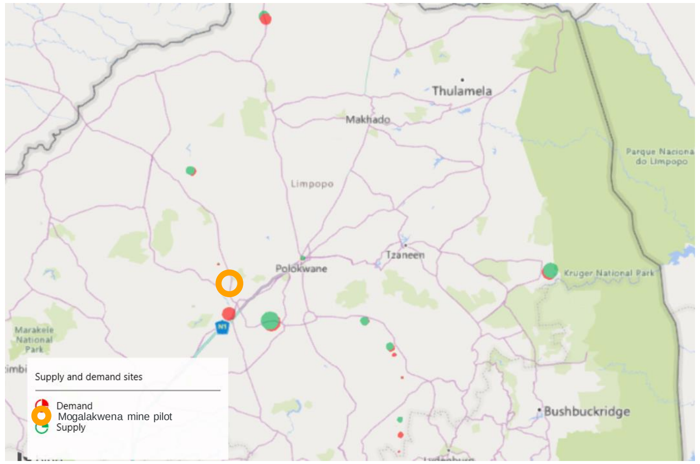
~30 to 160 MW on-site electrolyzer to be installed (~2 to 10 kTon H2/Year)

~60 to 320 MW of solar farms necessary to provide green H2

~65 to 325 million USD investment for mining trucks

~77 to 400 million USD for H2 infrastructure

How does the project contribute to the hub?



Test pilot can then be replicated and possibly scaled (depending on distance) to other mines in the hub

Who can be potential partners / players?

Truck producers: Komatsu, Caterpillar and Liebherr

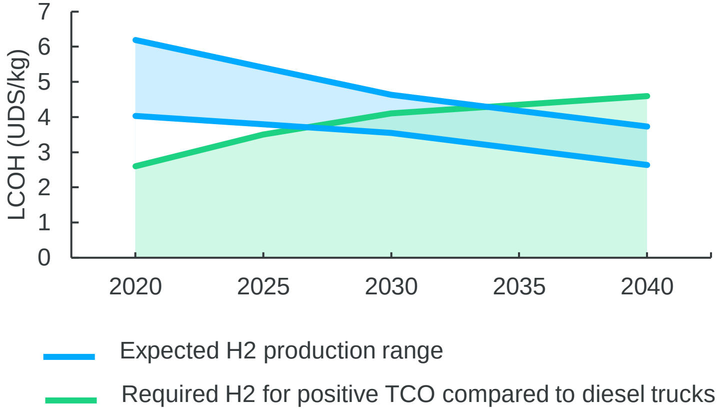
Mining companies: Anglo American, Sibanye Glencore, Ivanhoe, Ímpala, De Beers, etc.

Why does it make economic sense to pilot HDT?

Mining truck projects will get sooner too breakeven (~2025) as switching to hydrogen gives extra benefits:

- Lower maintenance costs on powertrain
- On-board battery allows regenerating energy while braking moving down into the mining pit
- A fuel cell battery system is more efficient than an internal combustion engine
- Battery as alternative green solution is difficult due to 24/7 operation

Required LCOH for breakeven TCO H2-diesel mining truck parity



Proposed Pilot 2: Mining Trucks in Open Pit Copper / PGM / Diamond Mines

Which just transition factors play a role?

- Mining companies have strong decarbonization goals of ~30% reduction in 2030 and net-zero in 2040-2050
- South Africa can become the world's provider of green minerals
- Job creation in rural areas in hydrogen production facilities
- Green H2 production plants can kickstart smaller local H2 projects

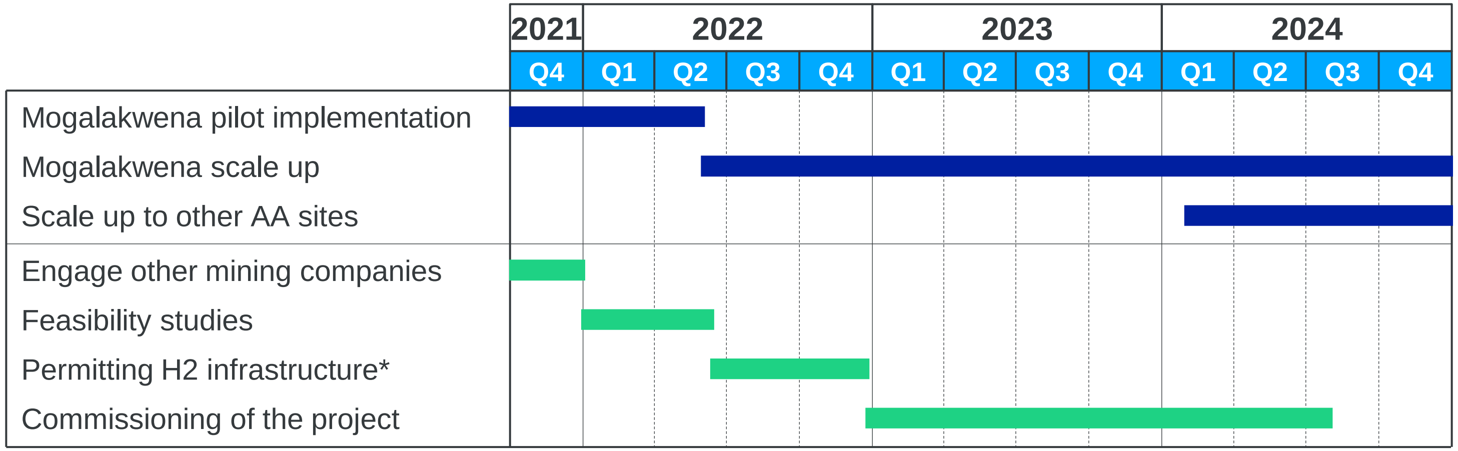
What momentum already exists?

- Anglo American is building the world's first hydrogen mining truck to start first pilot at the end of 2021 in Mogalakwena and switch completely by 2024
- Anglo American projecting to switch entire fleet to hydrogen by 2030
- Liebherr announcing green mining truck program

What regulatory/policy enablers are required?

- **Financial incentives:**
  - CAPEX subsidy or state tax exemption for H2 mining trucks and refueling stations
  - Low interest funding for H2 mining trucks projects
- **Future demand:**
  - % target for FCEV in mines
- **Regulation:**
  - Standards for H2 pressure in mining trucks and charging station

Recommended next steps (to be validated with stakeholders)



*H2 infrastructure includes H2 production location (electrolyzer, storage and compressing and refueling stations)

Proposed Pilot 3: Retrofitted Port Logistics in Durban and Richards Bay Ports

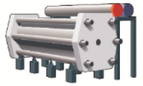
What does the project contain?

Retrofitting current port logistic diesel machinery (yard tractors, reachstackers, etc.) to hydrogen-diesel dual combustion, decarbonizing current assets.

~20 reachstackers

~20 yard tractors

1 refueling stations at the bus depots



~1.5 MW electrolyzer need to be installed (~0.2 KTon H2/Year)

1 tube trailers to transport hydrogen from electrolyzer to refueling stations

~3 million USD investment on reachstackers/yard tractors

~5 million USD investment on H2 infrastructure

How does the project contribute to the hub?

Potential to share refueling stations with heavy duty trucks on the N3

Who can be potential partners / players?

H2 dual fuel retrofit: Ulemco, Alset, etc.

Ports: Port of Durban and Richards Bay (operated by Transnet Port Authority)

Why does it make economic sense to pilot HDT?

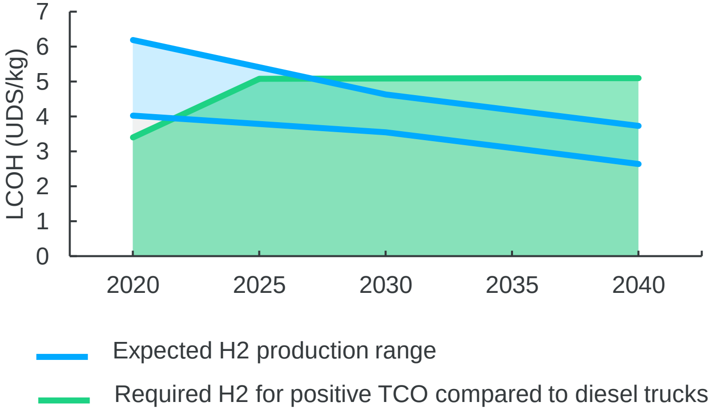
Retrofitting current diesel engines to hydrogen-diesel dual fuel allows a first hydrogen off-take with a limited investment.

Benefits compared to pure diesel ICE:

- Cleaner burning process allows lower maintenance cost of ICE
- Lowering CO2 emissions

Although increased efficiency and maintenance cost decrease of a hydrogen fuel cell is not achieved through this approach, lower CAPEX allows for quicker adaption.

Required LCOH for breakeven TCO dual fuel port applications



Proposed Pilot 3: Retrofitted Port Logistics in Durban and Richards Bay Ports

Which just transition factors play a role?

- Ports will become a major hydrogen hub within the valley and this project can kickstart hydrogen acceptance with a first hydrogen production project
- Direct job creation within exploiting the electrolyzer plant(s) and refueling stations

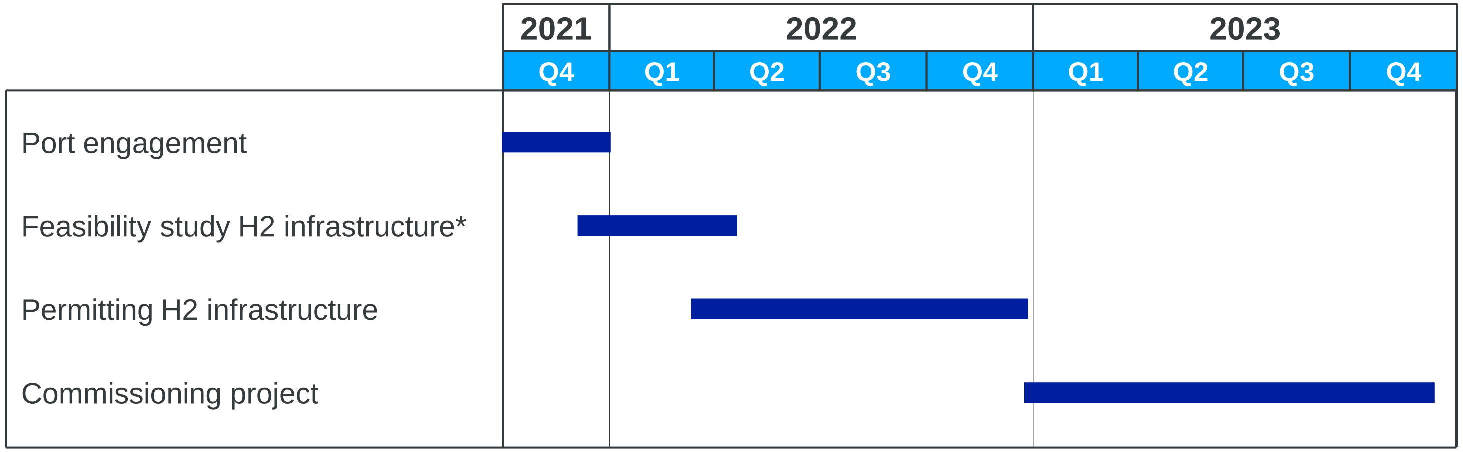
What momentum already exists?

- Hydrogen dual fuel projects are already up and running around the world

What regulatory/policy enablers are required?

- **Financial incentives:**
  - CAPEX subsidy or state tax exemption for forklifts and other logistics vehicles, and related refueling stations
  - Low interest funding for H2 port logistics projects
- **Future demand:**
  - Concretization of interest from logistic companies and ports
  - Non-financial incentives such as priority use of airport resources
- **Regulation:**
  - Standards for H2 pressure in buses and related charging stations

Recommended next steps (to be validated with stakeholders)



*H2 infrastructure includes H2 production location (electrolyzer, storage and compressing and refueling stations)

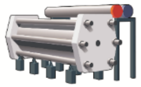
Proposed Pilot 4: Forklifts in Logistics Centers in the Rustenburg and Johannesburg Area

What does the project contain?

Hydrogen fuel cell powered forklifts for operations within major logistic centers being operated 24/7. Further work required to screen additional relevant logistics centers and increase scale of pilot.

~20 forklifts

1 refueling stations at the logistic center



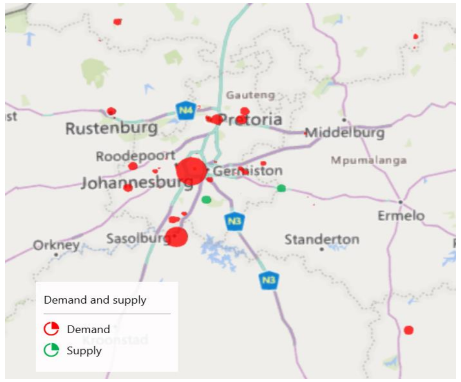
~0.8 MW electrolyzer need to be installed (~0.1 kTon H2/Year)

1 tube trailers to transport hydrogen from electrolyzer to refueling stations

~0.5 million USD investment for forklifts

~3.3 million USD investment for H2 infrastructure (possibility to be shared with other demands)

How does the project contribute to the hub?



Within the Johannesburg hub, this pilot project can be developed at different locations in logistic centers throughout the entire hub, and applications may extend beyond forklifts to other mobility solutions. **It is best to be combined with H2 off-take by heavy duty trucks.**

Who can be potential partners / players?

Forklift providers: Toyota, Linde, Still, Hyster-Yale and Plug Power

Logistic companies: Imperial logistics, Transnet, Chep, Interlogix

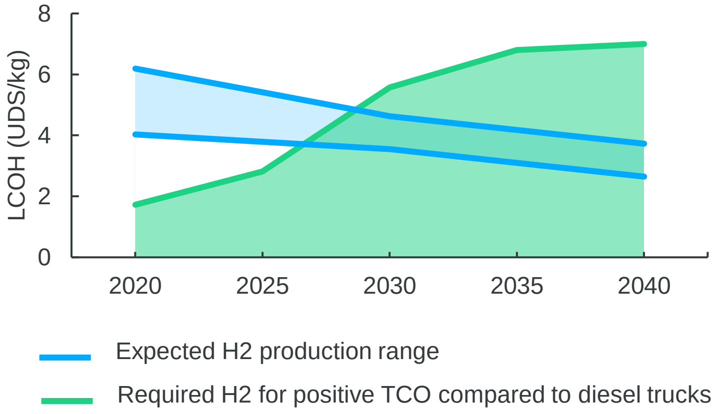
Why does it make economic sense to pilot HDT?

H2 forklifts will become cost competitive with the fossil fuel alternative sooner than other H2 applications (~2025) as switching to hydrogen buses has many benefits and efficiencies:

- Lower maintenance costs on powertrain
- On-board battery allows regenerating energy while braking
- A fuel cell battery system is more efficient than an internal combustion engine

Battery solutions are a strong green competitor but have limited operating time without recharging. Therefore, H2 forklifts need to be implemented in the right projects.

Required LCOH for breakeven TCO H2 - Forklift parity



Proposed Pilot 4: Forklifts in Logistics Centers in the Rustenburg and Johannesburg Area

Which just transition factors play a role?

- Direct job creation within exploiting the electrolyzer plant(s) and refueling stations
- On-site H2 refueling stations can be shared with hydrogen trucks at the same logistic center
- Less pollution on industrial sites for better health outcomes for workers

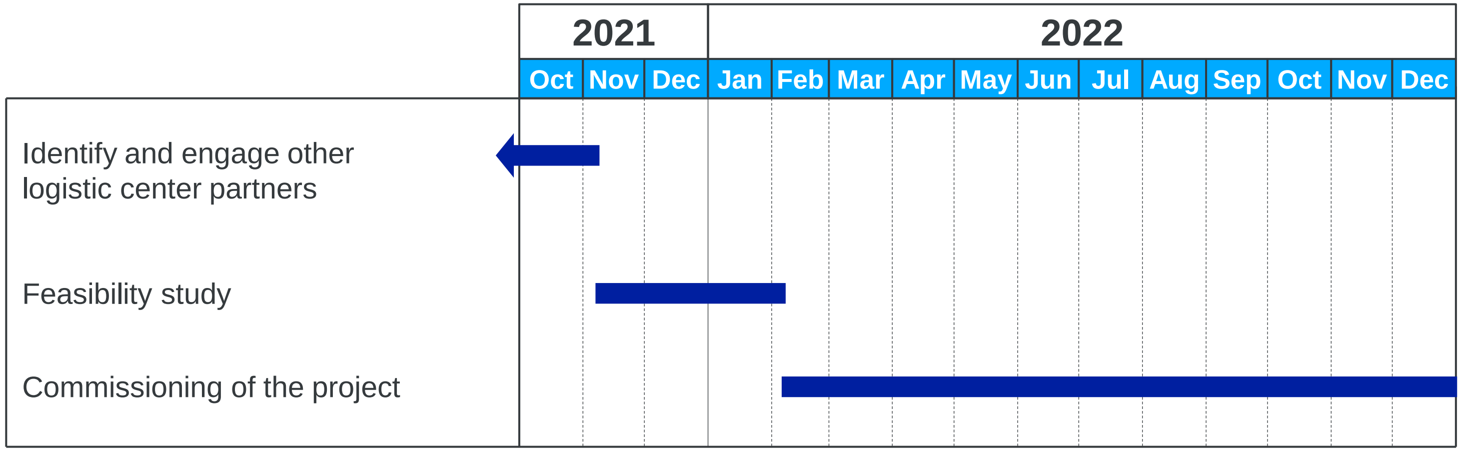
What momentum already exists?

- The biggest forklift OEMs have developed hydrogen fuel cell solutions
- Different projects operating around the world such as the Walmart project in Chile

What regulatory/policy enablers are required?

- **Financial incentives:**
  - CAPEX subsidy or state tax exemption for forklifts and refueling stations
  - Low interest funding for H2 forklift projects
- **Future demand:**
  - Concretization of interest from logistic companies
- **Regulation:**
  - Standards for H2 pressure in forklifts and related charging stations

Recommended next steps (to be validated with stakeholders)



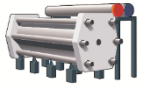
Proposed Pilot 5: Heavy Duty Trucks on the N3 between Johannesburg and Durban

What does the project contain?

Hydrogen road trucks at South Africa's biggest **freight corridor N3 between Johannesburg and Durban** by 2025.

100 FC powered trucks

4 refueling stations (2 Durban + 2 Johannesburg)



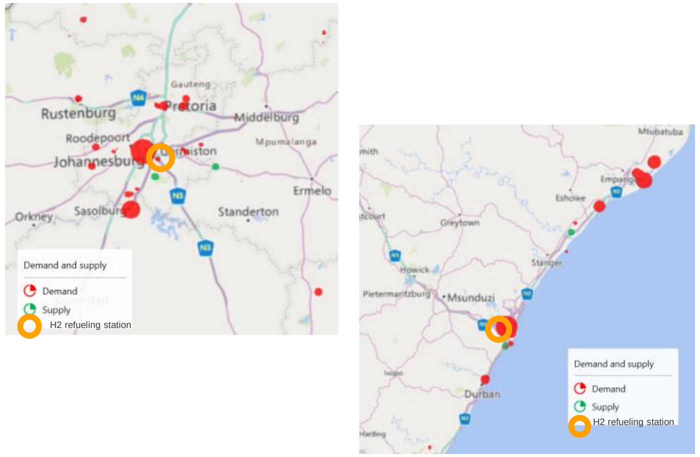
~2x 17 MW electrolyzer need to be installed around Durban and Johannesrurg(~2 kTon H2/Year)

4 tube trailers to transport hydrogen from electrolyzer to refueling stations

~40 million USD investment for H2 heavy duty trucks

~86 million USD investment for H2 infrastructure

How does the project contribute to the hub?



Potential to share refueling stations with bus, forklift and port logistics pilots

Who can be potential partners / players?

Truck producers: Hyzon, Toyota, Hyundai, Daimler

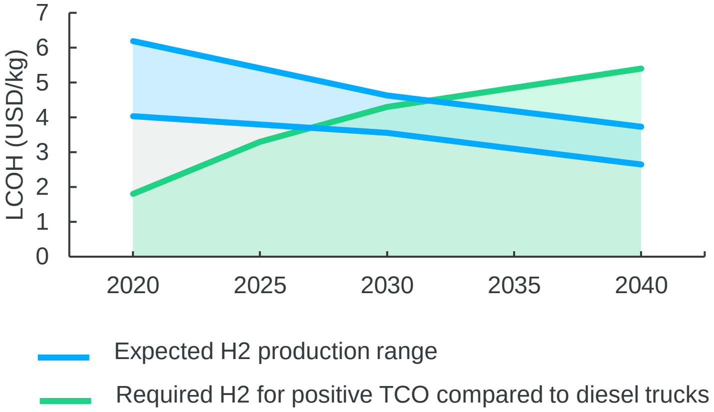
Logistic companies: Imperial logistics, Transnet, Chep, Interlogix

Why does it make economic sense to pilot HDT?

Heavy duty trucks will become cost competitive with the fossil fuel alternative sooner than other H2 applications (~2025) with the fossil fuel alternative as switching to hydrogen gives extra benefits:

- Lower maintenance costs on powertrain
- On-board battery allows regenerating energy while braking
- A fuel cell battery system is more efficient than an internal combustion engine
- Refueling times and autonomy are more comparable to diesel outcompeting battery solutions

Required LCOH for breakeven TCO H2-diesel road truck parity



Proposed Pilot 5: Heavy Duty Trucks on the N3 between Johannesburg and Durban

Which just transition factors play a role?

- Direct job creation at the electrolyzer plant(s) and refueling stations
- Expertise on hydrogen and possible production of hydrogen trucks within South Africa
- H2 refueling stations can kickstart other hydrogen mobility solutions (buses, vans, pickups, taxis, etc.) and become the backbone South Africa’s H2 infrastructure

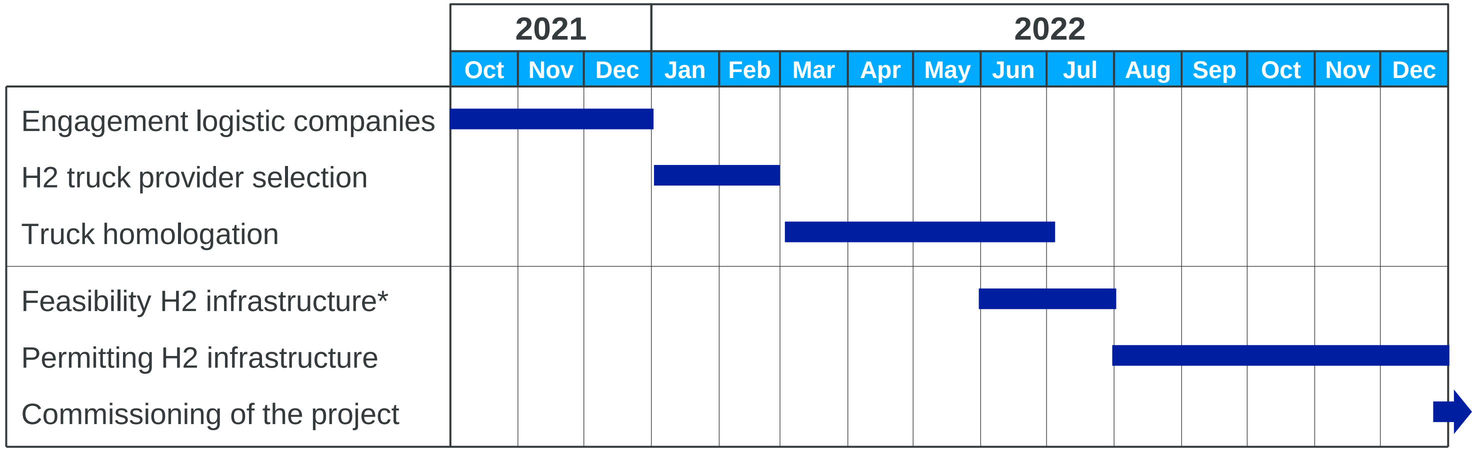
What momentum already exists?

- Rhynbow project of Anglo American, Bambili Energy and ENGIE aiming for 50 H2 trucks by 2025
- Toyota South Africa Motors and SASOL have formed a green hydrogen mobility partnership
- Interest from logistics companies (Imperial and Transnet) shown in stakeholder meetings

What regulatory/policy enablers are required?

- **Financial incentives:**
    - CAPEX subsidy or state tax exemption for FCEV and refueling stations
    - Low interest funding for H2 heavy duty trucks projects
- **Future demand:**
    - Clear target for H2 heavy duty truck
    - Concretization of the interest from logistics companies
    - Non-financial incentives implementation such as priority use of carpool lines on the N3
- **Regulation:**
    - Standards for H2 pressure in buses and related charging stations

Recommended next steps (to be validated with stakeholders)



	2021			2022											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Engagement logistic companies	■	■	■												
H2 truck provider selection				■	■										
Truck homologation						■	■	■	■						
Feasibility H2 infrastructure*									■	■					
Permitting H2 infrastructure											■	■	■	■	■
Commissioning of the project															➡

*H2 infrastructure includes H2 production location (electrolyzer, storage and compressing and refueling stations)

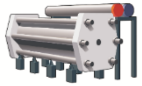
Proposed Pilot 6: Ethylene Production with Green Hydrogen for Heat in Sasolburg

What does the project contain?

Green ethylene created in a power-to-liquids process using naptha from Sasol’s novel Fishcer-Tropp process.

2.8 to 3.2 kT H2 per year in 2025 – 8.6 to 12.5 kT H2 in 2030

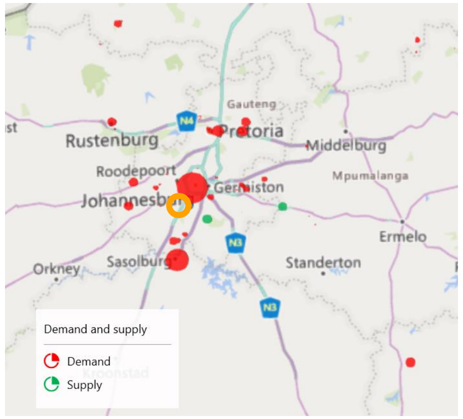
> 220-320 MW PV in 2030 in high case



Up to 170 MW electrolyzer in 2030 in high case

PV and electrzolyzer investment:
2025: 120-140 million USD
2030: 125-200 million USD

How does the project contribute to the hub?



Possibility to share green RES infrastructure with ammonia pilot; possibility to also share transport/off-taker agreements with green ammonia pilot should industrial players in hub have demand for both products

Who can be potential partners / players?

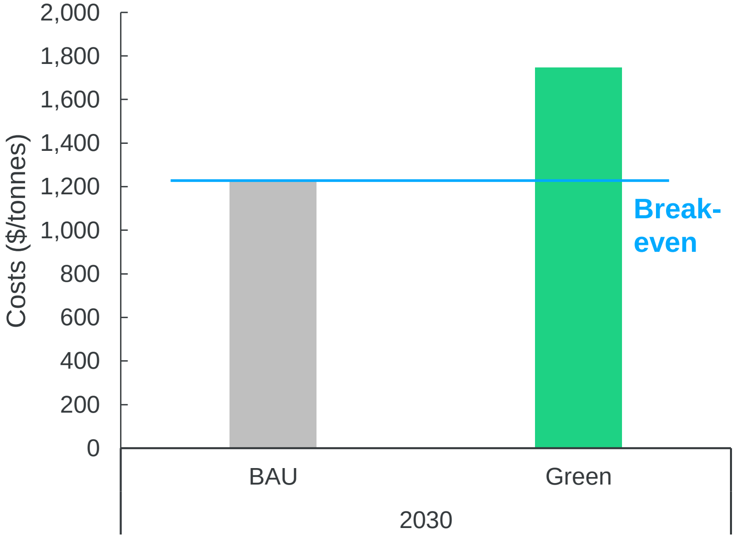
Sasol; potential off-takers to ethylene

Why does it make economic sense to pilot HDT?

Green ethylene remains less competitive than grey ammonia 2030 despite decreasing H2 production costs, but would make economic sense regarding:

- Limited alterations to the furnace design
- Existing gas pipelines near Sasolburg could be retrofitted for blending

Ethylene cost in Europe 2050, USD/tons



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(1) [22] Sasol Hydrogen Programme, Opportunities for collaboration and partnerships

Proposed Pilot 6: Ethylene Production with Green Hydrogen for Heat in Sasolburg

Which just transition factors play a role?

- Direct job creation within exploiting the electrolyzer plant(s) and downstream applications (compression, transport, etc.)
- Visible to the public and impact on air quality

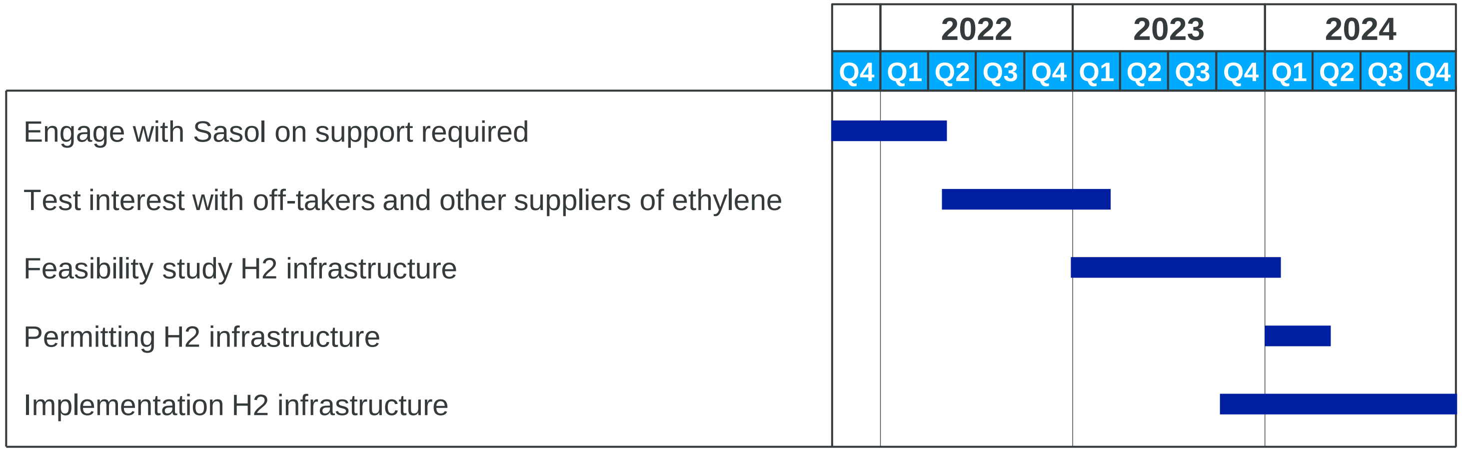
What momentum already exists?

- Partner who can successfully advocate for transitional policy that enables positive business cases for sustainable product production coproduced with fossil fuel-based products
- Diversifying Sasol's green H2 offering in addition to green ammonia commitment
- Leverage existing hydrogen infrastructure and experience of ammonia in Sasolburg
- Interest of Sasol in producing of green ethylene leveraging novel Fischer-Tropsch process

What regulatory/policy enablers are required?

- **Financial incentives:**
  - Applying higher (carbon) prices and quota to fossil fuel used for heat
  - Leverage existing SEZ to be eligible for incentives (e.g., tax exemption)
- **Future demand:**
  - Establish green gases targets for industrial heat
  - Leverage on IPAP to provide incentives to ethylene manufacturers to invest in H2 compatible plants
  - Encourage technology partnering
- **Regulation:**
  - Blending mandates for fuel for heat

Recommended next steps (to be validated with stakeholders)



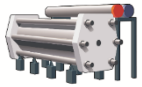
Proposed Pilot 7: Green Ammonia Production in Sasolburg

What does the project contain?

Producing ammonia from green hydrogen instead of grey hydrogen from steam methane reforming.

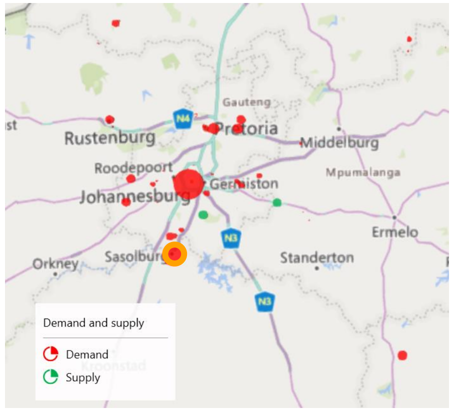
2x10MW solar farms in tender process

15 to 45 tonnes of ammonia per day



Existing 60 MW electrolyzer (that will also produce green hydrogen for export)

How does the project contribute to the hub?



Possibility to share green RES infrastructure with ethylene pilot; possibility to also share transport/off-taker agreements with green ethylene pilot should industrial players in hub have demand for both products

Who can be potential partners / players?

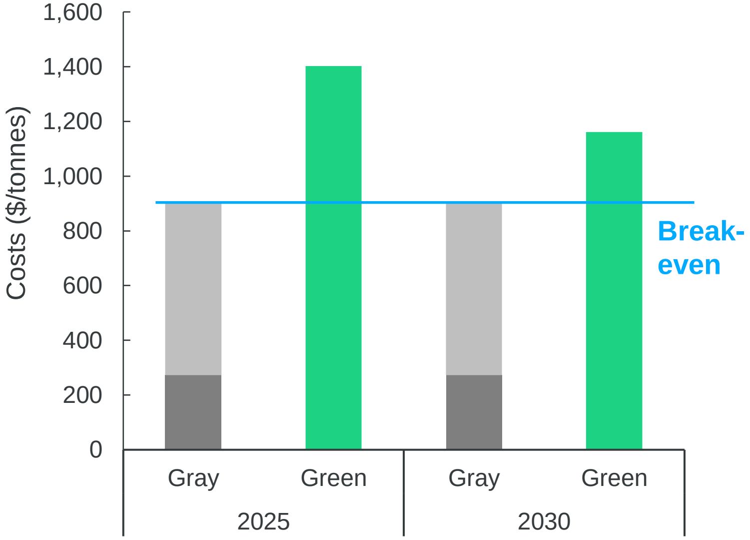
Ammonia producer: Sasol, off-takers willing to pay green premium

Why does it make economic sense to pilot HDT?

Green ammonia remains less competitive than grey ammonia in 2030 despite decreasing H2 production costs, but would make economic sense if:

- Customers accept that the green ammonia is part of a mixed product
- Customers are willing to pay a green premium for green ammonia

Ammonia cost in Sasolburg, USD/tons



(1) Gray ammonia production costs was modelled using gray hydrogen price (that depends on fuel costs) ranging from 0.7 to 2.8 $/kgH2

(2) Assuming green field hydrogen production

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(1) [22] Sasol Hydrogen Programme, Opportunities for collaboration and partnerships

Proposed Pilot 7: Green Ammonia Production in Sasolburg

Which just transition factors play a role?

- Repurposing electrolyzers already producing hydrogen
- Direct job creation within exploiting the electrolyzer plant(s) and downstream applications (compression, transport, etc.)
- Visible to the public and impact on air quality

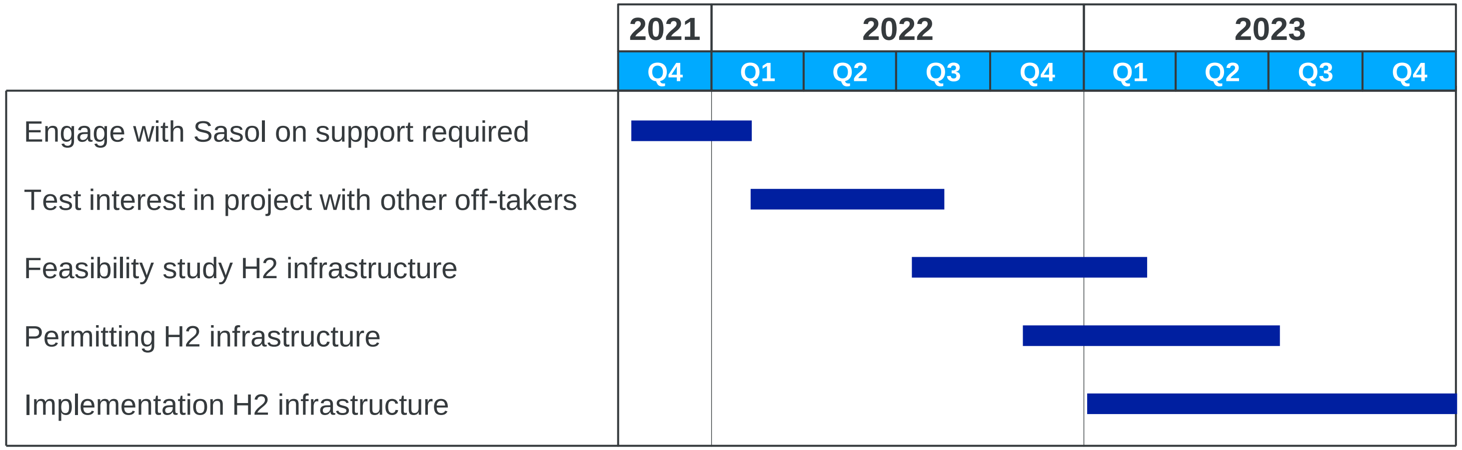
What momentum already exists?

- Announcement made by Sasol
- Partners who can successfully advocate for transitional policy that enables positive business
- Cases for sustainable product production coproduced with fossil fuel-based products
- Support in scaling the project by finding off-takers in the H2 Valley (Johannesburg hub) willing to pay green premium
- Supporting installation of RES for ammonia to be green thanks to the H2 Valley

What regulatory/policy enablers are required?

- **Financial incentives:**
  - Applying higher (carbon) prices and quota to grey hydrogen use for ammonia production
  - Leverage existing SEZ to be eligible for incentives (e.g., tax exemption)
- **Future demand:**
  - Expand on DTIC grant program to incorporate H2 applications
  - Encourage technology partnering
- **Regulation:**
  - Commercial mixed (green/grey) products standards
  - Clarity on requirements to sell hydrogen/hydrogen derivatives to customers (e.g., licenses)

Recommended next steps (to be validated with stakeholders)



Proposed Pilot 8: Data Center in Limpopo Science & Technology Park Power Supply

What does the project contain?

Powering Limpopo Science and Technology Park using fuel cell stationary power for buildings. Power to be used as primary power or as back up to data centres and provide additional source of power to certify data centres.

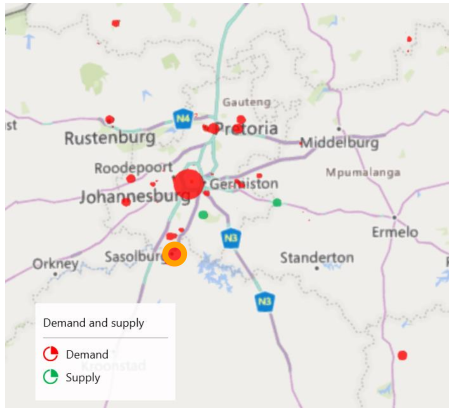
26 GWh_e of power required across the park

56-65+ tons of H2 demand by 2030

Local electorlyzer capacity required to power buildings and data cenres[1;]Local fuel cell capacity also required

(1) In-depth study underway to more precisely size electrolyzer and fuel cell requirements

How does the project contribute to the hub?



Limpopo to become a base for green H2 production in the Mogalakwena-Limpopo hub. Provides diversity (and subsequently, de-risks) hub by requiring H2 demand for fuel cells (while majority of demand is in mining sector)

Who can be potential partners / players?

Fuel Cells producers. E.g., Bambili Energy

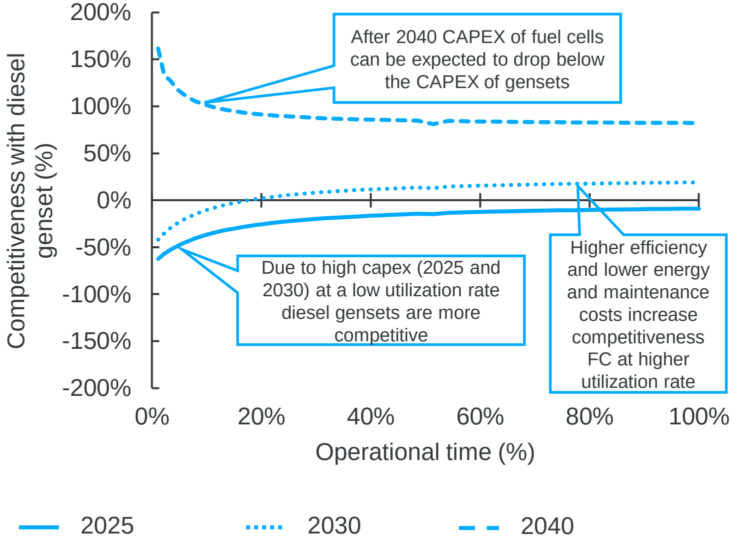
Key tenants: Data centres, residential real estate developers, commercial real estate developers

Why does it make economic sense to pilot this project?

Hydrogen fuel cells have a high CAPEX compared to diesel Gensets. Therefore, increasing the utilization increases the competitiveness of the business case.

To lower the influence of the high CAPEX of the fuel cell, the fuel cell can be combined with a net connect to have limited influence on the total electricity cost and have extra resilience in case of power outage.

Stationary FC competitiveness compared to diesel Gensets



After 2040 CAPEX of fuel cells can be expected to drop below the CAPEX of gensets

Due to high capex (2025 and 2030) at a low utilization rate diesel gensets are more competitive

Higher efficiency and lower energy and maintenance costs increase competiveness FC at higher utilization rate

Proposed Pilot 8: Data Center in Limpopo Science & Technology Park Power Supply

Which just transition factors play a role?

- Interest from building in leveraging fuel cells as backup power to improve their own reliability and resiliency against black outs
- Local job creation through development in Limpopo; fuel cell-based electricity system requires jobs along the hydrogen value chain
- Contributes to local economic development of the Limpopo region

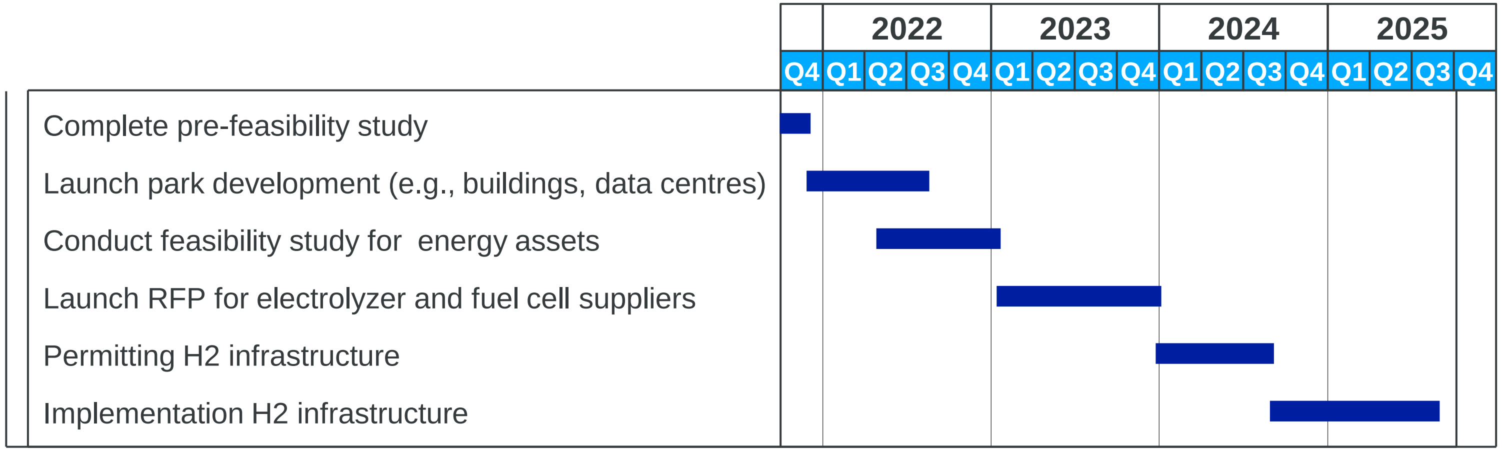
What momentum already exists?

- Pre-feasibility study underway to more precisely size electroylzer and fuel cells requirements for entire park, including data centres
    - Include techno-economic modelling to determine business case for H2 based on RES available in Limpopo

What regulatory/policy enablers are required?

- **Financial incentives:**
    - Subsidies and financial support to procure fuel cells
    - Applying (carbon) prices and quota to fossil fuel use for powering buildings
- **Future demand:**
    - Complete feasibility study to provide visibility on future demand
    - Identify key off-takers in LSTP willing to commit to H2 off-taker (e.g., data centres, other tenants)
- **Regulation:**
    - Safety standards to ensure transport and storage to populated areas

Recommended next steps (to be validated with stakeholders)



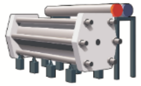
Proposed Pilot 9: Office Building Power Delivery

What does the project contain?

Using a hydrogen fuel cell as permanent/back-up power supply for an office building.

200 kW stationary fuel cell

1 ton 350 bar hydrogen storage

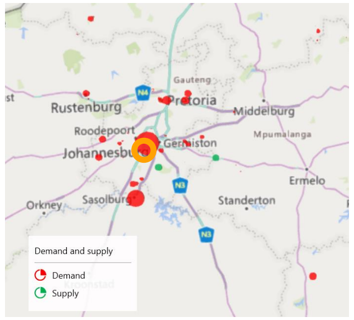


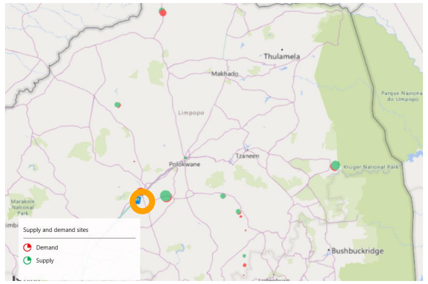
4.5 MW electrolyzer at 100% FC utilization

1 tube trailers to transport hydrogen from electrolyzer to the office building

~13 million USD investment

How does the project contribute to the hub?





Who can be potential partners / players?

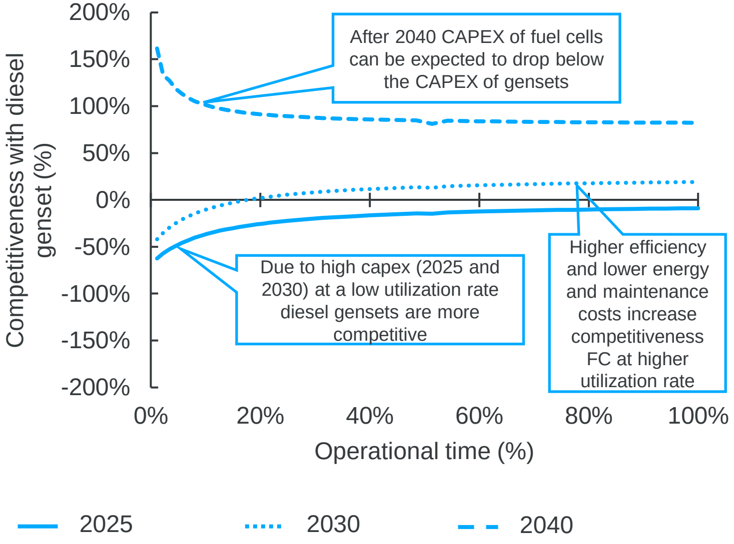
- Limpopo Science & Technology Park
- Anglo American (HQ)
- Bambili Energy (fuel cell provider)
- ENGIE (as hydrogen provider)

Why does it make economic sense to pilot HDT?

Hydrogen fuel cells have a high CAPEX compared to diesel Gensets. Therefore, increasing the utilization increases the competitiveness of the business case.

To lower the influence of the high CAPEX of the fuel cell, the fuel cell can be combined with a net connect to have limited influence on the total electricity cost and have extra resilience in case of power outage.

Stationary FC competitiveness compared to diesel Gensets



After 2040 CAPEX of fuel cells can be expected to drop below the CAPEX of gensets

Due to high capex (2025 and 2030) at a low utilization rate diesel gensets are more competitive

Higher efficiency and lower energy and maintenance costs increase competitiveness FC at higher utilization rate

Proposed Pilot 9: Office Building Power Delivery

Which just transition factors play a role?

- Direct job creation within exploiting the electrolyzer plant(s) and downstream applications (compression, transport, etc.)
- Visible to the public and impact on air quality

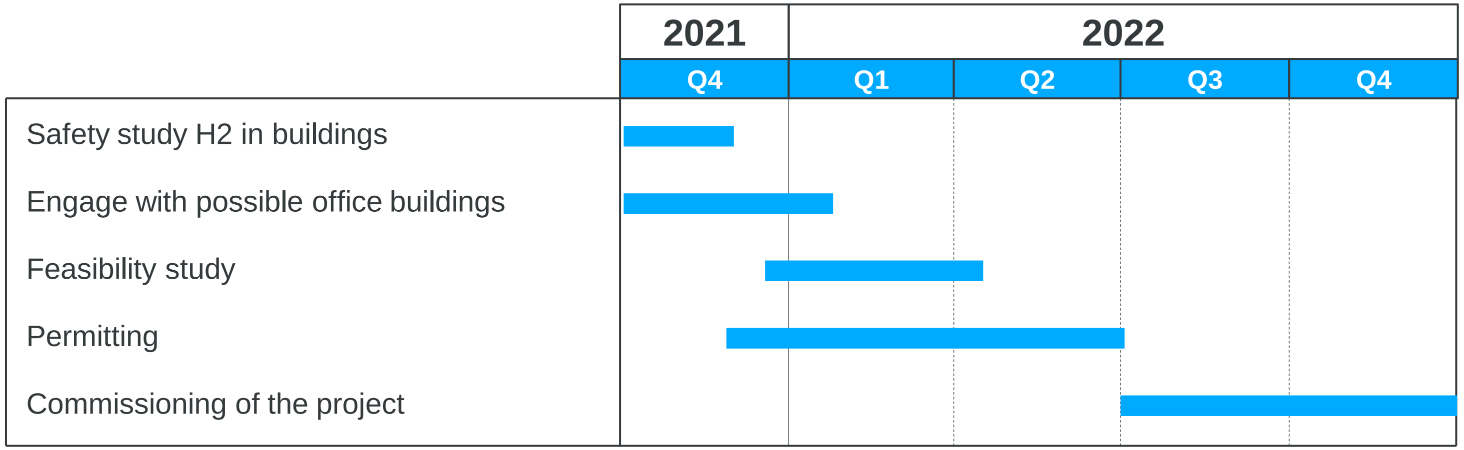
What regulatory/policy enablers are required?

- **Financial incentives:**
  - Applying (carbon) prices and quota to fossil fuel use for powering buildings
  - Leverage existing SEZ to be eligible for incentives (e.g., tax exemption)
- **Future demand:**
  - Government to lead the way as a key off-taker of green H2 powered buildings for resiliency purposes
- **Regulation:**
  - Safety standards to ensure transport and storage to populated areas

What momentum already exists?

- Anglo American's plans for their main office building
- Limpopo Science & Technology Park with mission to deploy fuel cell Capacity to buildings on site

Recommended next steps (to be validated with stakeholders)



Key Actions for Next Phase of the Project

Key actions for Next Phase of the Project

Launch report in line with public dissemination plan (e.g., webinar, executive summary release, PR)	Steerco Members with ENGIE Impact support
Select promising pilots amongst 9 highlighted; engage with key stakeholders on each project to build momentum	Steerco Members
Identify project sponsors and coalitions for each pilot	Steerco Members
Once sponsorship secured, launch tender process for detailed feasibility studies of pilot projects	Steerco members
In parallel, begin engagement with regulatory entities to lobby for near-term priority policy and regulatory enablers	Steerco members

ENGIE Impact is available to support this consortium through these activities in the next phase of the project

Table of Contents

Annex 1: Cost Assumptions

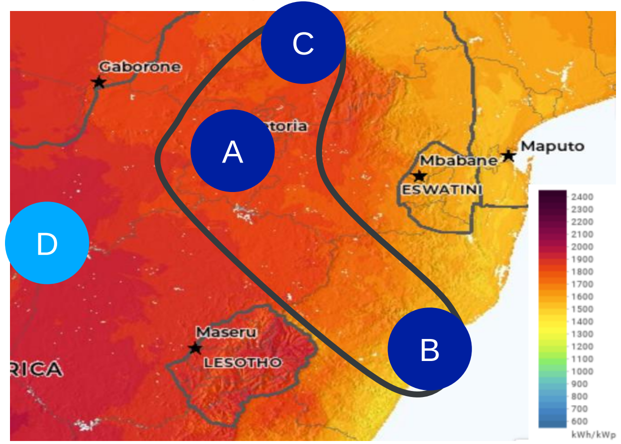
Technologies Cost Assumption

Techno	CAPEX (Total installed cost)		OPEX		Efficiency	Lifetime
	2025	2030	2025	2030		
Solar PV-utility scale	750 USD/kW	641 USD/kW	22 USD €/kW/y	18 USD €/kW/y	-	20
Wind – onshore	1209 USD/kW	1144 USD/kW	24 USD/kW/y	23 USD/kW/y	-	20
Wind – offshore	-	2000 USD/kW	-	30 USD/kW/y	-	20
PEM electrolyzers (>100 MW)	1050 USD/kWe	648 USD/kWe	8 USD/kW/y	8 USD/kW/y	0.558 kWH2/kWe	20
H2 storage	1526 USD/kgH2	1526 USD/kgH2	33 USD/kgH2	33 USD/kgH2	-	30
Water treatment plant	69,4935 USD/L/h	69,4935 USD/L/h	3.7 USD/L/h/y	3.7 USD/L/h/y	0.0071 kW/(L/h)	20
Fuel cell	2815 USD/kW	4023 USD/kW	73 USD/kW/y	51 USD/kW/y	0.45	20
Battery	160 USD/kW 520 USD/kWh	160 USD/kW 428 USD/kWh	13 USD/kWh/y	13 USD/kWh/y	-	10

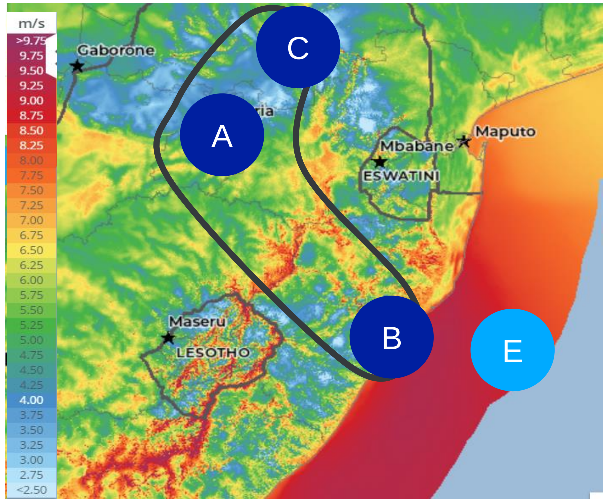
Total installed costs include equipment, design allowance, bulk materials, transport, mechanical installation, civil & sub contractual works, engineering & supervision, spare parts costs

Levelized Cost of Electricity

Solar energy potential



Wind



	Hub / Filter criteria	Solar/Wind	LCOE Range
A	Johannesburg (West Rand / Rustenburg)	Mostly solar	2025: 42-44 USD/MWh 2030: 35-37 USD/MWh
B	Durban / Richards Bay	Wind and solar	2025: 46-50 USD/MWh 2030: 43-46 USD/MWh
C	Mogalakwena / Limpopo	Only solar	2025: 43-46 USD/MWh 2030: 36-40 USD/MWh
D	Western Cape	Only solar	2025: 42-44 USD/MWh 2030: 34-36 USD/MWh
E	Durban off-shore	Only Wind	2025: 71-73 USD/MWh 2030: 68-70 USD/MWh

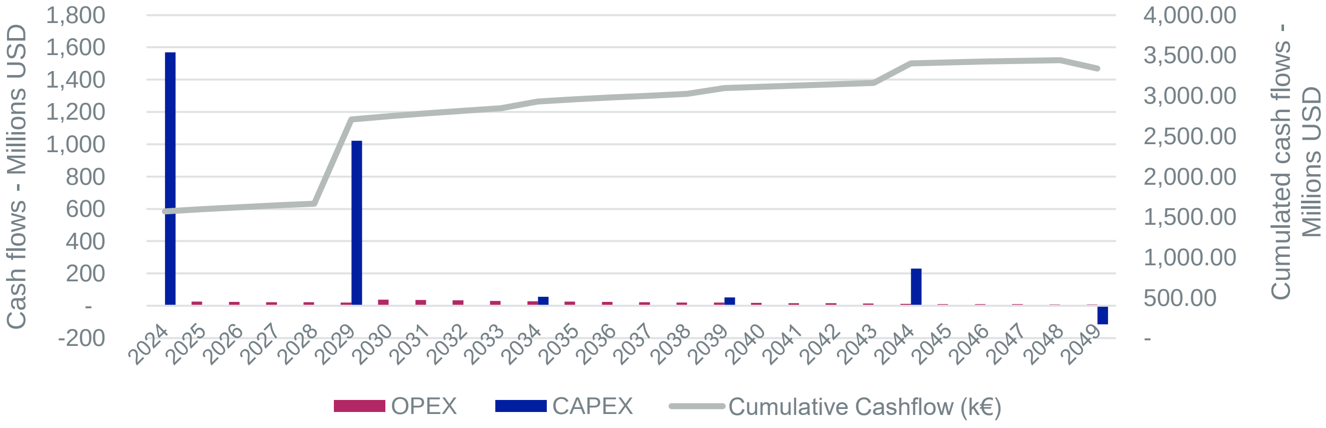
(1) Global Solar Atlas, Global Wind Atlas

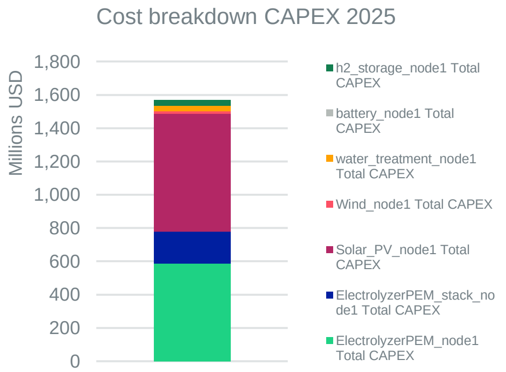
Cashflows

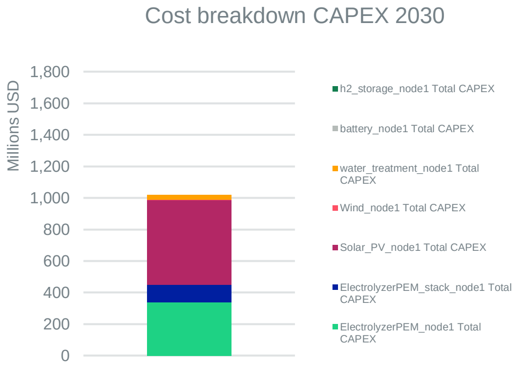
Johannesburg – high case

Year		2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
		-	1	2	3	4	5	6	7	8	9	10	11	12
ElectrolyzerPEM	Total CAPEX	584,544,965	0	0	0	0	337,263,653	0	0	0	0	0	0	0
ElectrolyzerPEM_stack	Total CAPEX	194,848,322	0	0	0	0	112,421,218	0	0	0	0	55,712,582	0	0
Solar_PV	Total CAPEX	708,518,892	0	0	0	0	537,195,379	0	0	0	0	0	0	0
Wind	Total CAPEX	12,964,137	0	0	0	0	2,593,382	0	0	0	0	0	0	0
water_treatment	Total CAPEX	33,934,534	0	0	0	0	31,717,528	0	0	0	0	0	0	0
battery	Total CAPEX	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage	Total CAPEX	34,643,030	0	0	0	0	0	0	0	0	0	0	0	0
ElectrolyzerPEM	Total OPEX	0	4,123,419	3,817,981	3,535,167	3,273,303	3,030,836	6,660,359	6,166,999	5,710,184	5,287,207	4,895,562	4,532,928	4,197,156
ElectrolyzerPEM_stack	Total OPEX	0	1,374,473	1,272,660	1,178,389	1,091,101	1,010,279	2,220,120	2,055,666	1,903,395	1,762,402	1,631,854	1,510,976	1,399,052
Solar_PV	Total OPEX	0	19,243,723	17,818,262	16,498,391	15,276,288	14,144,711	27,064,593	25,059,808	23,203,526	21,484,747	19,893,284	18,419,707	17,055,285
Wind	Total OPEX	0	238,289	220,638	204,295	189,162	175,150	210,453	194,864	180,430	167,065	154,689	143,231	132,621
buy_elec	Total OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0
buy_water	Total OPEX	0	868,820	804,463	744,873	689,697	638,608	1,355,739	1,255,314	1,162,328	1,076,229	996,509	922,693	854,346
water_treatment	Total OPEX	0	489,081	452,853	419,308	388,248	359,489	789,989	731,471	677,288	627,119	580,665	537,653	497,827
battery	Total OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage	Total OPEX	0	546,228	505,767	468,303	433,614	401,494	371,754	344,217	318,719	295,110	273,250	253,009	234,268
Cash flows		1,569,453,879	26,884,034	24,892,624	23,048,726	21,341,413	1,040,951,727	38,673,006	35,808,339	33,155,870	30,699,879	84,138,396	26,320,198	24,370,554
NPV costs ($) - project		3,336,266,039												

Year		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049
		13	14	15	16	17	18	19	20	21	22	23	24	25
ElectrolyzerPEM	Total CAPEX	0	0	0	0	0	0	0	77,417,115	0	0	0	0	-39,516,591
ElectrolyzerPEM_stack	Total CAPEX	0	0	52,072,776	0	0	0	0	25,805,705	0	0	0	0	-8,781,465
Solar_PV	Total CAPEX	0	0	0	0	0	0	0	117,526,203	0	0	0	0	-59,989,769
Wind	Total CAPEX	0	0	0	0	0	0	0	2,631,893	0	0	0	0	-1,343,417
water_treatment	Total CAPEX	0	0	0	0	0	0	0	7,280,593	0	0	0	0	-3,716,287
battery	Total CAPEX	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage	Total CAPEX	0	0	0	0	0	0	0	0	0	0	0	0	-843,084
ElectrolyzerPEM	Total OPEX	3,886,255	3,598,385	3,331,838	3,085,035	2,856,514	2,644,920	2,449,000	2,267,593	2,099,623	1,944,095	1,800,088	1,666,748	1,543,285
ElectrolyzerPEM_stack	Total OPEX	1,295,418	1,199,462	1,110,613	1,028,345	952,171	881,640	816,333	755,864	699,874	648,032	600,029	555,583	514,428
Solar_PV	Total OPEX	15,791,930	14,622,158	13,539,035	12,536,143	11,607,540	10,747,722	9,951,595	9,214,440	7,458,986	6,906,468	6,394,878	5,921,183	5,482,577
Wind	Total OPEX	122,797	113,701	105,279	97,481	90,260	83,574	77,383	71,651	64,213	59,457	55,053	50,975	47,199
buy_elec	Total OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0
buy_water	Total OPEX	791,061	732,464	678,207	627,969	581,453	538,383	498,502	461,576	427,385	395,727	366,414	339,272	314,141
water_treatment	Total OPEX	460,951	426,806	395,191	365,918	338,813	313,715	290,477	268,960	249,037	230,590	213,509	197,694	183,050
battery	Total OPEX	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage	Total OPEX	216,915	200,847	185,969	172,194	159,439	147,629	136,693	126,568	117,192	108,511	100,474	93,031	86,140
Cash flows		22,565,328	20,893,822	71,418,907	17,913,085	16,586,190	15,357,583	14,219,984	243,828,162	########	########	9,530,445	8,824,486	-106,019,792
NPV costs ($) - project														



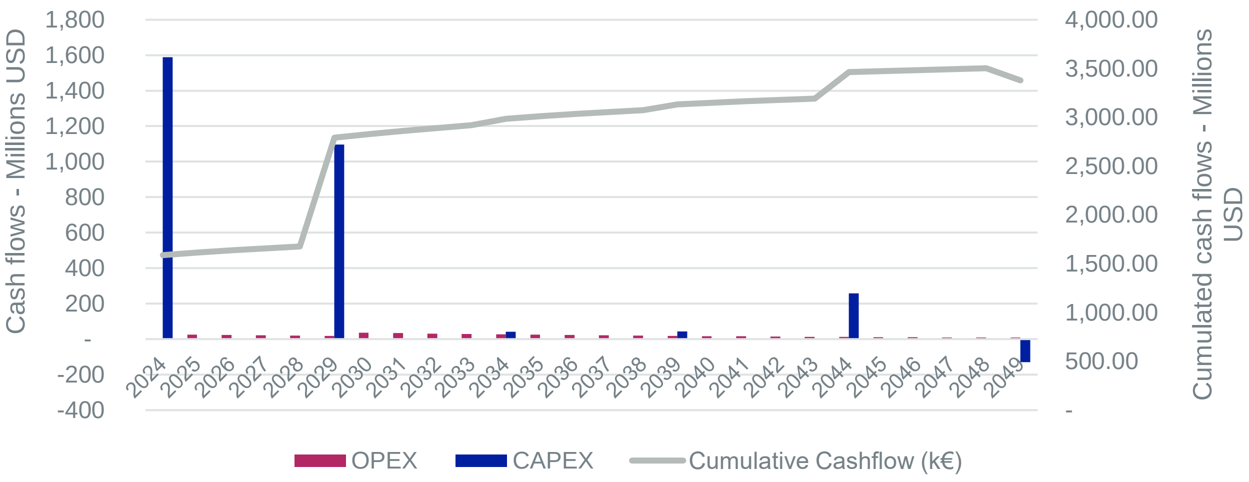


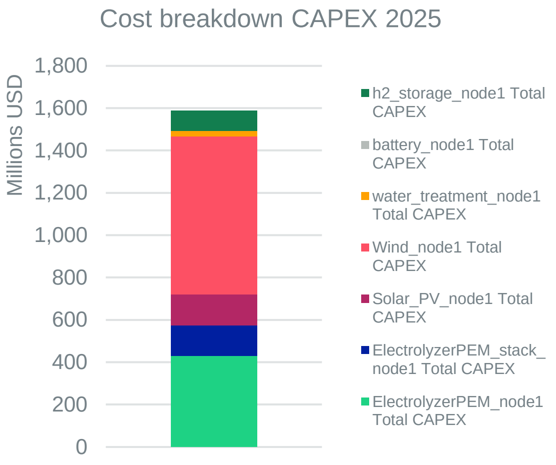


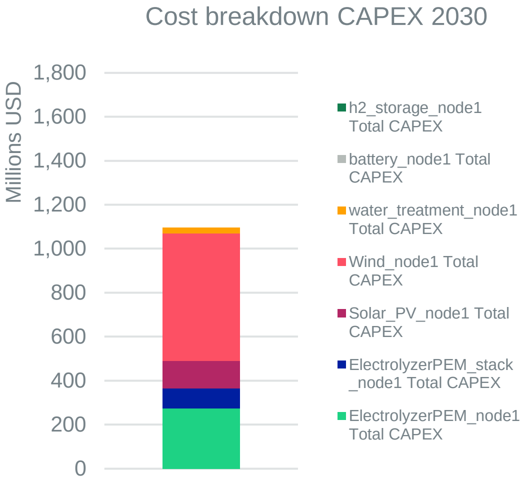
Cashflows

Durban – high case

Year			2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049
		-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
ElectrolyzerPEM_node1	Total CAPEX		430,300,324	0	0	0	0	273,313,407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56,988,960	0	0	0	0	-29,089,297
ElectrolyzerPEM_stack_node1	Total CAPEX		143,433,441	0	0	0	0	91,104,469	0	0	0	0	41,011,630	0	0	0	0	42,198,997	0	0	0	0	18,996,320	0	0	0	0	-6,464,288
Solar_PV_node1	Total CAPEX		145,852,918	0	0	0	0	125,270,991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24,193,483	0	0	0	0	-12,349,258
Wind_node1	Total CAPEX		747,578,897	0	0	0	0	581,106,655	0	0	0	0	0	0	0	0	0	0	0	0	0	0	151,768,502	0	0	0	0	-77,468,319
water_treatment_node1	Total CAPEX		24,980,184	0	0	0	0	25,703,409	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,359,454	0	0	0	0	-2,735,666
battery_node1	Total CAPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage_node1	Total CAPEX		96,177,470	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2,340,605
ElectrolyzerPEM_node1	Total OPEX		0	3,035,367	2,810,525	2,602,338	2,409,572	2,231,086	5,189,067	4,804,692	4,448,789	4,119,249	3,814,119	3,531,592	3,269,992	3,027,771	2,803,491	2,595,825	2,403,542	2,225,502	2,060,650	1,908,009	1,766,675	1,635,810	1,514,639	1,402,444	1,298,559	1,202,369
ElectrolyzerPEM_stack_node1	Total OPEX		0	1,011,789	936,842	867,446	803,191	743,695	1,729,689	1,601,564	1,482,930	1,373,083	1,271,373	1,177,197	1,089,997	1,009,257	934,497	865,275	801,181	741,834	686,883	636,003	588,892	545,270	504,880	467,481	432,853	400,790
Solar_PV_node1	Total OPEX		0	3,961,437	3,667,997	3,396,294	3,144,717	2,911,775	5,953,264	5,512,281	5,103,964	4,725,893	4,375,827	4,051,691	3,751,566	3,473,672	3,216,363	2,978,114	2,757,513	2,553,253	2,364,123	2,189,003	2,026,854	1,655,853	1,533,198	1,419,627	1,314,470	1,217,102
Wind_node1	Total OPEX		0	13,740,996	12,723,145	11,780,689	10,908,046	10,100,042	20,169,565	18,675,524	17,292,151	16,011,251	14,825,233	13,727,067	12,710,248	11,768,748	10,896,989	10,089,804	9,342,411	8,650,381	8,009,612	7,416,307	6,866,951	6,235,450	5,773,565	5,345,894	4,949,902	4,583,242
buy_elec_node1_market	Total OPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
buy_water_node1_market	Total OPEX		0	731,241	677,075	626,921	580,482	537,484	1,133,309	1,049,360	971,630	899,657	833,016	771,311	714,177	661,275	612,292	566,937	524,941	486,057	450,053	416,715	385,848	357,266	330,802	306,298	283,609	262,601
water_treatment_node1	Total OPEX		0	360,027	333,358	308,665	285,801	264,630	615,478	569,887	527,673	488,586	452,395	418,884	387,856	359,126	332,524	307,892	285,085	263,968	244,415	226,310	209,546	194,024	179,652	166,345	154,023	142,614
battery_node1	Total OPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage_node1	Total OPEX		0	1,516,463	1,404,132	1,300,122	1,203,817	1,114,645	1,032,079	955,629	884,841	819,298	758,609	702,416	650,385	602,208	557,600	516,296	478,052	442,641	409,853	379,493	351,383	325,354	301,254	278,939	258,277	239,145
Cash flows			1,588,323,234	24,357,320	22,553,074	20,882,476	19,335,626	1,114,402,287	35,822,451	33,168,936	30,711,978	28,437,017	67,342,202	24,380,159	22,574,221	20,902,056	19,353,756	60,119,141	16,592,726	15,363,635	14,225,588	13,171,841	269,502,868	###### ##	###### ##	9,387,028	8,691,693	-122,399,570
NPV costs ($) - project			3,378,288,762																									



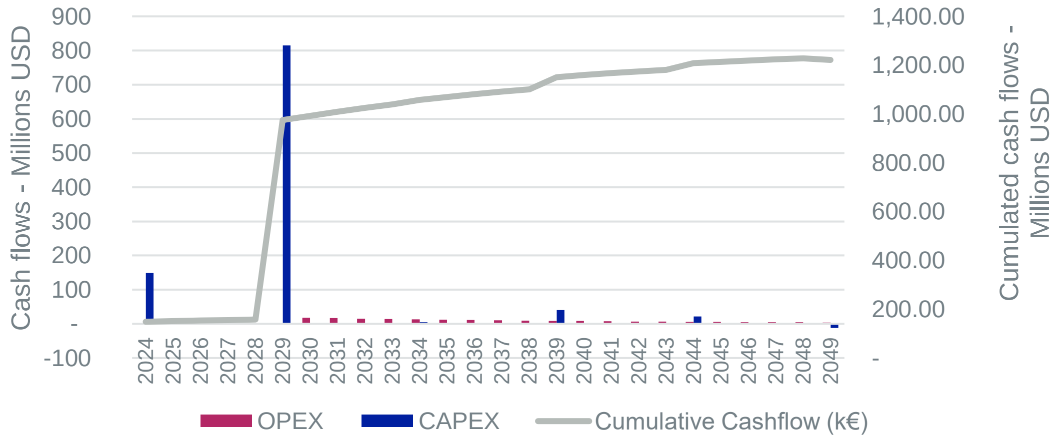


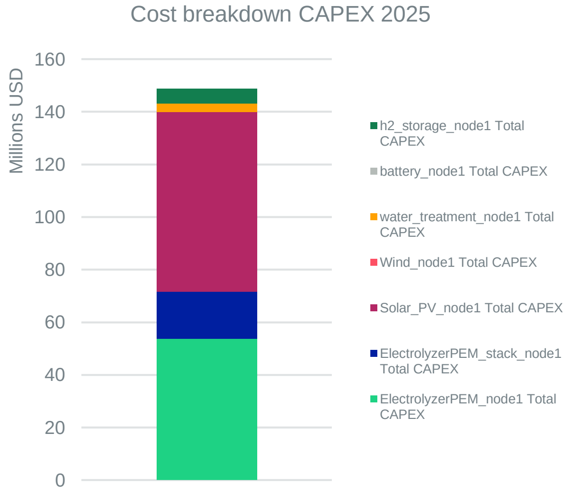


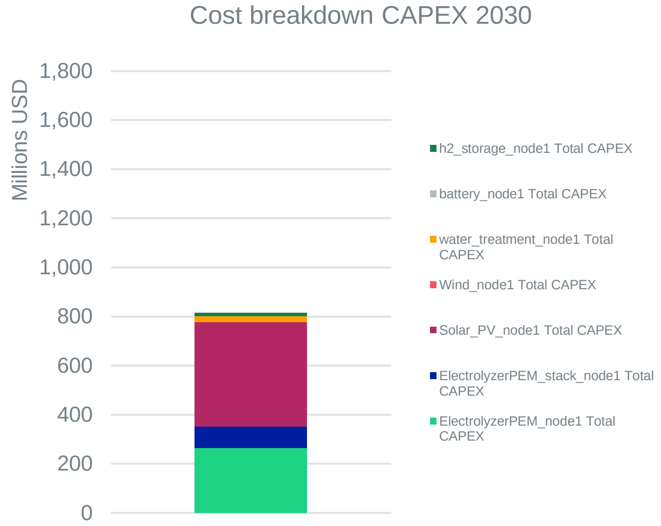
Cashflows

Mogalakwena – high case

Year			2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049
		-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
ElectrolyzerPEM_node1	Total CAPEX		53,769,532	0	0	0	0	264,154,387	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7,121,235	0	0	0	0	-3,634,945
ElectrolyzerPEM_stack_node1	Total CAPEX		17,923,177	0	0	0	0	88,051,462	0	0	0	0	5,124,737	0	0	0	0	40,784,86 4	0	0	0	0	2,373,745	0	0	0	0	-807,765
Solar_PV_node1	Total CAPEX		68,261,299	0	0	0	0	425,688,206	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11,322,904	0	0	0	0	-5,779,634
Wind_node1	Total CAPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
water_treatment_node1	Total CAPEX		3,121,478	0	0	0	0	24,842,061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	669,707	0	0	0	0	-341,844
battery_node1	Total CAPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage_node1	Total CAPEX		5,653,929	0	0	0	0	12,367,935	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1,022,102
ElectrolyzerPEM_node1	Total OPEX		0	379,294	351,198	325,183	301,096	278,792	3,276,725	3,034,004	2,809,263	2,601,170	2,408,491	2,230,084	2,064,892	1,911,937	1,770,312	1,639,178	1,517,758	1,405,331	1,301,233	1,204,845	1,115,597	1,032,9 60	956,445	885,597	819,997	759,257
ElectrolyzerPEM_stack_node1	Total OPEX		0	126,431	117,066	108,394	100,365	92,931	1,092,242	1,011,335	936,421	867,057	802,830	743,361	688,297	637,312	590,104	546,393	505,919	468,444	433,744	401,615	371,866	344,320	318,815	295,199	273,332	253,086
Solar_PV_node1	Total OPEX		0	1,854,011	1,716,676	1,589,515	1,471,773	1,362,753	12,330,145	11,416,801	10,571,112	9,788,066	9,063,024	8,391,689	7,770,083	7,194,521	6,661,593	6,168,142	5,711,243	5,288,188	4,896,470	4,533,769	4,197,934	3,783,6 08	3,503,3 41	3,243,8 34	3,003,550	2,781,065
Wind_node1	Total OPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
buy_elec_node1_market	Total OPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
buy_water_node1_market	Total OPEX		0	81,524	75,485	69,894	64,717	59,923	663,043	613,929	568,452	526,345	487,356	451,256	417,829	386,879	358,221	331,686	307,117	284,368	263,303	243,799	225,740	209,019	193,536	179,200	165,926	153,635
water_treatment_node1	Total OPEX		0	44,988	41,656	38,570	35,713	33,068	388,654	359,865	333,208	308,526	285,672	264,512	244,918	226,776	209,978	194,424	180,022	166,687	154,340	142,907	132,322	122,520	113,444	105,041	97,260	90,056
battery_node1	Total OPEX		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
h2_storage_node1	Total OPEX		0	89,147	82,544	76,430	70,768	65,526	255,682	236,742	219,206	202,968	187,934	174,013	161,123	149,188	138,137	127,904	118,430	109,657	101,535	94,014	87,050	80,602	74,631	69,103	63,984	59,245
Cash flows			148,729,414	2,575,396	2,384,626	2,207,987	2,044,432	816,997,044	18,006,490	16,672,676	15,437,663	14,294,132	18,360,045	12,254,914	11,347,143	10,506,614	9,728,346	49,792,59 2	8,340,489	7,722,675	7,150,625	6,620,949	27,618,099	5,573,0 29	5,160,2 12	4,777,9 74	4,424,050	-7,489,946
NPV costs ($) - project			1,221,237,667																									




Cost breakdown CAPEX 2025


Cost breakdown CAPEX 2030

Annex 2: Demand Off-take

We used external benchmarks and triangulate sector-specific uptake rates for industrial and mobility segments

	A. Build average H2 uptake curve for all segments	B. Categorize segments	C. Apply uptake curve to categorized segments	D. Triangulate with sector-specific sources

Activity steps	• Calculate share of **H2 demand in total energy demand** in other global or regional projections, to create **average H2 uptake curve**
	• Adjust for SA context
		• Categorize H2 applications:
		  • **Early adopters**: breakeven near 2030
		  • **Moderate uptakers**: Breakeven near 2035
		  • **Late adopters**: Breakeven even 2040+
			• Adapt H2 average H2 uptake curve to each segment category:
			  • **Early adopters**: Curve advanced by 5 years
			  • **Moderate uptakers**: Matches curve
			  • **Late adopters**: Curve delayed by 5 years
				• Research H2 uptake curves for high-priority/anchor segments to ensure alignment on the global level
				• Adjust final curves to reflect SA context

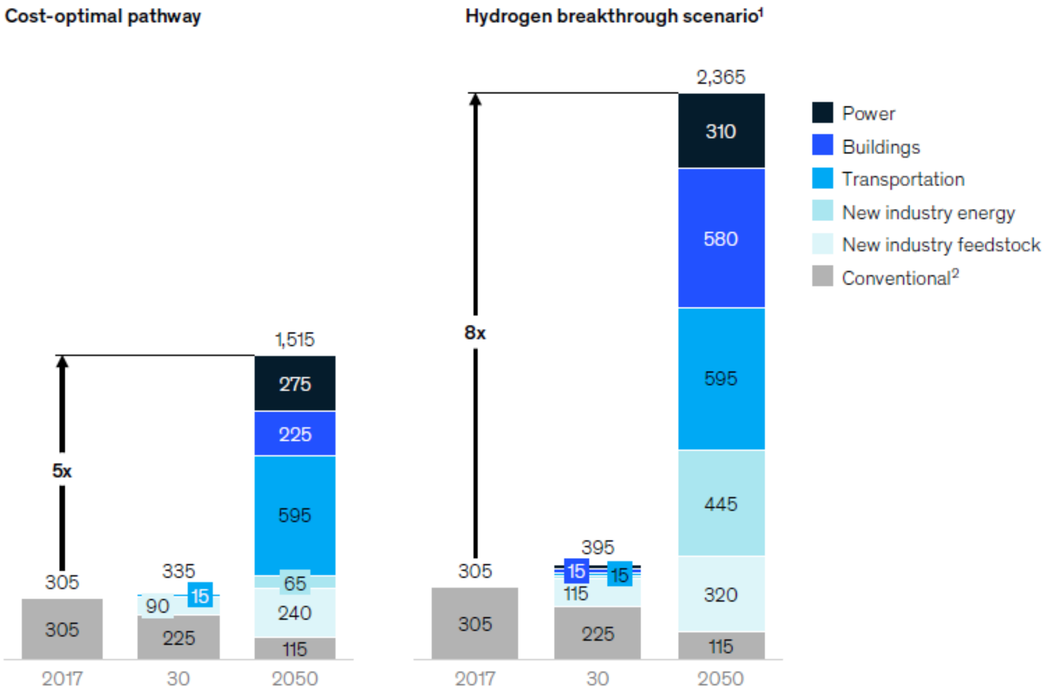
Sources used	• McKinsey & Company: Net-Zero Europe, Global energy Perspectives 2021 • KPMG: National Roadmap	• McKinsey & Company: Hydrogen: the next wave for electric vehicles? • Hydrogen Council: Hydrogen Insights 2021 • IEA: The Future of Hydrogen		• Industry-specific reports • KPMG: National Roadmap • PWC: Unlocking SA potential

A. For many segments, H2 uptake is drawn from a cross-sectoral uptake curve, based on expected uptake of Hydrogen in Europe in an accelerated context

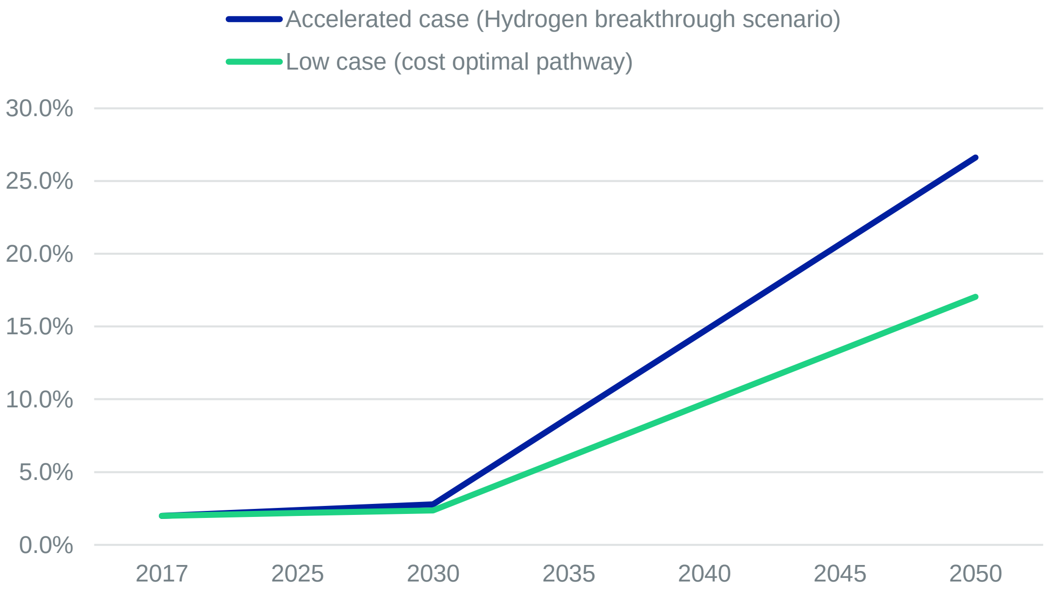
We used a low and high hydrogen scenario for future hydrogen demand in Europe

… and developed uptake curves based on the share of hydrogen in Europe's expected future energy mix in 2030

Hydrogen demand in Europe (EU-27), TWh



H2 uptake for generic sector in South Africa, %



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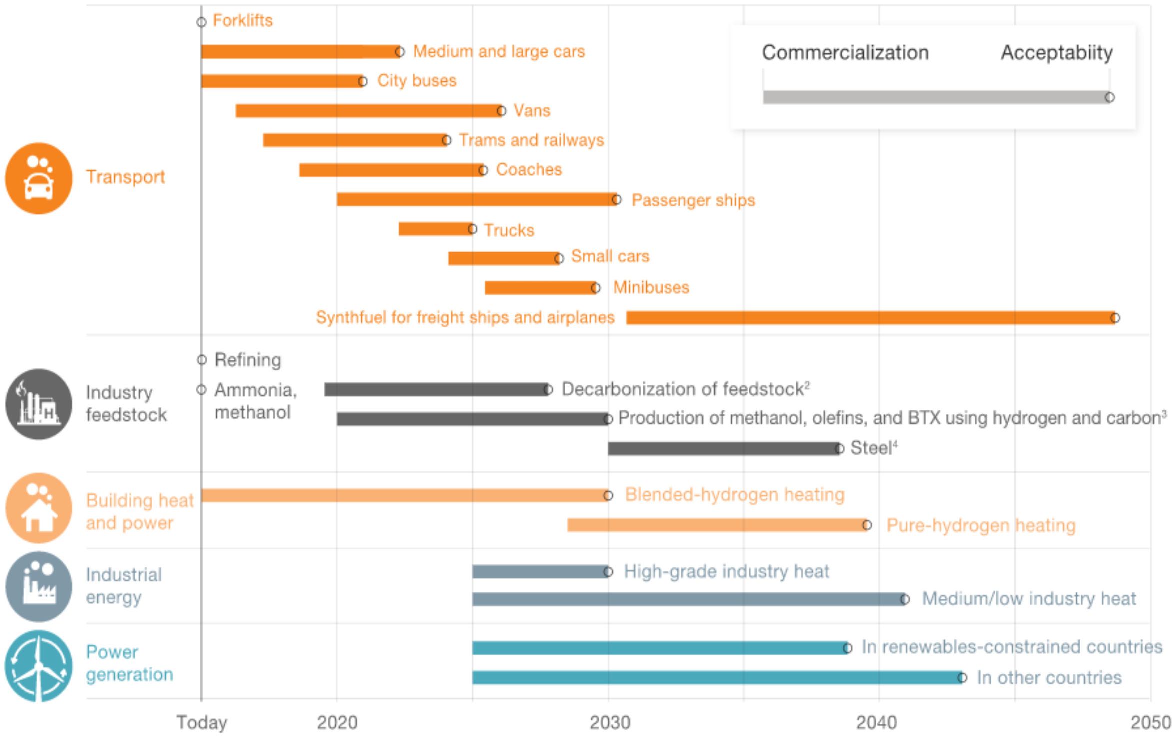
(1) McKinsey & Company, Net-Zero Europe

B. Segments were mapped as first adopters, moderate uptake sectors and late adopters

Commercialization and Adoptability of H2 applications, Timeline



Sector group	Sectors mapped
First adopters *H2 acceptability before 2030*	Forklifts Mining trucks Buses/Coaches Trams/railways Heavy goods vehicles Minibuses Refining ammonia/methanol Chemicals as feedstock
Moderate uptake sectors *H2 acceptability before 2040*	Steel Other high temp heat (e.g., cement)
Late adopters *H2 acceptability 2040+*	Freight ships Medium-temp heat industries Power to Power

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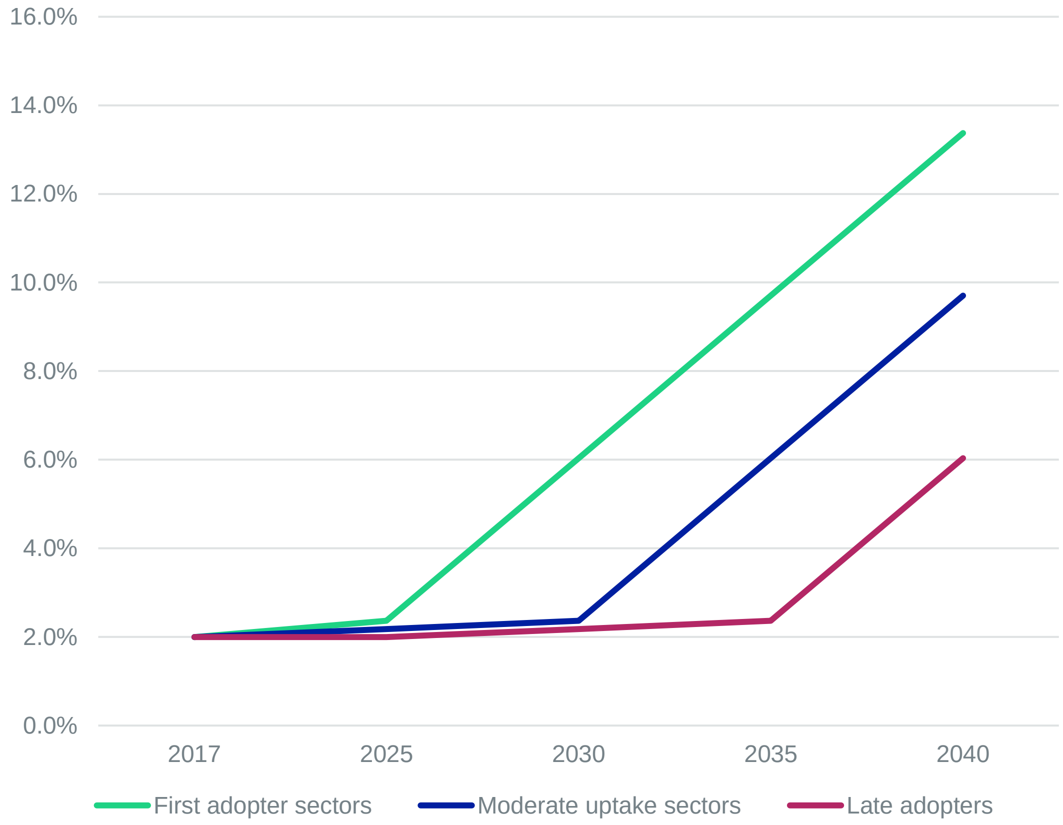
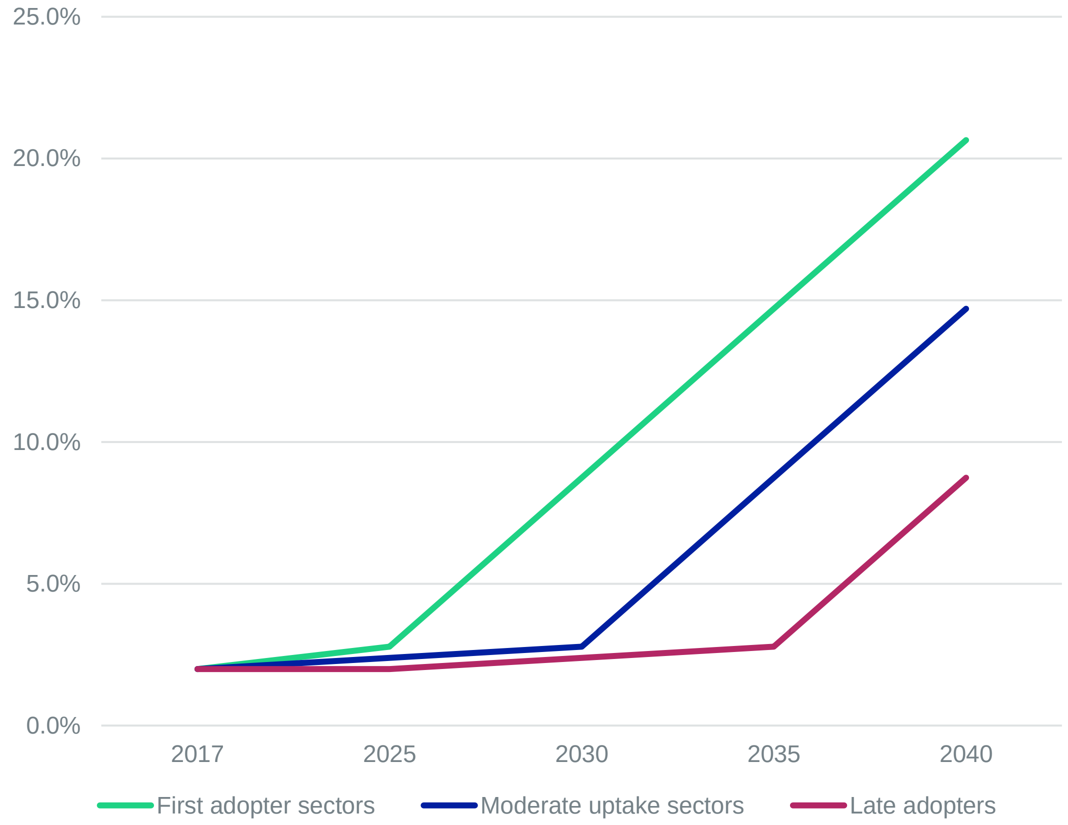
(1) McKinsey & Company, Hydrogen the next wave for electric vehicles

C. Each segment group is assigned an uptake curve


Low demand case uptake curves


Accelerated case uptake curves

First adopters shift generic sector uptake curve ahead by 5 years
Moderate uptake sectors use generic sector uptake curve
Late adopters shift generic sector uptake curve behind by 5 years

C/D. We have assessed hydrogen uptake on a per-sector basis, with some sectors drawing from this general H2 uptake curve

		Segment size	H2 uptake in Low Case	H2 uptake in High Case

Mobility	HDT / MDT	• N1 tonnage:
		  • 9.7 Mt/y (2025)
		  • 12.2 Mt/y (2030)
		• N3 tonnage:
		  • 52 Mt/y (2025)
		  • 66 Mt/y (2030)
			Based on first adopter group:
			• 2025: 2.4%
			• 2030: 6%
				• 2025: 3%, based on first adopter group
				• 2030: 10%, based on 6-7-year shift left from EU average with commitments seen in SA

	Mining trucks	• 238 Mt/y	• 2025: 1%, based on client input • 2030: 10%, based on client input	• 2025: 2%, based on client input • 2030: 30%, based on client input

	Rail	• Durban – Richards bay:
		  • 2,4 Gton-km / y (2025)
		  • 3,1 Gton-km / y (2030)
			• Full de-electrification by 2025
			• Based on first adopter group (2025: 2.4% - 2030, 6%)
				• Full de-electrification by 2025
				• Based on first adopter group (2025: 2.8% - 2030, 8.7%)

	Buses	• 14 700 buses in Johannesburg/Pretoria, 1 050 in Durban	• Base on first adopter group
			  • 2025: 2.4%
			  • 2030: 6%
				• 2025: 20% of Johannesburg/Pretoria buses, adapted from conversation with Busmark
				• 2030: 30% (same source)

	Port logistics/forklifts	• Berthing: 390 GWh/year
		• Handling equipment: 1,435 GWh/year
			• Based on first adopter group:
			  • 2025: 2.4%
			  • 2030: 6%
				• Based on first adopter group:
				  • 2025: 2.8%
				  • 2030: 8.7%

C/D. We have assessed hydrogen uptake on a per-sector basis, with some sectors drawing from a general H2 uptake curve (2/3)

		Segment size	H2 uptake in Low Case	H2 uptake in High Case

Mobility *(cont.)*	Marine bunkering	• 31 TWh marine fuel bunkering in 2025, 34 TWh in 2030	• 50% of high case potential:
			  • As of 2030: 1%
				• Based on global maritime fuel mix outlook
				  • As of 2030: 2%

	Rustenburg mobility	• 0.2 – 1 MW_e cumulative mobile fuel cell potential as of 2025 (85% trucks, 15% forklifts)	• Mobility use of 0,2 MW_e cumulative mobile fuel cell capacity	• Mobility use of 1 MW_e cumulative mobile fuel cell capacity

Buildings	Public buildings	• 490 GWh_e demand for public buildings in Jo-burg, 160 GWh_e in Durban	• Back up supply, moderate uptake
			  • 2025: 2.2%
			  • 2030: 2.4%
				• Primary supply, moderate uptake
				  • 2025: 2.4%
				  • 2030: 2.8%

	Airports	• 119 GWh_e in OR Tambo, 33 GWh_e in King Shaka airport	• Back up, moderate uptake
			  • 2025: 2.2%
			  • 2030: 2.4%
				• Primary, moderate uptake
				  • 2025: 2.4%
				  • 2030: 2.8%

	Limpopo Science Park	• 46 GWh_e across all buildings in the park	• Back up, moderate uptake
			  • 2025: 2.2%
			  • 2030: 2.4%
				• Primary, moderate uptake
				  • 2025: 2.4%
				  • 2030: 2.8%

	Rustenburg buildings	• 1 – 4.2 MW_e cumulative stationary fuel cell potential as of 2030	• Primary supply of 1 MW_e fuel cell capacity with 90% utilization	• Primary supply of 4.2 MW_e fuel cell capacity with 90% utilization

An average outage rate of 50 hours per year was incorporated (source: World Bank). For strategic locations (Airports), 40 hours per year were estimated

0,. MW_e of stationary fuel cell potential is considered in Rustenburg as of 2025

C/D. We have assessed hydrogen uptake on a per-sector basis, with some sectors drawing from a general H2 uptake curve (3/3)

		Segment size	H2 uptake in Low Case	H2 uptake in High Case

Industry	Oil refining	• 2025: 55 million brl/year
		• 2030: 36 million brl/year
		+ *Sasol Jet fuel*
			• Based on first adopter group:
			  • 2025: 2.4%
			  • 2030: 6%
				• Based on first adopter group:
				  • 2025: 2.8%
				  • 2030: 8.7%

	Ammonia	• 2025: 37.5 tons/day green NH3 • 2030: 45 tons/day green NH3	• Cfr Sasol announcements in segment size	

	Ethylene and methanol	• 2025: 1.5 M tons/year
		• 2030: 1.8 M tons/year
			• Based on first adopter group:
			  • 2025: 2.4%
			  • 2030: 6%
				• Based on first adopter group:
				  • 2025: 2.8%
				  • 2030: 8.7%

	Iron and Steel	• 2025: 10.7 M tons/year
		• 2030: 8.2 M tons/year
			• Based on moderate adopter group:
			  • 2025: 2.2%
			  • 2030: 2.4%
				• Based on moderate adopter group:
				  • 2025: 2.4%
				  • 2030: 2.8%

	Aluminum	• 2025: 4.2 M tons/year
		• 2030: 2.2 M tons/year
			• Based on moderate adopter group:
			  • 2025: 2.2%
			  • 2030: 2.4%
				• Based on moderate adopter group:
				  • 2025: 2.4%
				  • 2030: 2.8%

	Paper	• 2025: 2.8 M tons/year
		• 2030: 3.2 M tons/year
			• Based on late adopter group:
			  • 2025: 2%
			  • 2030: 2.2%
				• Based on late adopter group:
				  • 2025: 2%
				  • 2030: 2.4%

	Cement	• 2025: 7.1 M tons/year
		• 2030: 7.1 M tons/year
			• Based on moderate adopter group:
			  • 2025: 2.2%
			  • 2030: 2.4%
				• Based on moderate adopter group:
				  • 2025: 2.4%
				  • 2030: 2.8%

Zoom on Industrial Off-takers

Companies	Hub	Industries	H2 demand in 2025 - low	H2 demand in 2030 - low	H2 demand in 2025 - high	H2 demand in 2030 - high
BHP Billiton - Hillside Aluminum Smelter	Durban	Aluminum	1,371	1,476	1,504	1,740
Sasol - Sasolburg	Johannesburg	Ammonia	2,038	2,446	2,038	2,446
PPC - Hercules Cement Plant	Johannesburg	Cement	273	297	300	350
Afrisam - Roodepoort Cement Plant	Johannesburg	Cement	641	697	703	821
Cement Grinding Mill	Johannesburg	Cement	598	650	656	767
Lafarge - Randfontein Cement Grinding Grill	Johannesburg	Cement	427	464	469	548
PPC - Jupiter Cement Plant	Johannesburg	Cement	205	223	225	263
NPC - Durban Cement Plant	Durban	Cement	470	511	515	602
NPC - Port Shepstone Cement Plant	Durban	Cement	427	464	469	548
Sasol polymers	Johannesburg	Ethylene	1,605	4,982	1,892	7,218
Sasol Olefins & Surfactants	Johannesburg	Ethylene	1,181	3,668	1,393	5,314
Trident Steel – Roodekop, Germiston	Johannesburg	Iron&Steel	885	750	971	884
DAV Steel (Cape Gate holdings) - Vanderbijlpark	Johannesburg	Iron&Steel	759	643	833	758
Scaw Metals Group	Johannesburg	Iron&Steel	759	643	833	758
ArcelorMittal – Vereeniging	Johannesburg	Iron&Steel	506	428	555	505
ArcelorMittal Newcastle Works	Johannesburg	Iron&Steel	257	489	2,637	2,399
ArcelorMittal – Vanderbijlpark Integrated Steel Mill	Johannesburg	Iron&Steel	739	1,323	811	1,560
Evraz Highveld Steel and Vanadium	Johannesburg	Iron&Steel	108	206	119	243
Columbus Stainless (Pty) Ltd	Johannesburg	Iron&Steel	1	1	1	1

Hydrogen demand for industrial off-takers

Zoom on Industrial Off-takers

Companies	Hub	Industries	H2 demand in 2025 - low	H2 demand in 2030 - low	H2 demand in 2025 - high	H2 demand in 2030 - high
Sasol - Secunda	Johannesburg	Jet fuels	84	84	84	84
Sasol solvents - methanol	Johannesburg	Methanol	323	426	354	502
Natref - Sasolburg Oil Refinery	Johannesburg	Oil refining	127	107	191	266
Sapref - Durban Oil Refinery (Chevton SA)	Durban	Oil refining	0	178	319	444
EvonikPeroxide Africa (Pty) Ltd	Johannesburg	Peroxide	553	1,718	652	2,489
Safripol	Johannesburg	Polyethylene	177	225	208	325
Sappi - Enstra	Johannesburg	Pulp&Paper	360	450	360	493
Mpact - springs	Johannesburg	Pulp&Paper	247	308	247	338
Mondi	Durban	Pulp&Paper	839	1,047	839	1,149
Mpact - felixton	Durban	Pulp&Paper	387	483	387	530
Sappi - Refibre	Johannesburg	Pulp&Paper	777	970	777	1,064
Mondi	Durban	Pulp&Paper	2,575	3,213	2,575	3,525
Sappi - Saiccor	Durban	Pulp&Paper	2,488	3,104	2,488	3,406
Sappi - Stranger Mill	Durban	Pulp&Paper	233	291	233	319
Sappi - Tugela	Durban	Pulp&Paper	404	504	404	553

Hydrogen demand for industrial off-takers

Zoom on Mobility Off-takers’ Demand

Industries	Hub	H2 demand in 2025 - low	H2 demand in 2030 - low	H2 demand in 2025 - high	H2 demand in 2030 - high
Buses - Johannesburg	Johannesburg	310	790	2,618	3,927
Buses - Pretoria	Johannesburg	232	592	1,964	2,945
Buses	Durban	55	139	461	692
Freight Trains - Durban	Durban	62	198	73	287
Freight Trains - Richards Bay	Durban	62	198	73	287
Heavy Duty Trucks	Johannesburg	4,466	14,118	5,666	23,396
Heavy Duty Trucks	Durban	3,769	11,913	4,781	19,741
Heavy Duty Trucks	Mogalakwena	698	2,205	885	3,655
Port logistics - forklifts	Durban	1,019	2,601	1,202	3,768
Berthing	Durban	111	304	131	441
Marine Bunkering	Durban	-	5,303	-	10,605
Rustenburg - mobility	Johannesburg	15	15	74	74

Hydrogen demand for buildings off-takers, tonnes

Zoom on Public Buildings Off-takers' Demand

Sector	Industries	Hub	H2 demand in 2025 - low	H2 demand in 2030 - low	H2 demand in 2025 - high	H2 demand in 2030 - high
Buildings	Public buildings - Johannesburg	Johannesburg	2	2	342	399
Buildings	Public buildings - Pretoria	Johannesburg	1	1	245	285
Buildings	Public buildings	Durban	1	1	196	228
Buildings	Airport OR Tambo	Johannesburg	1	1	143	166
Buildings	King Shaka Tambo	Durban	0	0	40	47
Buildings	Limpopo Science Park	Mogalakwena	0	0	56	65
Buildings	Rustenburg - stationary	Johannesburg	79	395	79	1,657

Hydrogen demand for buildings off-takers, tonnes

Annex 3: Datasets

ANNEX 2: Datasets

1. eNaTIS (electronic national administration traffic information system) - https://www.natis.gov.za/
2. Mineral Council South Africa - https://www.mineralscouncil.org.za/
3. Global Solar Atlas database - https://globalsolaratlas.info/
4. Global Wind Atlas database - https://globalwindatlas.info/
5. Enerdata - https://www.enerdata.net/user/?destination=services.html
6. Renewable Energy IPP Procurement Programme Database - https://www.ipp-projects.co.za/

Annex 4:

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ANNEX 3: References (1/2)

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[15] KPMG, 2020, Draft High-Level Hydrogen Society Baseline Assessment Report

[16] KPMG, 2020, Draft High Level Hydrogen Society Roadmap

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ANNEX 3: References (2/2)

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Annex 5:

Glossary

ANNEX 5: Glossary

CAPEX	Capital expenditures
FC	Fuel cell
H2	Hydrogen
LCOH	Levelized Cost of Hydrogen
OPEX	Operation expenditures
RES	Renewable Energy Supply
TCO	Total cost of ownership

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