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

Implemented by
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

THE PATHWAY TO NET- ZERO SHIPPING

SOCIO-ECONOMIC OPPORTUNITIES FOR SOUTH AFRICA

IMPRINT

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Executive Summary

South Africa's maritime sector is at a critical juncture in the global transition to green shipping fuels. This socio-economic study examines the transformative potential of developing South Africa as a green shipping fuel hub, focusing on Power-to-X (PtX) technologies for producing green hydrogen fuels: green ammonia and methanol. The study conducted a mixed method approach consisting of desktop research and direct stakeholder consultations. The analysis utilised primary data from the Transnet National Ports Authority (TNPA) covering the period 2016-2023 on vessels calls to provide insights into the economic benefits, employment impacts, and community implications of this transition.

Key Findings:

1. Maritime Energy Demand and Green Fuel Projections: The analysis of TNPA vessel traffic data (2016 – 2023) in this study reveals that South Africa's port system handled an average maritime energy demand of 26.2 TWh per year during this period (2016 to 2023), with projections showing a peak of 36.7 TWh per year by 2050. This represents a 45-50% increase in energy demand between year 2024 and 2050, reflecting a steady sectoral growth. The Port of Durban (the largest port in Africa) accounts for the largest share (34%) of current energy demand, followed by Richards Bay (19%) and Cape Town (17%). By vessel type analysis shows bulk vessels (36%), containers (29%), and cargo vessels (24%) as the highest and/or primary energy consumers. Under the IMO Net Zero scenario, the study projects that green fuel demand will rise to over 3.3 Mt per year by 2050, with green ammonia accounting for approximately 33% of the maritime fuel mix and requiring approximately 250 kt per year of green hydrogen production to support sustainable fuel supply for the sector.

2. Economic Benefits and Revenue Generation: The study's revenue calculations demonstrate substantial economic opportunities across three IMO-aligned defossilization scenarios. For the revenue calculations, the study assumed that Green Ammonia accounts for the beforementioned 33% of the marine fuel mix. Under the most ambitious Net Zero pathway, green ammonia revenues could reach USD 0.6-1.1 billion by 2050, contributing 0.121%-0.222% to South Africa's national GDP. The low GDP share reflects that the analysis is based on current port-to-call activity rather than potential expansion into a regional bunkering hub. The analysis applied international fuel price projections to ammonia demand projections, converting tons per year to gigajoules using an energy density factor of 18.65 GJ/ton. This approach provided export-market revenue outcomes for South African ports within global decarbonisation trajectories.

3. Employment Creation and Skills Transformation: The green hydrogen value chain analysis indicates the potential for creation of approximately 542,000 direct jobs by 2050, including 33,500 positions requiring Technical and Vocational Education and Training (TVET) qualifications. The study identifies three distinct job categories emerging from the transition: "New Jobs" – primarily within renewable energy, hydrogen production and green fuel logistics; "Transition Jobs" – requiring the reskilling and upskilling of existing maritime workers, with over 70% skills transferability observed in areas such as chemical handling, vessel operationsand port operations; and the displacement of approximately 11,300 TVET jobs in fossil fuel sectors. In addition, critical occupations require scalling and expansion ("Scaled Jobs") are already recognised on the South African government's high-demand list (Identification of Skills Needed for the Hydrogen Economy). These include Marine Engineering Technologist, Chemical Engineer, and Electrical Engineer, confirming the strong and growing demand for technical expertise that will underpin the development of green shipping fuels ecosystem.

4. Community Impact and Local Development: The analysis highlights significant opportunities for Small and Medium Enterprises (SMEs) to integrate across the green shipping value chain through component manufacturing, maintenance services, environmental monitoring, and logistics support. While community engagement frameworks already exist through Environmental Impact Assessments and municipal planning systems, the study emphasizes the need to move beyond consultation towards genuine partnerships. The Coega Industrial Development Zone serves as a replicable national model for integrating employment creation, vocational training, and local procurement into port development projects.

ABBREVIATIONS

ABS	American Bureau of Shipping
AC	Air Conditioner (AC)
AIS	Automatic Identification System
ASU	Air Separation Unit
BAU	Business-as-Usual
BESIPPPP	Battery Energy Storage IPP Procurement Programme
BESS	Battery Energy Storage Systems
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CCA	Customs Controlled Area
CEF	Central Energy Fund
CIP	Critical Infrastructure Programme
CMTP	Comprehensive Maritime Transport Policy
CO_2	Carbon Dioxide
COP	Conference of the Parties
CSIR	Council for Scientific and Industrial Research
CTL	Coal-to-Liquids
DC	Direct Current
DFFE	Department of Forestry, Fisheries and Environment
DHERST	Department of Higher Education, Research, Science and Technology
DHET	Department of Higher Education and Training
DIRCO	Department of International Relations and Cooperation
DMRE	Department of Mineral Resources and Energy
DNV	Det Norske Veritas
DoT	Department of Transport
DPWI	Department of Public Works and Infrastructure
DSTI	Department of Science Technology and Innovation
DTIC	Department of Trade, Industry and Competition
DWAS	Department of Water and Sanitation
EJ	Exajoule
ETI	Employment Tax Incentive
ETS	Emissions Trading System
EU	European Union
FAME	Fatty Acid Methyl Ester
FT	Fischer–Tropsch
gCO_2eq/MJ	Grams of Carbon Dioxide Equivalent per Megajoule
GDP	Gross Domestic Product
GH_2	Green Hydrogen
GHCS	Green Hydrogen Commercialisation Strategy
GHG	Greenhouse Gas
GJ	Gigajoule
GJ/ton	Gigajoules per tonne
GT	Gross Tonnage
GTL	Gas-to-Liquids
GW	GigaWatts
HFO	Heavy Fuel Oil
HTW	Human Element, Training and Watchkeeping
HV	High Voltage
HVO	Hydrotreated Vegetable Oil

HySA	Hydrogen South Africa
IAPH	International Association of Ports and Harbors
ICCT	International Council on Clean Transportation
IDC	Industrial Development Corporation
IDZ	Industrial Development Zone
IEA	International Energy Agency
IKI	International Climate Initiative (Internationale Klimaschutzinitiative)
IMO	International Maritime Organization
IMPCA	International Methanol Producers and Consumers Association
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
Kt	Killotonnes
Kt/y	Killo Tonnes per Year
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSFO	Low Sulphur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
MGO	Marine Gas Oil
MPA	Megapascal
MoU	Memorandum of Understanding
MRV	Monitoring, Reporting and Verification
Mt	Million Tonnes
Mt/y	Million Tonnes per Year
MTBS	Maritime and Transport Business Solution
$MtCO_2e$	Metric Tons of Carbon Dioxide Equivalent
MTPA	Million Tonnes Per Annum
MW	Megawatt
NAEIS	National Atmospheric Emissions Inventory System
NAP	National Action Plan
NH_3	Ammonia
NQF	National Qualifications Framework
OFO	Organising Framework for Occupations
OPEX	Operational Expenditure
PAYE	Pay-As-You-Earn
PEM	Proton Exchange Membrane
PtX	Power-to-X
R&D	Research and Development
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RFI	Request for Information
RO	Reverse Osmosis
SA	South Africa
SA-H2 Fund	South Africa Green Hydrogen Fund
SAIIA	South African Institute of International Affairs
SAIMI	South African International Maritime Institute
SAMSA	South African Maritime Safety Authority
SAMTRA	South African Maritime Training Academy
SARS	South African Revenue Service
SBIDZ	Saldanha Bay Industrial Development Zone
SED	Socio-Economic Development
SEZ	Special Economic Zone
SETA	Sector Education and Training Authority
SGS	Société Générale de Surveillance

SIP	Strategic Integrated Project
SOE	State-Owned Enterprise
TEU	Twenty-foot Equivalent Unit
TNPA	Transnet National Ports Authority
TVET	Technical and Vocational Education and Training
TWh	TeraWatt-hours
TWh/y	TeraWatt-hours per Year
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
UNIDO	United Nations Industrial Development Organization
USD	United States Dollar
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital
WtW	Well-to-Wake
ZAR	South African Rand

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1. Introduction

South Africa stands at a pivotal moment in the global maritime energy transition. With abundant renewable energy resources, strategic positioning along major shipping routes, and established port infrastructure, the country has the potential to emerge as a significant green shipping fuel hub. This study examines the socio-economic implications of this transition, addressing two fundamental questions critical to national policy and investment planning decisions.

First, the study quantifies the economic benefits of transitioning to green shipping by analyzing vessel traffic data from South African ports to project green bunker fuel demand, particularly for green ammonia and methanol. This analysis encompasses the required green hydrogen production capacity, potential revenue generation, and carbon emissions reduction potential. The study also identifies emerging business opportunities and investment prospects across the maritime value chain.

Second, the study evaluates the social and economic benefits of implementing green shipping practices through a comprehensive assessment of the maritime Power-to-X (PtX) value chain. This includes mapping job creation potential across five integrated stages—from renewable energy generation through to port operations—and identifying the specific skills requirements for each role. Furthermore, the analysis examines how this transition will impact local communities, considering both the economic opportunities and potential challenges.

Building on South Africa's existing expertise in synthetic fuel production and leveraging its natural advantages, this socio-economic analysis provides evidence-based insights to guide the country's transformation into a competitive player in the global green maritime fuel market. The findings aim to inform stakeholders—including government, industry, and communities—in developing strategies that maximize economic returns while ensuring a just and inclusive transition.

Green fuels refer broadly to renewable hydrogen–derived energy carriers such as ammonia, methanol, e-diesel and e-kerosene that are produced using renewable electricity.

Power-to-X (PtX) describes the entire Power-to-X value chain, that uses renewable electricity to create carbon-neutral fuels or other products, symbolized by "X".

1.1. Policy Landscape and National Commitments

The growing international momentum for defossilising maritime transport is being driven by both global and regional policy shifts. Notably, the International Maritime Organization's (IMO), whose 2023 Greenhouse Gas (GHG) strategy sets ambitious defossilisation targets for the shipping industry. In parallel, regional mechanisms such as the European Union's Carbon Border Adjustment Mechanism (CBAM) are creating additional incentives for countries to adopt low-carbon production and export strategies, particularly in emission intensive sectors such as maritime transport that service the majority of global trade networks.

These policies are grounded in international climate agreements. At the 21st Conference of the Parties (COP21), representatives of 196 state parties, including developing nations, agreed to limit global temperature rise to well below 2°C, aiming for 1.5°C above pre-industrial levels (the Paris Agreement). Following this, the IMO was tasked with setting standards for international maritime transport.

The regulatory evolution began with the IMO's Initial GHG Strategy, adopted in April 2018, which called for reducing GHG emissions from international shipping (Joung et al., 2020). This was substantially strengthened by the IMO's 2023 GHG Strategy, which now aims to reach net-zero GHG emissions from international shipping by or around 2050, with indicative checkpoints for 2030 and 2040. These more ambitious global targets—supported and further accelerated by regional regulations—create immediate and expanding market opportunities for green fuel producers.

The European Union (EU) introduced the FuelEU Maritime Regulation as part of its "Fit for 55" package under the European Green Deal, driven partly by the need for more ambitious targets than those agreed at the IMO level (European Commission, 2023). The regulation requires ships calling at EU ports to progressively reduce their GHG intensity- 2% by 2025, 6% by 2030, 14.5% by 2035, 31% by 2040, 62% by 2045, and 80% by 2050, compared to a 2020 baseline of 91.16 gCO_2eq/MJ (European Commission, 2023). This applies to vessels over 5,000 GT and will be enforced through a monitoring, reporting, and verification (MRV) system.

From 2024, maritime transport will also be included in the EU Emissions Trading System (EU ETS) (DNV, 2024).

These international regulations open substantial market opportunities for countries capable of producing green maritime fuels. South Africa has demonstrated its commitment to green hydrogen by launching the Green Hydrogen Commercialisation Strategy (GHCS). According to the Presidency (2023), by 2050, the green hydrogen and related industries could contribute up to 3.6% to South Africa's GDP, while creating an estimated 380,000 jobs in the green hydrogen value chain. These projections are directly tied to meeting the rising international demand for green fuels driven by IMO and EU regulations.

To capitalise on this, South Africa's GHCS identifies that ZAR 319 billion (USD 16.8 billion) will be required from 2023 to 2027 to support the development of the green hydrogen sector, including funding for feasibility studies and capital investments in green hydrogen and methanol subsectors. However, significant challenges remain, including the need for large-scale infrastructure investments, workforce reskilling and upskilling (skills development), and the establishment of enabling regulatory frameworks. Overcoming these challenges will require coordinated public-private collaboration and political support.

As part of the global effort to comply with IMO objectives, South Africa, through its Department of Transport (DoT), is developing a National Action Plan (NAP) to implement the IMO GHG Reduction Strategy. This plan will be crucial for positioning South Africa as a competitive supplier in the international green shipping fuel market.

Finally, with increasing global demand for low-carbon energy fuels or carriers, South Africa has the potential to become a major exporter of green hydrogen and PtX products such as green ammonia and green methanol. This opportunity offers significant potential for foreign-exchange earnings, helping to improve the country's balance of payments and solidify its position in the global green fuel supply chain.

1.2. Research Methodology

The analysis was conducted through a combination of desktop research and direct stakeholder consultations. This mixed-methods approach (qualitative and quantitative) enabled a more nuanced review of the sector and provided valuable qualitative insights into stakeholder perspectives, institutional motivations, and contextual considerations across South Africa's emerging green shipping sector.

1.2.1. Desktop Research

The desktop research component provided the foundational analytical basis for the study. It included a review of relevant academic literature on maritime decarbonisation, hydrogen economy development and energy transition frameworks, industry reports and technical studies published by international organisations such as IMO, DNV, and IRENA, policy frameworks, National policy documents including South Africa's Green Hydrogen Commercialisation Strategy (GHCS), the National Climate Change Response Policy (NCCRP), the Intergrated Resource Plan (IRP 2019) and international case studies from leading maritime hubs such as (Rotterdam, Singapore and Norway) to benchmark progress and identify transferrable lessons for South Africa, particularly focusing on green shipping, defossilisation strategies, and hydrogen economy development. This analysis helped to contextualise South Africa's maritime and energy landscape within global defossilisattion trends and highlighted policy, infrastructure, skills and knowledge gaps addressed through stakeholder input.

1.2.2. Stakeholder Engagement Process

To complement the secondary research, a series of structured stakeholder engagements process were conducted across five key locations: Pretoria, Cape Town, Secunda, Coega, and Mossel Bay. These workshops and consultations were designed to gather expert and practitioner input from across government and related sectors.

The first workshop was held in Pretoria on 16 August 2024, served as an introductory session to present the research objectives and methodological framework, promote capacity building on maritime decarbonisation and the hydrogen value chain, and share international insights on developments within the emerging green hydrogen economy. Subsequent engagements focused on deepening the dialogue, identifying national opportunities and constraints in adopting green shipping fuels, and exploring key thematic areas across the Power-to-X (PtX) maritime value chain, including production, storage, distribution, and port readiness; Institutional coordination mechanisms required to align maritime decarbonisation with national climate and industrial policies relevant to South Africa's maritime defossilisation agenda. These stakeholders' insights were important in shaping the study framework, ensuring that the study's recommendations are grounded in South African realities while reflecting international best practices.

Stakeholder participants represented a wide range of key government departments, state-owned entities, and academic institutions, including:

- Department of Transport (DoT)
- Department of Trade Industry and Competition (DTIC)
- Department of Higher Education, Research, Science and Technology (DHERST)
- Department of Forestry, Fisheries and Environment (DFFE)
- Department of International Relations and Cooperation (DIRCO)
- Department of Water and Sanitation (DWAS)
- The Presidency
- National Treasury
- Department of Mineral Resources and Energy (DMRE)
- Department of Science Technology and Innovation (DSTI)
- Provincial Governments (Western and Eastern Cape)
- Transnet National Ports Authority (TNPA)
- South African Maritime Safety Authority (SAMSA)
- Central Energy Fund (CEF)
- South African International Maritime Institute (SAIMI)
- PetroSA
- SASOL
- University of Western Cape
- WESGRO

1.2.3. Focus Areas of Stakeholder Dialogue

While the stakeholder consultations did not aim to generate empirical findings, they were structured to probe key questions aligned with the study's Terms of Reference. These included

- ✓ What is the estimated energy demand associated with a green hydrogen (GH_2) economy in South Africa, and what are the most practical implementation pathways?
- ✓ What are the most promising local and international market opportunities for green fuels?
- ✓ How can policy instruments, including tax incentives and investment frameworks, facilitate adoption and enhance South Africa's competitive position?
- ✓ What are the employment implications of this transition, including quantitative job creation projections and sectoral distribution?
- ✓ How should South Africa approach reskilling, upskilling, and training to ensure an inclusive transition that benefits local communities?
- ✓ What skills gaps exist in the current workforce, and what training pathways can address these?

What role can South Africa play in international maritime transport services as the sector evolves? These inquiries laid the groundwork for subsequent analysis in the report, offering a qualitative foundation that complements the technical and economic assessments presented in later sections. The research accordingly focused on three main themes of analysis based on data and information gathered. These strands are illustrated in Figure 1.

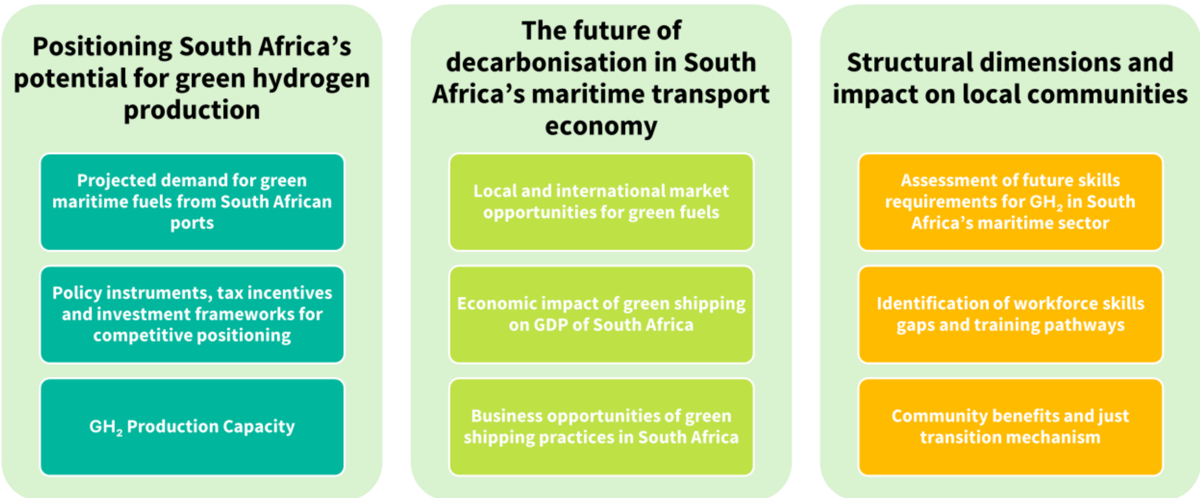

Figure 1: Boundary and scope analysis

2. Green Hydrogen and PtX Products Market Analysis

Green hydrogen is increasingly recognised as a critical energy carrier within global decarbonisation strategies, particularly for sectors that are difficult to electrify directly with renewable power. These include long-distance heavy transport modes, such as maritime shipping, aviation, and long-haul trucking, as well as energy-intensive industrial processes such as iron and steel manufacturing, ammonia production, and cement. The mining and construction sectors, especially prevalent in South Africa, also represent promising areas for the adoption of green hydrogen due to limited alternatives for deep electrification.

In recognition of hydrogen's strategic value, the South African government has implemented several initiatives aimed at positioning the country as a leader in green hydrogen technologies. In 2007, the Department of Science and Technology (now the Department of Science, Technology and Innovation – DSTI) launched Hydrogen South Africa (HySA) to build national capacity across the hydrogen value chain. More recently, the Department of Trade, Industry and Competition (DTIC) introduced the Green Hydrogen Commercialisation Strategy to foster a domestic green hydrogen industry capable of driving economic development while reducing GHG emissions. While these initiatives are not specific to the maritime sector, they create a foundational framework that supports its decarbonisation.

The maritime sector is particularly well suited to benefit from green hydrogen-derived PtX fuels, such as green ammonia and green methanol, both as export commodities and as low-carbon bunkering solutions for international vessels. With its strategic port infrastructure and renewable energy potential, South Africa is well-positioned to play a dual role: as a supplier of green hydrogen-based marine fuels to global markets, and as a facilitator of domestic decarbonisation within its own shipping industry. This vision is aligned with the country's Comprehensive Maritime Transport Policy (CMTP) and supports compliance with international climate goals, including the International Maritime Organization (IMO)'s 2030 target: strive for 20-30% reduction in total annual GHG emissions from international shipping, and a minimum 5% uptake of zero or near-zero emission fuels.

Nevertheless, South Africa's transition toward a green hydrogen economy faces legacy challenges, particularly the continued dominance of coal in its energy mix. Coal currently accounts for the majority of electricity generation and provides the feedstock for processes such as coal-to-liquids (CTL) via the Fischer–Tropsch (FT) process[i]. While the FT process has contributed to energy security and industrial capacity for decades, its reliance on fossil feedstocks highlights the urgency of transitioning toward cleaner alternatives. Beyond technical and environmental hurdles, the transition to green energy is also shaped by socio-economic factors, most notably, the fact that many previously disadvantaged South Africans have acquired shareholdings in coal mines and related extractive industries, creating complex interests that can slow the pace of change.

In this context, the maritime sector's pivot toward green hydrogen and PtX fuels offers both an opportunity and a challenge: to leverage existing industrial capabilities while accelerating the shift to sustainable, low-emission fuel systems. The following sections examine i) global trends in maritime defossilisation, ii) South Africa's green hydrogen initiatives, and iii) the specific market potential for PtX fuels in South African shipping.

2.1. Global Trends in Maritime Defossilisation

The drive for maritime defossilisation is strongly policy-led, guided by IMO's evolving strategies and targets outlined in previous sections. These regulations are driving the maritime industry to shift towards alternative fuels.

Supporting these efforts, the Clydebank Declaration—announced at COP26 in Glasgow—proposes the establishment of "green shipping corridors," which are zero-emission routes between two or more ports. The declaration aims to launch at least six such corridors by the mid-2020s, with plans to expand them in subsequent years (Department of Transport, 2023).

Green shipping corridors promote environmentally sustainable shipping by encouraging the adoption of low- and zero-carbon fuels, innovative technologies, and sustainable business models along specific routes. They aim to make green shipping more practical and cost-effective for the maritime industry, thereby reducing its environmental footprint.

In the short term, the international maritime industry prioritises deploying monitoring and enforcement mechanisms to ensure compliance with IMO mandates, thereby improving vessel energy efficiency. Over the medium to long term, the focus shifts toward replacing fossil fuels with renewable alternatives, including advanced biofuels and e-fuels such as e-methanol and green ammonia (IRENA, 2021).

Currently, the maritime fuel mix predominantly consists of Heavy Fuel Oil (HFO), Marine Gas Oil (MGO), Liquefied Natural Gas (LNG), and Low Sulphur Fuel Oil (LSFO) (International Maritime Organization, 2020; IRENA, 2021).

Hydrogen emerges as a promising defossilisation option, usable both directly in fuel cells and internal combustion engines, particularly on short voyages, and indirectly as a feedstock for producing e-fuels for long-haul international shipping (IRENA, 2021). Hydrogen-derived e-fuels, including green ammonia and green methanol, are among the most promising zero-carbon fuels for large commercial vessels such as tankers and bulk carriers.

These e-fuels each offer unique advantages and challenges for maritime decarbonisation:

- **Green Methanol:** Renewable methanol requires minimal engine modifications and can achieve substantial 80% GHG emission reductions. However, securing non-fossil carbon dioxide sources remains a significant challenge (IRENA, 2021; Global Maritime Forum, 2022). Maersk, for example, has identified green methanol as a foundation of its decarbonisation strategy, launching the Laura Maersk in 2023, the world's first container vessel equipped with a dual-fuel engine capable of operating on green methanol (Maersk, 2023). Both methanol and ammonia can reduce tank-to-propeller GHG emissions by over 80%. Methanol is less toxic and easier to handle than ammonia, requiring less specialised infrastructure. However, it has lower energy density, necessitating increased onboard fuel storage.
- **Green Ammonia:** Containing no carbon, ammonia eliminates carbon dioxide emissions during production and use, potentially making it a more cost-effective option (IRENA, 2022). It is expected to play a central role in maritime decarbonisation over the medium to long term (IRENA, 2021). However, ammonia's toxicity and corrosiveness present safety challenges. Both DNV (2022) and Lloyd's Register (2020) highlight risks to human health and marine ecosystems in case of leaks during transport or bunkering. To mitigate these risks, DNV recommends double-walled containment systems and real-time leak detection on ships and port facilities. Comprehensive crew training, certification, and regular emergency drills are also essential to ensure safe operations (Lloyd's Register, 2020). This includes the modification of the STCW of IGF Code to also factor alternative fuels such as green ammonia or create a completely new course to accommodate the new fuels including green ammonia.

Countries such as South Korea and Belgium are actively advancing ammonia-powered vessels prototypes, with pilot projects testing ammonia's viability as a zero-carbon marine fuel (DNV, 2022). For example, Belgian company CMB.TECH is developing the *Yara Eyde*, the world's first ammonia-powered container ship. This 1,400 TEU ice-class vessel is scheduled for delivery by mid-2026 and will operate on clean ammonia between Norway and Germany (CMB.TECH, 2024). Similarly, EXMAR, also based in Belgium, collaborates with South Korean shipyards (Hyundai Mipo Dockyard) to pioneer ammonia-powered dual-fuel midsize gas carriers. Six such vessels, each with a cargo capacity of 46,000 cubic meters, ordered from Hyundai Mipo Dockyard, are expected to be delivered between 2025 and 2026 and will achieve near-zero emissions (EXMAR, 2023).

Early signs of transition are becoming visible, with more newly ordered vessels designed to run on green methanol and ammonia (DNV, 2023), and engine manufacturers anticipating commercial availability of ammonia-capable engines by 2024–2025 (Schuller et al., 2024). There is also significant potential for growth in the marine manufacturing sector, particularly in retrofitting engines for green fuels and modifying vessels to accommodate compliant storage systems. These developments could stimulate domestic job creation, bolster industrial capacity, and contribute to South Africa's broader green economy.

As South Africa charts its course toward maritime defossilisation, understanding its current green fuel production and infrastructure development efforts is essential. The following chapter explores South Africa's initiatives, policies, and opportunities that position the country as a key player in the global green shipping transition.

2.2. South Africa's Green Hydrogen Initiatives

In South Africa, the transition to green maritime fuels remains in its early stages. While alternative engine production has not yet commenced, efforts are underway to develop alternative fuel supply chains, particularly focused on the potential production of green hydrogen and its PtX products.

A notable step in this direction is the Transnet National Ports Authority (TNPA) Request for Information (RFI), which was publicly issued to gauge technical and commercial capacity related to alternative marine fuels. The RFI defines alternative fuels as: "Alternative Fuels – refers to the targeted alternative fuels such as Natural Gas (in either Liquid or Gas phase), Biodiesel, Methanol, Hydrogen/Ammonia (in either Liquid or Gas phase)" for use in retrofitted tugboats.

The RFI requirement for information is described as follows:

REQUEST FOR INFORMATION (RFI) IN RESPECT OF THE PROCUREMENT OF THE PROVISION OF TECHNICAL AND COMMERCIAL SERVICES FOR TECHNICAL ASSESSMENT OF EXISTING/OLD TUGBOATS AND THE CONVERSION/RETROFIT TO UTILISE ALTERNATIVE FUELS (INCLUDING NATURAL GAS, BIODIESEL, HYDROGEN/AMMONIA AND METHANOL).

RFI NUMBER TNPA/2024/10/0008/80711/RFI
ISSUE DATE: 28 OCTOBER 2024 - CLOSING DATE: 29 NOVEMBER 2024

The RFI describes the key objectives amongst others as: Retrofitting TNPA's marine fleet with low-to-no carbon fuel alternatives to the current fossil fuel-based products is a key step in the decarbonisation journey of Port-related equipment and vessels. As such national awareness and demand is apparent inclusive of the international market opportunities. As TNPA is a State-Owned Enterprise (SOE) it demonstrated a Governmental Entity wishing to attain global standards.

Furthermore, South Africa's commitment to global defossilisation is demonstrated through the designation of nine Strategic Integrated Projects (SIPs) on 6 December 2022 by the Department of Public Works and Infrastructure (DPWI). Of these nine projects, five have direct maritime applications, focusing on green hydrogen production and PtX fuel solutions for the shipping sector. Table 1 presents these maritime-relevant SIPs and their potential contributions to the green shipping fuel supply chain.

Table 1: Maritime related Gazetted Strategic Integrated Projects (SIPs)[ii] for hydrogen production in South Africa

Name of Project	Location	Description
Boegoebaai Green Hydrogen Port	Northern Cape	Focus: Green hydrogen and PtX products production. Capacity: The initiative plans to install 1.2 GW of electrolyser capacity by 2028, scaling up to 5 GW by 2035, and ultimately reaching 9–20 GW by 2050. Maritime Impact: Boegoebaai is strategically located on the West Coast, making it an ideal hub for the production and export of green hydrogen and green ammonia to global shipping routes. Source: Global African Network. (2023)
Atlanthia Green Hydrogen	Western Cape, Saldanha Bay Industrial Development Zone (SBIDZ)	Focus: This project is focused on the production of green hydrogen and green ammonia using solar and wind renewable energy, along with battery energy storage systems (BESS). The plant will produce 6,570 tons per annum of green hydrogen, alongside green nitrogen, which will be combined to produce 35,950 tons per annum of green ammonia in its first phase. Capacity: The first phase will generate 40 MW for electrolysis, desalination, and ammonia production. Future expansions envision a significant scale-up, with the phase 4 iteration projected to be 25 times the capacity of phase 1. Maritime Impact: Saldanha Bay's location within a special economic zone (SEZ) offers strategic proximity to shipping routes, enhancing its role in the global maritime fuel supply chain. Source: Atlanthia Green Hydrogen (Pty) Ltd. (2024)
Hive Coega Green Ammonia	Eastern Cape	Focus: Production of green ammonia Maritime Impact: Once operational, this project will provide green ammonia to meet both domestic and international shipping fuel needs. Source: Hive Hydrogen. (2025)
Sasolburg Green Hydrogen Production Hub	Free State	Focus: Transitioning from fossil fuels to green hydrogen for various industrial applications, including maritime use. Source: Sasol (2023)
SASOL HyshiFT	Mpumalanga	Focus: Transition to more sustainable feedstocks, focusing on green hydrogen produced via electrolysis. Maritime Impact: While primarily industrial, this project's green hydrogen production will support maritime fuel supply chains. Source: SASOL LIMITED (2024).

2.3. The PtX Maritime Market Potential in South Africa

The economic benefits of transitioning to green shipping solutions in South Africa require a comprehensive evaluation of relevant factors, with a focus on maritime opportunities. Although South Africa does not currently possess a substantial domestic fleet to defossilise, the country has a strategic opportunity to position itself as a key supplier of green bunker fuels and Power-to-X (PtX) products for the global maritime industry (Uhorakeye, Kopp-Moini, & Cohen, 2023).

By focusing on fuelling foreign vessels and developing clean energy solutions, South Africa can align itself with the global transition to sustainable shipping, while addressing potential challenges such as carbon-trade policies. This approach not only offers a pathway to overcoming these challenges but also opens doors for both local and international market opportunities.

Several feasibility assessments have already been conducted to evaluate South Africa's potential in the green hydrogen and alternative maritime fuels market (Carpenter-Lomax, Wilkinson, & Ash, 2021; Roos, 2021; Abhold & Shaw; Roos, Chauke, Oloo & Mbatha, 2022, World Bank, 2024), demonstrating the viability of the country's green fuel ambitions.

2.3.1. Local Demand as a Driver for Green Fuel Development

The growth in global sea freight volumes is expected to significantly drive demand for sustainable bunker fuels, positioning South Africa's green hydrogen production as a key player in this shift. While most fuels are intended for export, there is significant potential to address local needs, particularly in industries difficult to decarbonise. For example, ArcelorMittal South Africa's Saldanha Works is projected to require 104 kt/year of hydrogen for green steel production, while Transnet's bunker fuel operations at Saldanha Bay and Ngqura are expected to demand 504 kt/year and 242 kt/year, respectively. This domestic demand could help reduce reliance on fossil fuels, decarbonise local industries, and lower greenhouse gas emissions (Roos, Chauke, Oloo, & Mbatha, 2022).

2.3.2. Global Partnerships and Market Demand

South Africa's key trading partners, Japan and Germany, have ambitious targets for importing green hydrogen, presenting significant opportunities. If South Africa captures just 10% of this market, it could produce 300 kt/year from Saldanha Bay and 30 kt/year from Ngqura (Roos et al., 2022). Japan aims to import 300 kt/year by 2030, and Germany's demand could reach 3 million tons annually by then. Both countries recently updated their targets: Japan's Basic Hydrogen Strategy sets a 2040 goal of 12 million tons/year, and Germany aims to double domestic green hydrogen production to 10 GW by 2030 (World Economic Forum, 2024; Clean Energy Wire, 2024).

Germany anticipates that 50–70% of hydrogen demand will be met via imports, highlighting the importance of international partnerships and infrastructure.

2.3.3. Regional and Global Competition

South Africa faces strong competition from regional players such as Morocco, Egypt, Tunisia, and Namibia. Northern African countries' proximity to Europe lowers transport costs, making them attractive hydrogen suppliers (Bayssi, 2024). Namibia's Hyphen project is developing a green hydrogen-to-ammonia hub with over USD 10 billion in investment (Hyphenafrica, 2021). Additionally, global competitors in Australia, Chile, and elsewhere add further pressure.

To succeed, South Africa must leverage unique strengths such as renewable energy resources, port infrastructure, and strategic partnerships.

2.3.4. Port-Level Infrastructure and Export Capacities

Studies show that South Africa's captive bunker fuel market could support production of about 504 kt/year of bunker fuel at Saldanha Bay and Cape Town, and 242 kt/year at Ngqura and Gqeberha (Roos et al., 2022). Saldanha Bay and Ngqura are strategically positioned for ammonia exports. Projections estimate green ammonia exports could range from 5,515 kt in 2030 to 8,925 kt by 2050, with green methanol demand growing from 175 kt to 1,511 kt in the same period (Uhorakeye et al., 2024).

Richards Bay, currently South Africa's only ammonia terminal, is positioned for future export readiness. Saldanha Bay could serve European export routes; Ngqura, the Far East (Japan, South Korea). These port advantages support South Africa's goal to become a regional green fuels hub.

2.3.5. Emerging Opportunities from Changing Shipping Routes

Safety risks in the Suez Canal are forcing vessels to sail around the Cape of Good Hope instead. This longer route means more ships need to refuel at South African ports, making the country an important fuel stop for international shipping.

3. Potential Maritime Energy Demand in South Africa

This section provides critical estimates of maritime energy demands for South Africa, projected against current vessel traffic data and estimates of current fossil fuel energy demand. The analysis is structured in two key parts:

1. A synthesis of existing literature on maritime energy demands in South Africa, and
2. Use-case estimation of energy demands based on analysis of TNPA vessel traffic data.

This analysis provides a foundation for evaluating the adoption of green hydrogen, using projected future demand estimates and positioning ammonia as a representative proxy for maritime e-fuels. It therefore bridges existing global and national studies with context specific estimates for South African ports.

3.1. Literature Review Findings

A review of existing literature indicates a range of estimates regarding maritime energy demand in South Africa, as summarized in Table 2.

Table 2 : Energy demand scoping based on study findings estimates

Study/Source	Details	Energy Demand (TWh/y)	Green Fuel Demand Projection and Renewable Energy Needed
Carpenter-Lomax et al. (2021)	All commercial vessels departing SA Ports (2018); estimated total 147 TWh/y (145 TWh/yr from vessel with automatic identification system (AIS) data and 2 TWh/y from non-AIS vessels)	147, Saldanha Bay: 16; Ngqura: 10; Richards Bay: 27	*Green Fuel Demand Projection:* not assessed in this study *Renewable Energy Needed:* • IMO 5% Target: ~13.7 TWh/y green energy by 2030 • IMO Net Zero Target: ~275 TWh/y by 2030
Roos, Chauke, Oloo, & Mbatha (2022)	Port-specific ammonia equivalent provided		*Green Fuel Demand Projection:* 28.1 Mt total ammonia quivalent/year, Port-specific ammonia quivalent/year: • Saldanha Bay: 3.1 Mt/y, • Ngqura: 1.9 Mt/y, • Richards Bay: 5.2 Mt/y *Renewable Energy Needed:* not assessed in this study, builds on the findings in the Carpenter-Lomax et al. (2021) study.
Abhold & Shaw (2022)	Lower estimate of 42.5 TWh/y; assumed 5% transition to zero-carbon fuels by 2030 (~3.8 TWh/y)	42.5	*Renewable Energy Needed:* • IMO 5% Target: ~3.8 TWh/y green energy by 2030
World Bank (2024) - Calling Vessels	Average energy demand from 3 year (2020-2022) for international departures: 26.8 TWh/y; port level demand breakdown: Durban (24%), Richards Bay (21%), Cape Town (17%), Saldanha Bay (15%), Gqeberha (11%), Ngqura (10%)	26.8	*Green Fuel Demand Projection:* not assessed in this study *Renewable Energy Needed:* Hydrogen-based fuel energy demand for calling vessels: 4.9 TWh (2035); 16.5 TWh (2050)
World Bank (2024) - Passing Vessels	Energy demand potential including passing fleet: 52.9 TWh; projected hydrogen and ammonia needs by 2030, 2040, and 2050	52.9	Hydrogen-based fuel energy demand: passing fleet: 11.2 TWh (2035); 38.5 TWh (2050); Ammonia demand: 0.32 Mt (2030), 1.66 Mt (2040), 3.2 Mt (2050)

The literature review highlights several key insights:

Varying Estimates: (Carpenter-Lomax et al., 2021) estimated that the fossil fuel energy demand from all commercial vessels departing from South Africa's eight commercial ports in 2018 was approximately 147 TWh/year, based on vessel traffic data. Conversely, (Abhold & Shaw, 2022) concluded a lower estimate of 42.5 TWh/year using similar 2018 voyage data. These differences likely stem from different methodological approaches and boundary assumptions during data processing. Both estimates appear to exclude bypass vessel traffic, although differences may be attributed to underlying methods and assumptions during data processing and boundary setting. This illustrtates the importance of clearly defining systems boundaries when compating maritime energy demand studies. In the same assessment from Abhold & Shaw (2022), it is reported that, assuming a 5% transition to zero- or lower-carbon fuels by 2030, green energy demand (zero- or low-carbon fuels) would be approximately 3.8 TWh/year (only 0.2% of South Africa's total renewable energy potential).

Port-Specific Data: (Carpenter-Lomax et al., 2021) provided more granular estimates for specific ports, with Saldanha Bay, Ngqura, and Richards Bay requiring 16 TWh/year, 10 TWh/year, and 27 TWh/year respectively. Roos et al., (2022) study converted these energy demands into ammonia requirements: 3.1 Mt/year for vessels departing from Saldanha Bay, 1.9 Mt/year for Ngqura, and 5.2 Mt/year for Richards Bay, showing the scale of potential PtX demand at individual ports.

Port	Estimated Energy Demand (TWh/y)	Ammonia Requirement (Mt/y)
Saldanha Bay	16	3.1
Ngqura	10	1.9
Richards Bay	27	5.2

Recent Assessments: The most recent World Bank (2024) assessment reports that the average energy demand, examined across three years of data (2020-2022), for international departing voyages of vessels calling at all eight South African commercial ports is approximately 26.8 TWh/year. Their assessment found that Durban, Richards Bay, Cape Town, and Saldanha Bay are the ports with the highest demands, at 24%, 21%, 17%, and 15% respectively, while Gqeberha and Ngqura combined account for 21% of demand. East London and Mossel Bay exhibit relatively low energy demand, accounting for approximately only 2%. However, considering port calling demand versus offshore supply dynamics, Mossel Bay presents potential for supply, especially to transit traffic. These newer estimates provide a more recent benchmark than the 2018 based studies and refflects post-COVID traffic patterns.

Transit Traffic Potential: World Bank (2024) also identified significant potential in vessels passing through South African waters without calling at ports. For this fleet, the potential demand for international departing voyages is estimated to be 52.9 TWh/year, approximately twice the energy demand for vessels calling in all eight ports (not accounting for the Suez Canal diverted traffic). This underlines the strategic opportunity to serve not only calling vessels but also passing traffic through offshore or ship-to-ship bunkering solutions.

Transition Projections: Based on the World Bank (2024) projections, which assume an average uptake of 6% by 2030 and 55% by 2050, it is estimated that by 2035, ships departing on international voyages will require approximately 4.9 TWh of hydrogen-based fuels, growing to 16.5 TWh by 2050. For passing vessels, the estimated energy requirement is 11.2 TWh in 2035, increasing to 38.5 TWh by 2050. The study projects green hydrogen demand of 56,000 tons (2030), 293,000 tons (2040), and 570,000 tons (2050) across all South African ports for international shipping. Converting these hydrogen requirements into ammonia as a marine fuel proxy, this translates to approximately 0.32 Mt (2030), 1.66 Mt (2040), and 3.2 Mt (2050) of ammonia demand, with the Eastern Port Region (Durban & Richards Bay) projected to hold the largest demand share (World Bank, 2024).

3.2. Energy Demand Projections

Building on the maritime traffic analysis from allied research, this assessment further estimates the energy demand across different vessel types within the South African Port System. This ensures consistency with international sudies while adding vessel type granularity specific to South African conditions. Following upon the literature review, an independent analysis of maritime energy demand was conducted, utilising primary data obtained from the Transnet National Ports Authority (TNPA). A more current and detailed picture of potential energy demands across South Africa's port system is provided by this original analysis. It completements previous high-level estimates by directly using observed vessel movement data. The projections were developed using the following methodology:

1. Data Collection: Comprehensive vessel traffic data from TNPA covering the period 2016-2023, including vessel arrivals by port, vessel type distribution, and tonnage, was obtained.
2. Baseline Calculation: A baseline energy demand profile for each port was established based on the historical vessel traffic data, with vessel calls converted to energy requirements using standard conversion factors for different vessel types. These conversion factors reflect typical specific fuel consumption and average voyage profiles.
3. Growth Assumptions: For projections from 2024 to 2050, a 1.5% annual growth rate in vessel traffic was applied, which aligns with long-term maritime traffic growth expectations for the region.
4. Port Distribution Analysis: The existing share and distribution of vessels across ports was maintained based on the historical pattern, as no major shifts in regional port dynamics are expected. The assumption reflects a conservation view of port markets share evolution.
5. Fuel Consumption Patterns: For this baseline projection, no significant changes in vessel fuel consumption patterns were assumed, though alternative fuel-uptake scenarios are considered in the following section ‘Ammonia or Methanol Proxy Demand Calculations’.

3.2.1. Results of TNPA Data-Based Projections

The results of the analysis are presented in Figure *2* and **Fehler! Verweisquelle konnte nicht gefunden werden.**, which shows the total annual energy demand (TWh/year) by share of South African Ports and vessel type respectively over both the historical (2016-2023) and projection (2024-2050) time periods.

Annual Energy Demand Trends in South African Ports: Baseline (2016–2023) and Forecast (2024–2050)

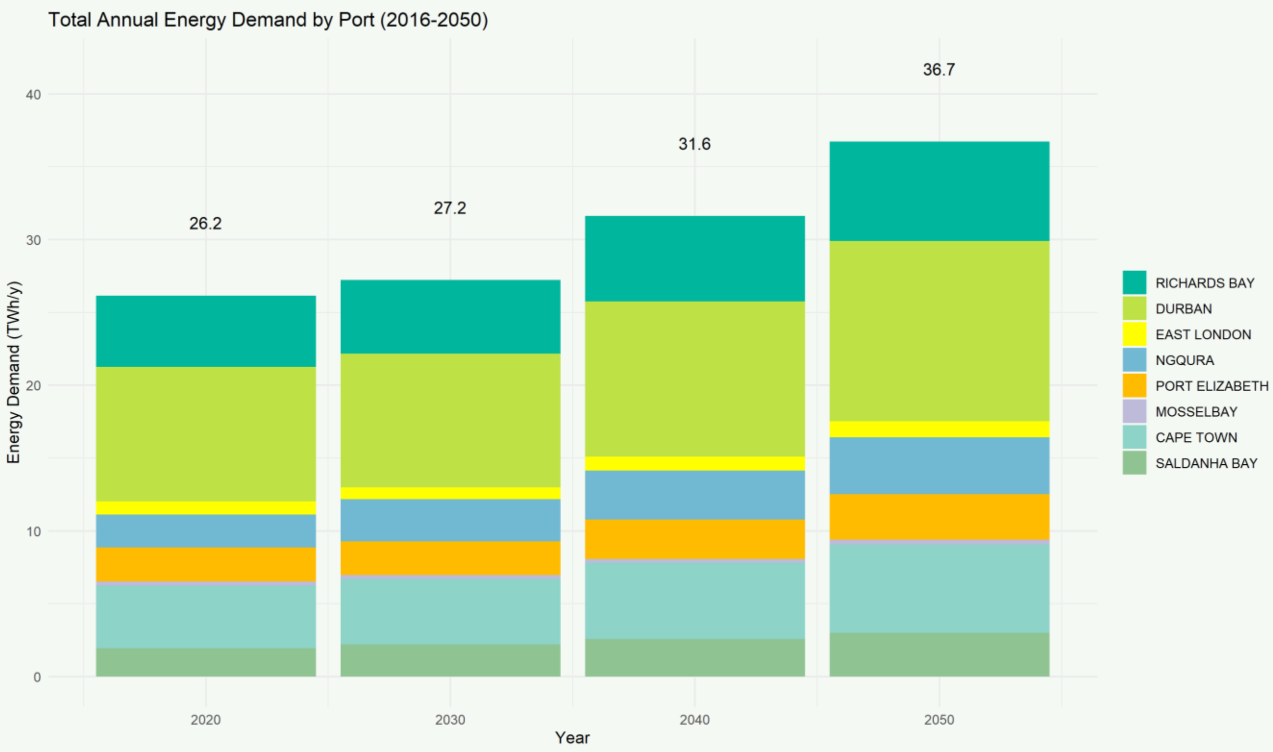

Figure 2 : Own calculations

Total annual energy demand (TWh/year) by share of vessel types over the data (2016-2023) and projection (2024-2050) period .

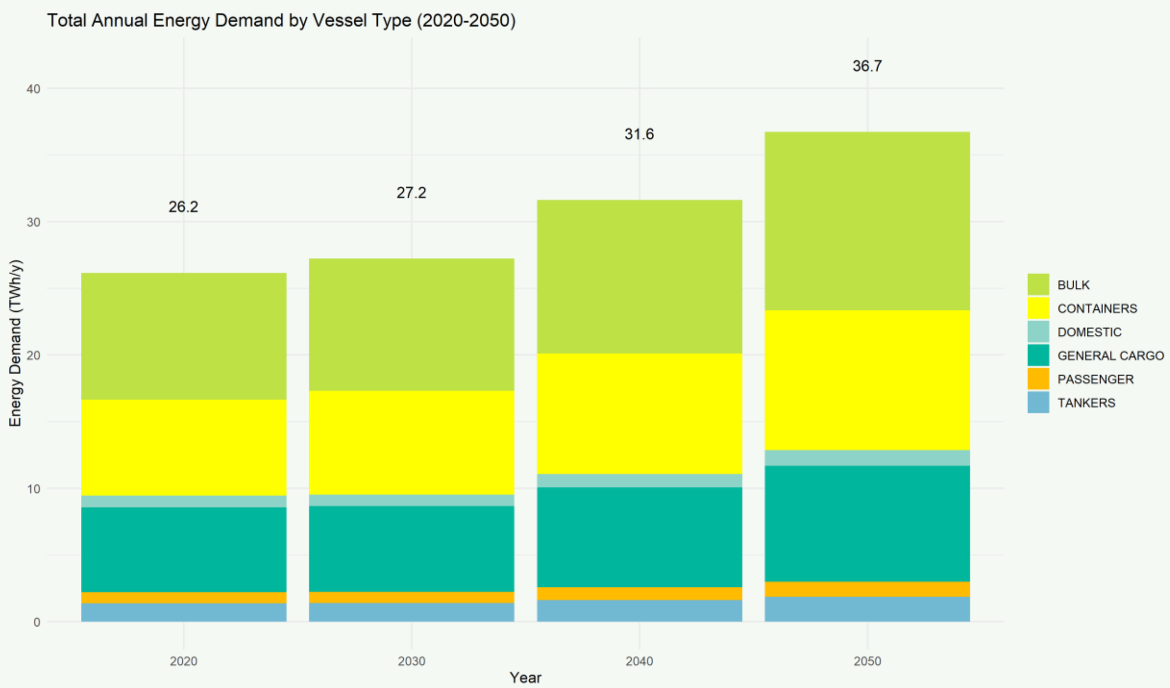

Figure 3: Own calculations

GREEN HYDROGEN SOUTH AFRICA
International PtX Hub
On behalf of:
Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany
IKI INTERNATIONAL CLIMATE INITIATIVE
Implemented by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HEAT

Important patterns in the distribution of energy demand are shown by the analysis:

Port Distribution: The Port of Durban accounts for the largest share (34%) of energy demand, followed by Richards Bay (19%) and Cape Town (17%) over the projection period (2020-2050).

Vessel Type Analysis: The vessel categories with the highest energy demands include bulk vessels (36%), containers (29%), and cargo vessels (24%), followed by other vessel categories. This granular vessel-type analysis is unique to the projection and provides important insights for targeted defossilisation efforts.

These findings highlight the significant energy demand at South Africa's largest ports, particularly for larger vessels. The potential for alternative marine bunker fuels, especially for the large, carbon-intensive vessel categories, is also underscored.

Overall, the TNPA data-based projections highlight the necessity for future energy planning and infrastructural investment, particularly in the context of South Africa's ambitions to defossilise its maritime sector and to provide green hydrogen-based fuels for the international maritime sector at its ports. They also provide a quantitative basis for priotising port-specific investment and sequencing infrastructure roll-out.

3.2.2. Ammonia or Methanol Proxy Demand Calculations

To estimate the potential demand for alternative marine bunker fuels, the next step involved converting the energy demand data into equivalent ammonia or methanol along with associated hydrogen estimates. For comparative purposes, it was assumed that all conventional fuel would be replaced by a green fuel alternative, with green ammonia or green methanol used as a representative proxy. The "domestic vessel" category was excluded from this estimation, as these vessels are more likely to transition to alternative green energy sources such as electricity and onboard battery systems, which are considered more suitable for short-haul operations (DNV, 2023).

It was initially considered to exclude 'tankers' as they predominantly transport fossil fuels, with some using LNG, however, considering that there is likely a chance that alternative fuel standards/ requirements could apply to tankers in the future, they were included in the analysis. Furthermore, a study by C-Job Naval Architects (2023) projects that from 2030 onwards, tankers could utilise ammonia both as cargo and fuel, effectively consuming the same product they transport. This dual functionality positions tankers as potential consumers of green ammonia, justifying their inclusion in the demand estimation alongside other vessel types.

Keeping all other assumptions constant, converting the total energy demand across SA ports and assuming 100% alternative fuel adoption translates to an increase in ammonia demand, ranging from 4.6 Mt/year in 2023, 5.1 Mt/year in 2030, 5.9 Mt/year in 2040 and finally 6.9 Mt/year in 2050 as can be seen in Figure *4*. Considering the ratio of hydrogen to the molecular mass of ammonia, this translates to hydrogen demand of 812 kt/year in 2023, 900 kt/year in 2030, 1Mt/year in 2040 and 1.2 Mt/year in 2050 as shown in Figure *4*.
Assuming all conventional fuel demand were replaced by green methanol instead of green ammonia, the resulting methanol demand would range from 4.3 Mt/year in 2023, 4.8 Mt/year in 2030, 5.5 Mt/year in 2040 and 6.5 Mt/year in 2050. Considering methanol's energy content of 19.9 GJ/ton compared to ammonia's 18.6 GJ/ton, and a hydrogen mass fraction of approximately 13% in methanol versus 18% in ammonia, this translates to an estimated hydrogen demand of 540 kt/year in 2023, 600 kt/year in 2030, 690 kt/year in 2040, and 811 kt/year in 2050.

The assumption of 100% adoption of green fuels from the present, however, is unrealistic, and not all energy demand will directly translate into ammonia, methanol or green hydrogen demand. These values are therefore only indicative of the potential fuel demands in the maritime sector in South Africa.

Ammonia and hydrogen demands in Mt/y based on a 100% alternative fuel adoption scenario Annual.

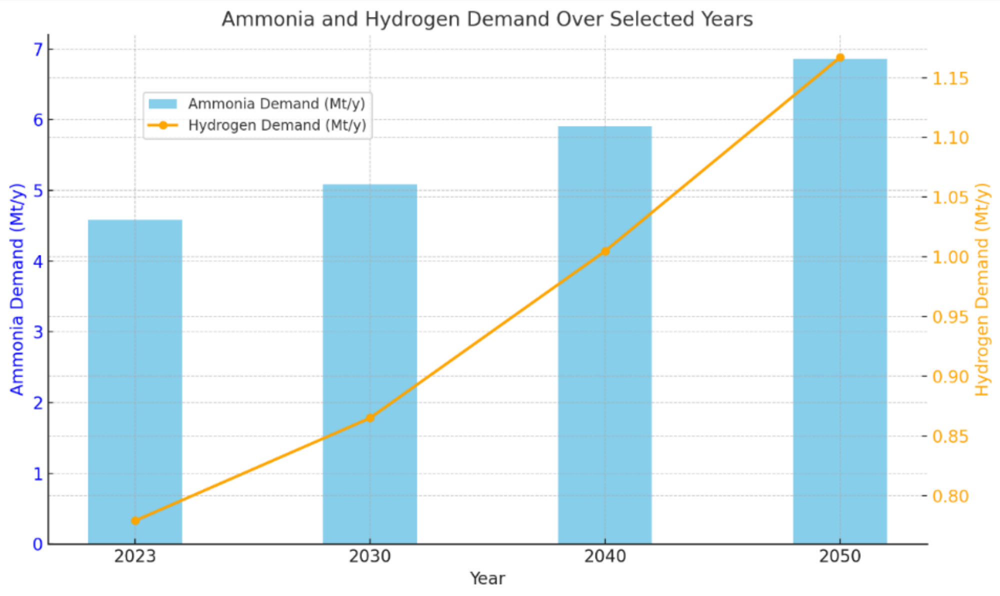

Figure 4: Own calculations

3.3. Environmental benefits

This section examines the environmental benefits of adopting alternative fuels in the maritime sector, focusing on emissions avoidance under different scenarios for green ammonia uptake. The analysis uses 2016 as the baseline emissions year (due to data availability, rather than the IMO's official 2008 baseline), with GHG emissions estimates derived from TNPA vessel traffic data recorded from that year. To be more specific, these are treated as the total annual GHG emissions from vessels call at South African ports. The analysis assumes that the global fuel mix applies to international vessels arriving at South African ports, as international traffic represents a significant portion (~82%) of total vessel arrivals.

The Well-to-Wake (WtW) emission factors provided by the IMO thereby form the basis of our calculations (IMO, 2024), which accounts for the entire life cycle of fuels, from extraction and production to conversion, transportation, and final use onboard ships. Our analysis considers a mix of green fuels and technologies adoption to meet IMO decarbonisation targets, comprising green ammonia, green methanol, waste-based biofuels comprising (Hydrotreated Vegetable Oil (HVO)) and Fatty Acid Methyl Ester (FAME)), alongside adoption of energy efficiency measures including wind-assisted propulsion systems, battery electrification for short-distance vessels, and waste heat recovery technologies.

Recent studies show that green fuels can deliver substantial, but not zero, well-to-wake (WtW) greenhouse-gas reductions. While green ammonia offers major tank-to-wake benefits, lifecycle emissions remain significant unless production is sourced entirely from renewable energy (DNV, 2024). Green methanol, when produced using renewable hydrogen and captured CO_2, can achieve deep WtW reductions—but actual emissions vary widely depending on feedstock quality and processing methods (ICCT, 2023). Waste-based biofuels—such as hydrotreated vegetable oil (HVO) and residue-derived FAME—typically deliver >80% reductions under optimal conditions, yet their WtW performance can be impacted by feedstock logistics, processing efficiency, and lifecycle accounting methods (DNV, 2019).

For this analysis, an idealised zero-emission factor is applied, assuming ammonia and methanol are produced entirely via renewable-powered electrolysis without fossil inputs, and biofuels are derived exclusively from sustainable waste streams. While peerreviewed studies show that residual well-to-wake emissions remain, this assumption illustrates the maximum mitigation potential of green fuels. The approach aligns with South Africa's renewable energy potential and available waste resources, while complementary measures—such as vessel efficiency improvements and alternative propulsion technologies—further reduce the maritime sector's overall emissions footprint.

The green fuels uptake projections are further aligned with the 2023 IMO GHG Strategy's defossilisation goals (IMO, 2023), which require that "zero or near-zero GHG emission technologies, fuels and/or energy sources represent at least 5%, striving for 10% of the energy used by international shipping by 2030." The strategy also calls for a 20–30% reduction in GHG emissions by 2030, a 70% reduction by 2040, and net-zero emissions by 2050. In addition to the Business-as-Usual (BAU) scenario, these three scenarios are tested to reflect the adoption of green ammonia in South Africa's maritime sector.

Scenarios	Description
BAU scenario	No uptake of green fuels, with a continuation of the current fuel mix
Scenario 1	IMO 5% Target: 5% uptake of green fuels by 2030
Scenario 2	IMO 10% Target: 10% uptake of green fuels by 2030
Scenario 3	IMO Net Zero Target: 100% adoption of green fuels to achieve net-zero emissions by 2050

This analysis determines South Africa's green fuels mix by following global market projections, as the local maritime sector will develop alongside international trends. While actual green fuel mix compositions may vary based on technological breakthroughs, policy changes, and market dynamics, this analysis models scenarios based on one of the currently available projections. DNV projects global ammonia demand for shipping at 2.3 MTPA in 2030, increasing to 62 MTPA by 2040 and 245 MTPA by 2050 (DNV, 2024a). By 2050, ammonia is expected to comprise 24% of the global maritime fuel mix (DNV, 2024b).

For 2030, with global maritime energy demand at 8.47 EJ (ClassNK, 2023), green ammonia will represent only 0.5% of the green fuels. The remaining IMO 5% target will be met through green methanol (1.5%) and sustainable biofuels & other technologies (3%).

Year	2030
Green Ammonia	0.5%
Green Methanol	1.5%
Biofuels & Other Technologies	3%

For the IMO 10% scenario in 2030, the green fuels mix shares are considered double: green ammonia (1%), green methanol (3%), biofuels & other technologies (6%).

Year	2030
Green Ammonia	2%
Green Methanol	3%
Biofuels & Other Technologies	6%

DNV's 2050 projections show green fuel mix reaching only 72% of the maritime fuel mix, falling short of IMO's net-zero target (DNV, 2024b). DNV projects 28% of fuel mix still relying on conventional fossil fuels. To bridge the gap between DNV's current projections and the IMO requirements, each fuel type and technology are scaled by the same scaling factor (1.389x) to reach 100%. This scaling assumes proportional growth across all green fuels, though actual deployment may favor specific fuels based on regional advantages and technological developments

Year	2050 (72%)	2050 (100%)
Green Ammonia	24%	33.3%
Green Methanol	12%	16.7%
Biofuels & Other Technologies	36%	50%

The graph in Figure *5* illustrates the four distinct emission trajectories from 2020 to 2050 based on varying levels of green fuel uptake, each representing different policy approaches with significantly divergent outcomes. The BAU scenario shows emissions steadily climbing to approximately 14 million $MtCO_2e$ by 2050, representing the consequences of climate inaction. In contrast, the IMO scenarios demonstrate varying levels of ambition and effectiveness. The IMO 10% by 2030 pathway achieves modest reductions, reaching about 12.5 million $MtCO_2e$ by 2050, while the slightly less ambitious IMO 5% by 2030 scenario results in emissions of roughly 13.5 million $MtCO_2e$ by the same year. Notably, the IMO net-zero by 2050 scenario follows a significantly different trajectory, showing steady and accelerating emissions reductions after 2025 until reaching net-zero by 2050. All scenarios depart from the base year near 12 million $MtCO_2e$ in 2016 and show an initial decline before diverging significantly from 2025 onward, with historical data (orange line) tracking actual emissions through approximately 2022. The initial decline observed from 2020–2024 partly reflects the impact of COVID-19 on maritime traffic and subsequent economic recovery patterns.

Projected GHG emission reduction under IMO scenarios (2020-2050) through the uptake of green ammonia.

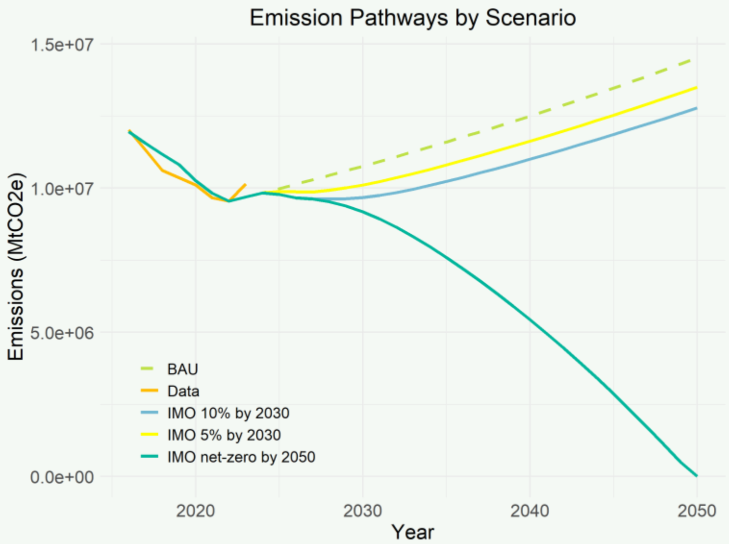

Figure 5: Own calculations

Figure 6 illustrates the projected maritime fuel demand and corresponding green hydrogen requirements across four scenarios through 2050. The first three graphs project the green fuel demand till 2050 with also showing the green fuel mix composition under three IMO scenarios, while the fourth graph shows the aggregated hydrogen demand needed to produce these green fuels.

Green hydrogen demand is calculated using the H_2 mass conversion ratios to fuel type: 0.17 tons of hydrogen per ton of green ammonia and 0.13 tons of hydrogen per ton of green methanol. The scenarios reveal starkly different trajectories. The Business-as-Usual (BAU) scenario maintains negligible green fuel adoption throughout the period, with hydrogen demand remaining at zero. This reflects the absence of regulatory drivers or economic incentives. Given the minimal values, this scenario is not displayed in the figure. The IMO 5% by 2030 scenario achieves its initial target with modest growth thereafter. By 2050, total green fuel demand reaches approximately 150 kt/year, dominated by biofuels and other technologies, with green ammonia comprising a small fraction. This translates to roughly 10 kt/year of green hydrogen demand, with certain demand coming from green ammonia and certain coming from green methanol based on fuel mix. The IMO 10% by 2030 scenario doubles the early adoption rate, reaching approximately 300 kt/year of green fuels by 2050. The fuel mix remains diverse, with biofuels and other technologies still dominant. Green hydrogen demand reaches approximately 20 kt/year by mid-century.

The IMO net-zero by 2050 scenario demonstrates exponential growth, particularly after 2040. Total green fuel demand surges to over 3.3 Mt/year by 2050, with green ammonia becoming increasingly dominant at approximately 33% of the mix. This ambitious pathway requires approximately 250 kt/year of green hydrogen—more than 12 times the 10% scenario—highlighting the massive infrastructure investments needed for full maritime decarbonisation.

With only 5-10% of the fleet adopting green bunker fuels and no additional policy interventions, trends indicate that emissions will continue to rise through 2050 relative to the baseline period used in the analysis (i.e., 2016) (Table 3). Therefore, additional policy measures are necessary to amplify the impact of existing efforts and increase adoption rates to achieve net-zero emissions.

Projected green fuel and hydrogen demand under IMO scenarios (2020-2050).

Figure 6: Own calculations

Table 3: Modelled GHG emissions in Mt/y CO_2 equivalent for the different scenarios.

Scenarios	2016	2024	2030	2040	2050
IMO 5%	12.0	9.8	10.1	11.6	13.5
IMO 10%	12.0	9.8	9.7	11.0	12.8
IMO Net Zero	12.0	9.8	9.2	5.4	0.0

The analysis further shows that the IMO's reduction targets, 20–30% by 2030, 70% by 2040, and 100% by 2050, could approach IMO-equivalent reduction trajectories if baseline year differences are accounted for with a consistent annual green fuel adoption rate of approximately 4.5% starting from 2025. This adoption rate is slightly higher than the projected growth of the global fleet, underscoring the need for stricter enforcement of zero- and low-carbon fuel mandates from 2030 onwards (Figure *5* and Table 4).

Table 4 presents the percentage change in GHG relative to the 2016 baseline of 12 Mt CO_2e, calculated using the formula [(future year GHG emissions – 2016 baseline) / 2016 baseline] × 100, where negative values indicate emission reductions and positive values represent increases above the baseline. The analysis shows a critical pattern where the IMO 5% and 10% scenarios achieve initial emission reductions by 2030 (-15% and -19% respectively), but these gains progressively diminish through 2040 (-3% and -8%) and ultimately leads to net increase in emissions by 2050 (+13% and +7%). This highlights how modest green fuel adoption rates are insufficient to offset continued fleet growth and maritime activity expansion over the projection period. Meanwhile, the net-zero scenario maintains consistent and accelerating emission reductions throughout the timeline (-25% in 2030, -55% in 2040, and -100% in 2050), indicating that only comprehensive decarbonisation through complete green fuel adoption can achieve sustained emission reductions and meet long-term climate objectives.

Table 4: Modelled change in GHG emissions in Mt/y CO_2 equivalent relative to the initial data point (2016).

Scenarios	2030	2040	2050
IMO 5%	-15%	-3%	13%
IMO 10%	-19%	-8%	7%
IMO Net Zero	-25%	-55%	-100%

While these results provide valuable insights into potential emission trajectories, the emission reduction and green fuel adoption pathways presented here depend on underlying assumptions, with the results only indicative of potential trends. It should be noted that the production of green fuels could follow many production pathways, each with different WtW emissions as shown in Schuller et al., (2024). Lastly, to increase the robustness of this analysis, additional historical data is required to accurately measure emission reduction targets relative to the IMO's baseline year of 2008. In the absence of 2008 historical data, this analysis is based on the relative contribution to the initial data point of 2016, which may affect direct comparability with international reduction targets.

Nonetheless, these scenarios provide an exploratory outlook for South Africa's maritime sector as it works towards the global transition to cleaner fuels. By addressing both the technological and logistical challenges, the adoption of green ammonia and other green maritime fuels can play a key role in defossilising the maritime sector.

The following section further addresses the cost considerations and the effects on the uptake of alternative bunker fuels. It will link these technical and environmental findings to economic feasibility and policy design

4. Cost-considerations

Green shipping fuel production costs in South Africa will strongly influence their adoption and competitiveness. This section outlines the current cost landscape for green hydrogen and Power-to-X (PtX) fuels in South Africa's maritime sector, while also examining the future cost projections and the role of policy interventions.

4.1. Current Production Costs

Green hydrogen production in South Africa currently faces significant cost challenges. Studies indicate that production costs range from USD 5-8/kg (approximately ZAR 89-143/kg), which is five times the cost of hydrogen derived from fossil fuels (Young & McGregor, 2024). These costs are largely driven by capital expenditures (CAPEX) for electrolysis plants and the cost of renewable electricity required for production. In addition, project risk profiles and financing structures further influence the realised levelized cost of hydrogen.

When converted into maritime fuels, these costs multiply. Green hydrogen-derived marine fuels can cost 1.4 to 4.3 times more than conventional marine fuels, depending on financing conditions, weighted average cost of capital (WACC), and project-specific variables (World Bank, 2024). The production of green ammonia and green methanol adds additional conversion costs, making green marine fuels significantly more expensive compared to traditional fuels in South African ports. This current cost premium is a central barrier to immediate large-scale adoption in the absence of trong policy or market incentives.

4.2. Future Cost Projections

International studies project substantial cost reductions in the coming years. The IEA's 2024 Global Hydrogen Review suggests that global low-emissions hydrogen production costs could fall to USD 2-9/kg by 2030—essentially halving current prices. This reduction would narrow the cost gap between green hydrogen and fossil hydrogen, making green hydrogen more competitive in global markets. These projections, however, are contingent on rapid deployment of electrolysers, reduction in technology costs, and sustained declines in renewable electricity prices.

The South African Green Hydrogen Commercialisation Strategy (GHCS) aligns with these projections, anticipating cost parity between green hydrogen and fossil fuels by 2030 (IDC, 2023). This projection assumes that technological advancements, economies of scale, and decreasing renewable energy prices will continue to drive down costs. If realised, such parity would fundimentally change the investment case for green marine fuels in South African ports and along associated value chains.

4.3. The Role of Carbon Pricing

Carbon pricing mechanisms could accelerate the transition to green fuels. The introduction of carbon levies would offset the cost premium of green hydrogen relative to diesel, making green fuels more economically viable. IRENA's 2024 study suggests that carbon levies could make green hydrogen and PtX fuels more competitive by effectively increasing the cost of fossil alternatives, thereby improving the economic attractiveness of renewable fuels (IRENA, 2024). In other words, carbon pricing can shift the market from viewing green fuels as high-cost option to a risk-hedging and compliance-oriented investment.

4.4. Challenges in Green Fuel Adoption for Maritime Transition

Even if cost parity is achieved by 2030, the total transition costs—which include infrastructure upgrades, port modifications, and operational adjustments—will remain a critical factor. Studies show that, while green hydrogen presents a promising solution for defossilisation, its high production costs relative to diesel remain a barrier to large-scale adoption, particularly in South Africa's maritime sector (Roos et al., 2022). Additional challenges include uncertainty around future fuel standards, technology lock in risks, and limited early offtakes guarantees.

In summary, while green hydrogen offers a promising solution to the maritime sector's defossilisation, achieving cost competitiveness will depend on policy interventions, including carbon levies and ongoing cost reductions in production. The total cost of transition—including infrastructure investments—will remain a significant factor influencing the feasibility of green fuel adoption in the maritime industry. Cost dynamics must therefore be considered alongside regulatory signals, investment incentives and just transition priotities when designing implementation pathways.

5. Investment and Financial Enablers

Having examined the energy demand and cost considerations for green hydrogen and PtX products in previous chapters, this analysis now turns to how South Africa can meet this demand and achieve cost competitiveness through strategic investments. This chapter looks into the investment landscape, funding mechanisms, and incentives at both national and international levels that can enable South Africa to realize its green hydrogen ambitions. It focuses on where capital come from, how it can minimise risks, and which investments instruments are most relevant for the maritime value chain. This chapter examines where capital will come from, how financial instruments can minimise risk, and which mechanisms are most relevant for enabling investments in green hydrogen and PtX production, port infrastructure and green shipping corridors.

5.1. Current Investment Landscape and Requirements

There is a pressing global need for investments to enable the green shipping transition. A recent study by MTBS & International Association of Ports and Harbors (IAPH) estimates that it will require between USD 1-2 trillion in global investments to achieve IMO's decarbonisation targets by 2050 (MTBS & IAPH, 2024). This investment spans across the entire maritime value chain—which includes zero-emission vessels, alternative fuel production, bunkering infrastructure, and port readiness. Mobilising such large-scale capital is complex and will require a blend of public and private financing, supported by innovative financial instruments and strong international cooperation to accelerate this transition. Concessional finances, blended finance structures, and green bonds are particularly important in this context.

South Africa holds strong potential to attract foreign investment for its green shipping transition. According to a study by Ricardo and EDF for the P4G Getting to Zero Coalition (2021), the adoption of zero-carbon propulsion technologies and fuel production systems could generate between ZAR 122 and 175 billion (USD 6.8–9.8 billion) in onshore investment by 2030. In parallel, the Global Maritime Forum (2022) estimates that developing scalable zero-emission fuel infrastructure at South

African ports could mobilise an additional ZAR 34 to 49 billion (USD 1.9–2.8 billion). These investments are expected to yield economic benefits well beyond the maritime sector—supporting industrial development, job creation, and enhancing South Africa's competitiveness in the global green economy. They also position South African ports as strategic nodes in global green shipping corridors.

Unlocking this investment potential will require strategic alignment between financing strategies, spatial development zones, and national policy frameworks. While South Africa is highly dependent on international climate funding and private sector partnerships, these efforts must be supported by Special Economic Zones (SEZs), which have already developed green hydrogen strategies (Saldanha IDZ, Coega IDZ, and Northern Cape). Supportive national policies aligned with the IMO's decarbonisation goals will strengthen South Africa's investment proposition, ensuring progress in green fuel production, digital port technologies, and green shipbuilding. Coherent communication across departments and clear pipelines will be important to build investors confidence.

5.2. Special Economic Zones as Investment Catalysts

According to the DTIC (Department of Trade and Industry), which serves as the custodian of the SEZ policy legislation and programme, SEZ programme represents one of the critical tools for accelerating the country's industrial development agenda. The programme was mandated through the SEZ Act, which was proclaimed on February 9, 2016 (DTIC, 2016).

SEZs are strategically designed to serve multiple development objectives and help (DTIC, 2021a):

i) promote industrial agglomeration.
ii) build the required industrial infrastructure.
iii) promote coordinated planning among key government agencies and the private sector.
iv) guide the deployment of other necessary development tools.
v) provide financial investment cash flow benefits.
vi) boost exports.

SEZs in South Africa are therefore purposefully designed regions that aim to attract investments and foster economic growth, with existing SEZs having developed strategies specifically for green hydrogen production (see Table 5). Each zone offers specific infrastructure and incentives that make them particularly attractive for various industries, including production of green hydrogen and PtX products. With their focus on infrastructure development, tax incentives, and streamlined logistics, SEZs are positioned as critical tools for establishing South Africa as a competitive player in the global green energy market. The SEZs function as anchor locations for first mover of green hydrogen projects

In the context of green hydrogen and PtX products such as methanol and ammonia, SEZs offer several key advantages:

Renewable Energy Resources: Many SEZs are strategically located in regions with high solar and wind potential, which are crucial for low-cost, sustainable green hydrogen production. Proximity to renewable energy resources in zones such as Coega and Boegoebaai ensures access to low-cost green electricity, a key input for electrolysis (CSIR, 2023). Since both green methanol and green ammonia rely on green hydrogen as a feedstock, access to renewable energy resources is essential for reducing production costs and ensuring alignment with South Africa's environmental targets.

Proximity to Port Infrastructure: SEZs provide critical access to port infrastructure, which is essential for exporting hydrogen-based products to international markets. SEZs near major ports, such as Saldanha Bay, Coega/Ngqura, and Richards Bay, provide direct access to export routes for green hydrogen, methanol, and ammonia. With deep-water access, these ports can accommodate large vessels for transporting bulk quantities, enhancing South Africa's position as a supplier of green fuels to international markets. The planned Boegoebaai deep-water port will further support these exports, allowing for expanded export capacity and reducing logistical bottlenecks (DTIC, 2021a, Transnet, 2023).

Financial Incentives: SEZs offer streamlined regulatory processes and comprehensive financial incentives that significantly reduce the cost of establishing green hydrogen facilities:

- Preferential corporate tax rate of 15% (compared to the standard 28%)
- Accelerated depreciation allowances on capital structures (buildings)
- Customs duty and VAT exemptions for qualifying businesses
- Employment tax incentives for businesses hiring employees earning below ZAR 60,000 per annum

These incentives help reduce both CAPEX and OPEX costs for green hydrogen, methanol, and ammonia investments, making SEZs an attractive option for scaling up production (DTIC, 2021a). They also support earlier project bankability by improving projects cash flows in the initial years of operation.

Value Chain Advantages: SEZs encourage clustering of industries, enabling co-location of electrolysers, ammonia plants, and transport infrastructure for improved efficiency (IRENA, 2022). This clustering effect supports the development of integrated value chains that can optimize costs and operational efficiency.

Green Shipping Corridors: Their proximity to the ocean positions most SEZs to support the development of hydrogen corridors that link production to consumption hubs globally, facilitating the creation of green shipping corridors (IRENA, 2022).

The stakeholders engaged in the study expressed concern about the feasibility and practicality of enabling the SEZ's potential for green hydrogen production and the mechanisms required to address high capital and infrastructure costs. This is noteworthy, as the study found that the infrastructure required for green hydrogen, methanol, and ammonia production, such as electrolysers, carbon dioxide capture and storage systems, and nitrogen separation units, is capital-intensive. The assumption, nonetheless, is that while SEZ incentives provided through their policy will reduce some costs, the upfront capital investment remains high, potentially limiting smaller investors' ability to enter the market.

However, considering that investors will require the most favourable return on investments, and that imports of machinery, infrastructure, and potentially feedstock raw materials will be prevalent, these may attract import duty costs and VAT payments at the time of import. Under the SEZ framework, Schedule 4, item 498.01, in relation to Section 21A of the Customs Act, it rebates all duties and Schedule 1 exemptions of the VAT Act, permitting the non-payment of VAT, enabling large cash flow benefits and lowering the requirement for capital cash flow investments. This enhances the financial attractiveness of large-scale hydrogen and PtX projects located within the SEZs boundaries.

Table 5 presents the current and planned SEZ investments for green hydrogen production capacity, demonstrating South Africa's strategic positioning in the emerging global green hydrogen economy. These projects represent a combined investment of over USD 8 billion and showcase the scale of ambition in developing South Africa's green hydrogen export capabilities.

The Saldanha Bay IDZ hosts the Saldanha Green Hydrogen project, which represents a relatively moderate entry point with 85 kt/year green hydrogen production capacity (equivalent to 500 kt/year ammonia) powered by approximately 2.5 GW of renewable energy. With a projected CAPEX of USD 2.5 billion and target startup in 2026, this project demonstrates the near-term viability of green hydrogen production in South Africa's established industrial zones.

Coega SEZ (Ngqura) features the most ambitious project in the pipeline - Hive Hydrogen's facility targeting over 1 Mt/year green ammonia production, requiring approximately 3.31 GW of renewable energy capacity (Hive Energy, 2025). The USD 5.8 billion investment with a 2029 startup target represents the largest single green hydrogen investment commitment in South Africa to date, highlighting the Port Elizabeth region's potential as a major green hydrogen hub.

The Boegoebaai project in the Northern Cape, a joint venture between Sasol and the Industrial Development Corporation (IDC), targets 400 kt/year green hydrogen equivalent production with a 2028 startup timeline. While the CAPEX remains undisclosed pending ongoing feasibility studies, this project is particularly significant as it represents established industry players' commitment to green hydrogen and could leverage Sasol's existing synthetic fuels expertise.

These SEZ-based developments collectively demonstrate how South Africa's IDZ are being repositioned as green hydrogen production hubs, leveraging existing port infrastructure, industrial expertise, and preferential investment conditions to attract large-scale green hydrogen investments that will position the country as a major player in the global green hydrogen trade. For the maritime sector, these hubs are also potential anchor points for future bunkering and green shipping corridor initiatives.

Table 5: Production capacity of key ports

SEZ/Port	Project Name	Projected production capacity	Indicative CAPEX (USD billion)	Target start-up year	Reference
Saldanha Bay IDZ	Saldanha Green Hydrogen	85 kt/y GH_2 (→ 500 kt/y ammonia), powered by ~2.5 GW renewable energy	2.5	2026	(Engineering News, 2024)
Coega SEZ (Ngqura)	Hive Coega Green Ammonia	1 Mt/y green ammonia (requiring ~3.31 GW of renewable energy)	5.8	2029	(Hive Energy, 2025)
Boegoebaai (Northern Cape)	Boegoebaai Green Hydrogen Port	400 kt/y- GH_2 equivalent	n/a (Feasibility study ongoing)	2028	(Sasol, 2021)

5.2.1. Regulatory Framework and Eligibility

The DTIC advocates for SEZs by establishing design and eligibility criteria for each incentive to balance achieving higher levels of investment, growth, and employment creation while ensuring incentives are appropriately targeted for efficiency and minimizing deadweight loss to the fiscus.

Businesses located within a Customs Controlled Area (CCA) of an SEZ qualify for VAT and customs relief. The employment tax incentive (ETI) is available to businesses located in any SEZ. Businesses operating within approved SEZs (approved by the Minister of Finance, after consultation with the Minister of Trade, Industry and Competition) are eligible for additional tax incentives. First, such businesses can claim accelerated depreciation allowances on capital structures (buildings) and, second, certain companies (carrying on qualifying activities within an approved SEZ) benefit from a reduced corporate tax rate (i.e., 15% instead of 28%).

Regarding socio-economic advantages, all employers of low-salaried employees (below ZAR 60,000 per annum) in any SEZ are entitled to the employment tax incentive. This aims to encourage employers to hire young and less experienced work seekers, with the employee age restriction not applying to SEZs. It reduces an employer's cost of hiring people through a cost-sharing mechanism with Government, while leaving the employee's wage unaffected. The employer may claim the ETI and reduce the amount of Pay-As-You-Earn (PAYE) tax payable by the amount of the total ETI calculated for all qualifying employees.

This SEZ investment enablement facilitates employment creation and skills transfer. The Atlantis SEZ in the Western Cape, as published by the DTIC, promotes itself for five reasons for the renewable energy and green technology sector:

i) Strong and growing South African and African markets for green technology
ii) Well-located and development-ready area
iii) Strong support base and existing relationships for investors
iv) One-Stop-Shop for wide-ranging investor support
v) Comprehensive incentives for investors and tenants

However, companies engaged in certain activities, based on the Standard Industrial Classification Code issued by Statistics South Africa, will not qualify for the building allowance:

- Spirits and ethyl alcohol from fermented products and wine (SIC code 3051)
- Beer and other malt liquors and malt (SIC code 3052)
- Tobacco products (SIC code 3060)
- Arms and ammunition (SIC code 3577)
- Biofuels if that manufacture negatively impacts on food security in South Africa

As such, biofuel industries will require environmental compliance. The aspect of compliance on a policy level affects both national and international mandates and is discussed further in the following section. This regulatory framing is important for investors to understand which activities qualify for SEZs related tax benefits and which do not qualify.

5.3. Policy Drivers for Green Hydrogen Investment

The transition toward green hydrogen in shipping and other hard-to-abate industries will require substantial long-term investment. Securing this investment depends on more than technological readiness alone. It requires clear and predictable policy frameworks that reduce risk for investors, generate demand for low-carbon fuels, and create the conditions for market growth.

At the international level, several policy drivers are already shaping investment decisions. Environmental standards such as the International Maritime Organization's (IMO) net-zero strategy and the European Union's FuelEU Maritime regulation are creating binding requirements for the use of low-carbon fuels. In parallel, fiscal instruments such as carbon pricing, tax incentives, and preferential financing are being introduced to reduce the cost burden of early projects. Just as importantly, frameworks that guarantee investment security—through transparent permitting, long-term offtake agreements, and predictable regulation—are enabling large-scale capital commitments in hydrogen production and related infrastructure.

For South Africa, these dynamics present both opportunities and challenges. Domestically, the Hydrogen Society Roadmap and the development of green hydrogen Special Economic Zones, such as Coega and Boegoebaai, signal strong governmental support and provide dedicated infrastructure for future projects. At the same time, integration with global markets—particularly Europe and Asia—offers an export pathway that can anchor local demand and strengthen investor confidence. By combining national policy instruments with alignment to international compliance frameworks, South Africa can position itself as a competitive hub in the emerging green hydrogen economy.

Ultimately, investment will flow where there is policy certainty, predictable demand, and credible long-term planning. For South Africa, this means translating high-level strategies into concrete measures that attract capital, build industrial capacity, and ensure that green hydrogen contributes not only to decarbonisation but also to economic growth and job creation. This includes clear timelines, sector specific roadmaps and coordinated implementation across energy, transport, and industrial policy domains.

5.4. Carbon Taxation and Maritime Investment Impacts

Carbon taxation has become one of the most widely adopted policy tools to drive decarbonisation. By placing a price on greenhouse gas emissions, governments aim to shift investment toward cleaner fuels and technologies while discouraging continued reliance on carbon-intensive energy sources. For South Africa, the Carbon Tax Act of 2019 forms the backbone of this approach and signals the government's intent to align domestic policy with global climate objectives.

The current South African carbon tax applies mainly to stationary sources of emissions and domestic fuel combustion. While international shipping is not directly taxed under the Act, the maritime sector is still indirectly affected. Rising domestic fuel levies increase operating costs for port activities, bunkering, and coastal shipping, while energy-intensive exporters—such as steel, cement, and chemicals—face growing exposure. Since these industries drive a large share of South Africa's maritime trade, their competitiveness under a rising carbon price directly influences shipping volumes and port throughput.

At the international level, developments such as the European Union's Carbon Border Adjustment Mechanism (CBAM) and ongoing discussions at the International Maritime Organization (IMO) add another layer of complexity. CBAM will impose carbon costs on imports of carbon-intensive goods into Europe, creating both risks and opportunities for South African exporters. If these industries are unable to decarbonise, shipping demand could decline; conversely, successful adoption of low-carbon production methods could strengthen South Africa's position in international markets and generate new green trade flows.

Looking forward, the prospect of a global carbon levy on shipping—currently under discussion at the IMO—could reshape cost structures across maritime trade. For South Africa, this would reinforce the importance of investing in low-carbon port infrastructure, green bunkering facilities, and competitive renewable fuel production, such as green hydrogen and ammonia. In this way, carbon taxation, both domestic and international, is not only a compliance challenge but also a strategic driver of long-term investment in the maritime sector and its role in South Africa's green economy transition. It sharpens the business case for early movers in green maritime fuels and related infrastructure.

5.4.1. Overview of the South African Carbon Tax Act and its Investment Implications

The foundation of South Africa's carbon pricing policy is the Carbon Tax Act (Act No. 15 of 2019), which imposes a tax on the carbon dioxide equivalent of greenhouse gas emissions. The fundamental principle underpinning this legislation is the "polluter pays" principle, asserting that those responsible for generating emissions should bear the costs associated with their environmental impact.

The Act covers a range of key greenhouse gases, including carbon dioxide, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons, and sulphur hexafluoride. The initial phase of the tax primarily targets emissions from fossil fuel combustion, industrial processes, and fugitive emissions. Implementation is occurring in phases, with the first phase spanning from June 2019 to December 2025, and the second phase commencing in 2026.

Emissions generated from South African port-based activities, such as cargo handling equipment operation, terminal operations, and industrial processes conducted within port areas, could potentially be subject to the carbon tax if they exceed the established threshold. The Carbon Tax Act applies to entities operating emissions generation facilities with a combined installed thermal capacity equal to or above 10 MW for combustion activities. Port authorities and companies operating within ports often utilize significant energy for operations, and if these operations involve fuel combustion exceeding the threshold, they would likely be considered liable for the carbon tax.

Regarding the applicability to foreign vessels, the SARS FAQ document on Carbon Tax clarifies that: "The carbon tax design hinges on the greenhouse gas emissions reporting to The Department of Environment, Forestry and Fisheries (DEFF) under its National Atmospheric Emissions Inventory System (NAEIS). In general, therefore, the carbon tax applies to those persons (legal entities) that are required to report their greenhouse gas emissions to DEFF and Fisheries under NAEIS. As foreign ships fall outside the scope of this DEFF emissions reporting obligation, they by implication also fall outside the scope of the carbon tax." This explicit exemption means international shipping is not directly subject to South Africa's domestic carbon tax regime. However, the carbon tax framework indirectly influences the maritime sector in two significant ways:

1. The South African government has increased the carbon fuel levy on petrol to 11 cents per litre and on diesel to 14 cents per litre, effective from April 2024. This increase impacts operational expenses of domestic shipping companies relying on these fuels for smaller vessels and port-based transport such as trucks and harbor tugs. While large international shipping vessels typically procure bunker fuel outside South Africa, the increased cost of petrol and diesel raises operating costs for land-based logistics and domestic maritime activities integral to the overall functioning of the maritime sector in South Africa.
2. Discussions and proposals for a global carbon levy on shipping are actively underway within the IMO, with proposed levies ranging significantly from USD 18 to over USD 300 per ton of carbon dioxide equivalent. Implementation of such a levy would substantially increase operational costs for international shipping companies calling at South African ports, potentially leading to increased freight rates, reduced international trade, and GDP impacts.

Considering these global and national developments, entities must monitor and report their emissions and potentially incur carbon tax costs, thereby incentivizing adoption of more energy-efficient technologies and practices within port operations. South Africa's tax framework should be considered emerging and likely to follow more stringent global trends, creating an investment environment that increasingly favours low-carbon solutions like green hydrogen.

For investors in green hydrogen and related maritime infrastructure, this evolving carbon pricing landscape presents both challenges and opportunities. While the current carbon tax primarily affects domestic operations, the trajectory toward more comprehensive carbon pricing creates a clear long-term investment signal favouring clean fuel alternatives. Strategic investments in green hydrogen production and distribution infrastructure now position stakeholders to capitalize on the inevitable transition toward a carbon-constrained maritime economy. For the maritime sector, aligning investments decisions with trajectory can reduce future regulatory risk and enhance long-term competitiveness.

6. Socio-Economic Impacts of Green Maritime Transition

South Africa's maritime economy includes a range of activities from maritime shipping (transport), marine manufacturing, offshore oil and gas exploration as well as fishing and aquaculture. These sub-sectors contribute directly to South Africa's GDP at varying degrees as enumerated in the Operation Phakisa overview launched in July 2014 to unlock the economic potential of South Africa's oceans (DEA, 2014). The maritime shipping sector holds particular significance in the context of this study, as it is closely linked to vessel traffic and the bunkering industry - both of which require a shift towards green energy to address GHG emissions.

This section of the study provides a socio-economic analysis of the maritime transport sector's transition to low-carbon operations, with a focus on the integration of green hydrogen technologies. It assesses potential revenue generation, and the contribution of green hydrogen-related industries to GDP across the maritime value chain. In addition, it considers distributional impacts on employment, skills, and local communities, ensuring that economic opportunities are evaluated alongside just transition

6.1. South Africa's Maritime Economy

South Africa's strategic geographic position servicing major global shipping routes leverages a competitive advantage for its role in international trade, with the maritime economy contributing approximately USD 6.3 billion annually (Abhold & Shaw, 2022). This substantial economic contribution operates on the back of a connected port system that enables efficient trade flows, particularly in mineral exports.

Nonetheless, South Africa's economy has been underperforming, growing at a rate of about 1% over the past decade, with severe socio-economic challenges, such as high unemployment 34.9% as of 2021 (Stats SA, 2021), 32.1% in 2024 (Stats SA, 2024) and rising again to 33.2% in Q2 2025 (Stats SA, 2025). The country continues to face deep-rooted inequality represented by the highest Gini coefficient in the world at approximately 0.67, a measure of income inequality where 0 indicates perfect equality and 1 indicates maximum inequality. This structural inequality continues to limit inclusive growth and equitable participation in emerging green sectors.

The COVID-19 pandemic and climate-related disruptions have worsened poverty levels globally, intensifying the urgency for sustainable economic reforms. While unemployment remains critically high, the renewable energy sector presents significant opportunities for job creation as global transitions toward clean energy accelerate (IRENA, 2024). This shift is relevant to the maritime value chain, where ports infrastructure, shipbuilding, and fuel supply offer pathways for new green employment.

Against this backdrop, green hydrogen has emerged as a transformative opportunity for South Africa's maritime and broader economic system. Leveraging its abundant renewable energy, export-ready ports, and growing global demand for low-carbon fuels, South Africa can position itself as a strategic producer and exporter of green hydrogen and PtX products—particularly green ammonia. These opportunities extend beyond export revenue, offering a chance to stimulate coastal economies, develop green skills, and re-industrialise ports adjacent zones. The next chapter explores the projected macroeconomic contributions of green hydrogen to South Africa's GDP and employment base.

6.1.1. Green Hydrogen's Contribution to GDP

South Africa is well-positioned to capture a substantial share of the global hydrogen economy over the long term (DSI, 2021; CSIR, 2021/2022). These projections are summarised in Table 6 and draw primarily on modelling conducted by the World Bank (2024) and the Millennium Institute (2023).

Table 6: Economic impact projection of South Africa's green hydrogen economy

Metric	Value/Projection by 2050	Source
Contribution to national GDP (2050)	3.6%	The Presidency Republic of South Africa 2023
Job creation (range)	200,000 – 556,000	Millennium Institute, 2023
Maritime sector specific jobs	380,000	The Presidency Republic of South Africa 2023
Projected GH_2 consumption	1.1 – 6.4 million tons per year	Millennium Institute, 2023
Projected industry value	ZAR 77 – 370 billion (USD 4.5 – 22 billion) annually	World Bank, 2024
Revenue from pure GH_2	ZAR 14 – 45 billion (USD 820 million – 2.6 billion) per year	Millennium Institute, 2023

Insights from stakeholder consultations at PetroSA and SASOL further indicate that existing fossil-based production facilities offer a ready-made platform for transition—allowing for reskilling and upskilling of existing labour forces in preparation for green hydrogen-based production. This pathway is particularly important for ensuring a just transition that safeguards existing jobs while building capacity in new industries.

Based on scenario analysis from the World Bank (2024) and the Millennium Institute (2023), the annual demand for green hydrogen and PtX products—including ammonia, synthetic methane, and synthetic diesel—is expected to reach between 1.1 and 6.4 million tons by 2050. This level of demand translates into a projected industry value of between ZAR 77 billion and ZAR 370 billion annually (USD 4.5 billion–USD 22 billion). This figure is equivalent to approximately 15% of South Africa's current GDP, signifying that green hydrogen could evolve into one of the nation's most important industrial and export sectors by mid-century.

6.1.2. Green Ammonia's Revenue Assessment

While green hydrogen presents economy-wide opportunities, the maritime sector emerges as one of the most immediate and high-impact application areas—particularly through the adoption of green hydrogen derived fuels i.e. green ammonia and green methanol. This section focuses specifically on green ammonia, assessing its revenue generation potential and estimated contribution to South Africa's national GDP. Green ammonia is priorotised because it aligns with IMO decarbonisation pathways and can be directly applied as a maritime fuel or as an energy carrier for hydrogen exports. This analysis applied the same scenario framework used in the earlier chapter to model GHG emission reduction pathways and green ammonia and hydrogen uptake projections.

To model realistic export-market revenue outcomes, the analysis relied on international fuel price projections from Lloyd's Register & UMAS (2020). While other studies such as Roos, 2021 provide reasonable estimates for domestic cost, the former provides forward-looking international price benchmarks, making it appropriate for assessing export-driven revenue potential. This ensures consistency with global cost competitiveness assessments and reflects South Africa's positioning as a potential green fuel exporter rather than solely a domestic supplier. The international fuel price of green ammonia is hence derived from the levelised cost of production, an appropriate proxy for market-based pricing. This distinction is crucial in determining whether South Africa can competitively supply green ammonia to global markets at commercially viable price points.

Figure 7 illustrate the estimated revenue generation and corresponding GDP contribution, based on the application of lower and upper bound green ammonia price projections (see table 8) reported by Lloyd's Register & UMAS (2020). These price estimates were applied to the projected ammonia demand under three IMO-aligned decarbonisation scenarios: i) 5% uptake, ii) 10% uptake, and iii) net-zero pathway (see table 7). To ensure consistent valuation, ammonia demand (in tons per year) was converted to gigajoules (GJ) per year using an energy density of 18.65 GJ/ton and monetised using the respective international price bounds (USD/GJ).

Table 7: Total energy demand based on ammonia fuel (GJ/yr)

Scenario	2025	2030	2040	2050
IMO 5%	22113	184138	262746	305587
IMO 10%	44226	368276	525493	611175
IMO Net Zero	147273	1919172	9553286	20148717

Table 8: Price schedule for green ammonia

Green ammonia fuel price (USD/GJ)	2020	2030	2040	2050
Lower bound	55	47	39	30
Upper bound	96	82	68	55

Revenue contribution as a percentage to national GDP was calculated using real GDP data from the World Bank (see table 9) and projections were forwarded to 2050.

Table 9: World bank real GDP values

Year	2025	2030	2040	2050
GDP (billion USD)	376	401	455	499

Projected green ammonia revenue generation and contribution to GDP under IMO scenarios (2020-2050).

Figure 7: Own calculations

Table 10: Estimated revenue generation of a green ammonia share of ~33% of total green-fuel demand by 2050

** Values refer only to the ammonia share (~33 %) of total green-fuel demand; other e-fuels are excluded from this revenue estimate; energy density = 18.65 GJ/ton*

Scenario	Revenue (Lower Bound)	Revenue (Upper Bound)
IMO 5% Scenario	USD 9.2 million	USD 16.8 million
IMO 10% Scenario	USD 18.3 million	USD 33.6 million
IMO Net Zero Scenario	USD 0.6 billion	USD 1.1 billion

Under the IMO 5% scenario, estimated annual revenue for South Africa from green ammonia production ranges from USD 9.2 million to USD 16.8 million, contributing approximately 0.002% to 0.003% of national GDP. In the IMO 10% scenario, revenues nearly double, reaching USD 18.3 million to USD 33.6 million, with a GDP contribution of 0.004% to 0.007%.

The low GDP share reflects that the analysis is based on current port-to-call activity rather than potential expansion into a regional bunkering hub. Under the IMO Net Zero scenario, green ammonia energy demand could reach roughly 20 million GJ per year by 2050. This could generate between USD 0.6 billion and USD 1.1 billion in annual revenue, contributing up to 0.2% of South Africa's GDP by 2050. The vessel mix, dominated by bulk carriers and container ships making routine cargo calls, typically involves minimal bunkering for next-leg voyages rather than the substantial refueling volumes seen at major hubs such as Singapore or Rotterdam. This highlights the strategic potential for South Africa to reposition selected ports particularly Coega and Saldanha as competitive green fuel bunkering centres.

Additionally, the 8,970 annual vessel calls represent existing traffic serving South African trade, not the induced demand that competitive green fuel pricing would attract from vessels specifically diverting for bunkering. A true hub analysis could model South Africa capturing additional market share from the 245 MTPA global ammonia demand projected for 2050, potentially increasing revenues by five-tenfold through strategic positioning along major shipping routes.

Also, similar study from World Bank, project around 3.2 million tons of ammonia demand from passing vessels by 2050, which could correspond to potential revenues of USD 1.79 – 3.28 billion considering the projected price range of USD 30–55 per GJ (World Bank, 2024). This range is roughly three to six times larger than the current Net Zero port-of-call estimate and highlights the scale of opportunity if South Africa develops into a dedicated green-fuel bunkering hub. To validate the revenue projections discussed above, it's useful to examine specific project economics from ongoing project. The Hive Coega green ammonia project provides a concrete example of achievable revenue potential within the South Africa's investment context.

The project, developed by Hive Hydrogen SA (a joint venture between Hive Energy UK and BuiltAfrica), targets production of 1 million tons of green ammonia annually at the Coega SEZ. According to Reuters(2025), the project aims for production costs of USD 650 per ton, positioning it competitively against global green ammonia benchmarks of USD 760 per ton. At these cost levels, the Coega project demonstrates the commercial viability of large scale green fuel exports and provides a replicable model for similar developments across South Africa's SEZ networks.

Hive Coega Green Ammonia Project Economics

Production Capacity: 1 million tons green ammonia annually
Pricing:

- Production cost target: USD 650/ton (Reuters, 2025)
- Global benchmark: USD760/ton (Reuters, 2025)
- Market comparison: USD 906-1,054/mt delivered globally (S&P Global, 2024)

Revenue Potential:

- Annual: USD 650-760 million
- Five-year: USD 3.25-3.8 billion

Investment: USD 5.8 billion total project value (H2 View, 2025)
Timeline: Commercial operations Q4 2029

Technical and Economic Validation:
The project's technical specifications include 1.12 GW of electrolyser capacity powered by 3.31 GW of integrated renewable energy (1.88 GW wind and 1.43 GW solar), demonstrating the scale required to achieve cost-competitive green ammonia production (Hive Energy, 2025). The USD 5.8 billion project has secured Strategic Integrated Project status from the South African Presidency and received USD 20 million in development funding from the SA-H2 Fund (H2 View, 2025).

Current market analysis shows South African production costs significantly below delivered green ammonia costs in major global markets, positioning the country favorably due to abundant renewable resources, strategic port location, and Special Economic Zone incentives (S&P Global, 2024).

The HIVE Coega project demonstrates that individual facilities can achieve substantial revenues, validating South Africa's potential to develop as a major green ammonia export hub rather than merely serving passing maritime traffic. The project's scale and cost positioning indicate that South Africa can compete effectively in global green

6.2. Maritime PtX Value Chain Analysis

The Maritime Power-to-X (PtX) value chain describes the entire chain of activities required to produce, convert, transport, store and utilise green hydrogen and PtX products for maritime applications. For South Africa, this value chain leverages the country's unique comparative advantages, including abundant renewable energy and mineral resources, existing industrial expertise and strategic positioning between the Indian and Atlantic Oceans. The PtX value chain is not only an industrial process but also a strategic framework for reconfiguring South Africa’s maritime economy towards decarbonisation and competitiveness. The study identifies five integrated stages in South Africa's PtX value chain for maritime applications, each representing distinct industrial sectors and economic opportunities:

Stage 1: Upstream Renewable Energy & Green Hydrogen Production

This foundational stage establishes the core infrastructure and production capacity for green hydrogen. It includes developing large-scale solar and wind farms leveraging South Africa's exceptional renewable resources (DMRE, 2022), upgrading electrical grid infrastructure to handle distributed generation, and building coastal desalination plants to supply water for electrolysis. Energy storage systems, including grid-scale batteries and pumped hydro storage, ensure continuous hydrogen production despite renewable energy intermittency, enabling 24/7 electrolyser operation. The stage encompasses establishing green hydrogen production facilities through water electrolysis, utilising South Africa's platinum reserves used for PEM electrolyser catalysts for electrolyser manufacturing, and developing hydrogen production hubs at ports such as Boegoebaai, Saldanha Bay, and Coega (DTIC, 2023). This infrastructure (upstream stage) forms the essential feedstock for all downstream green maritime fuel production.

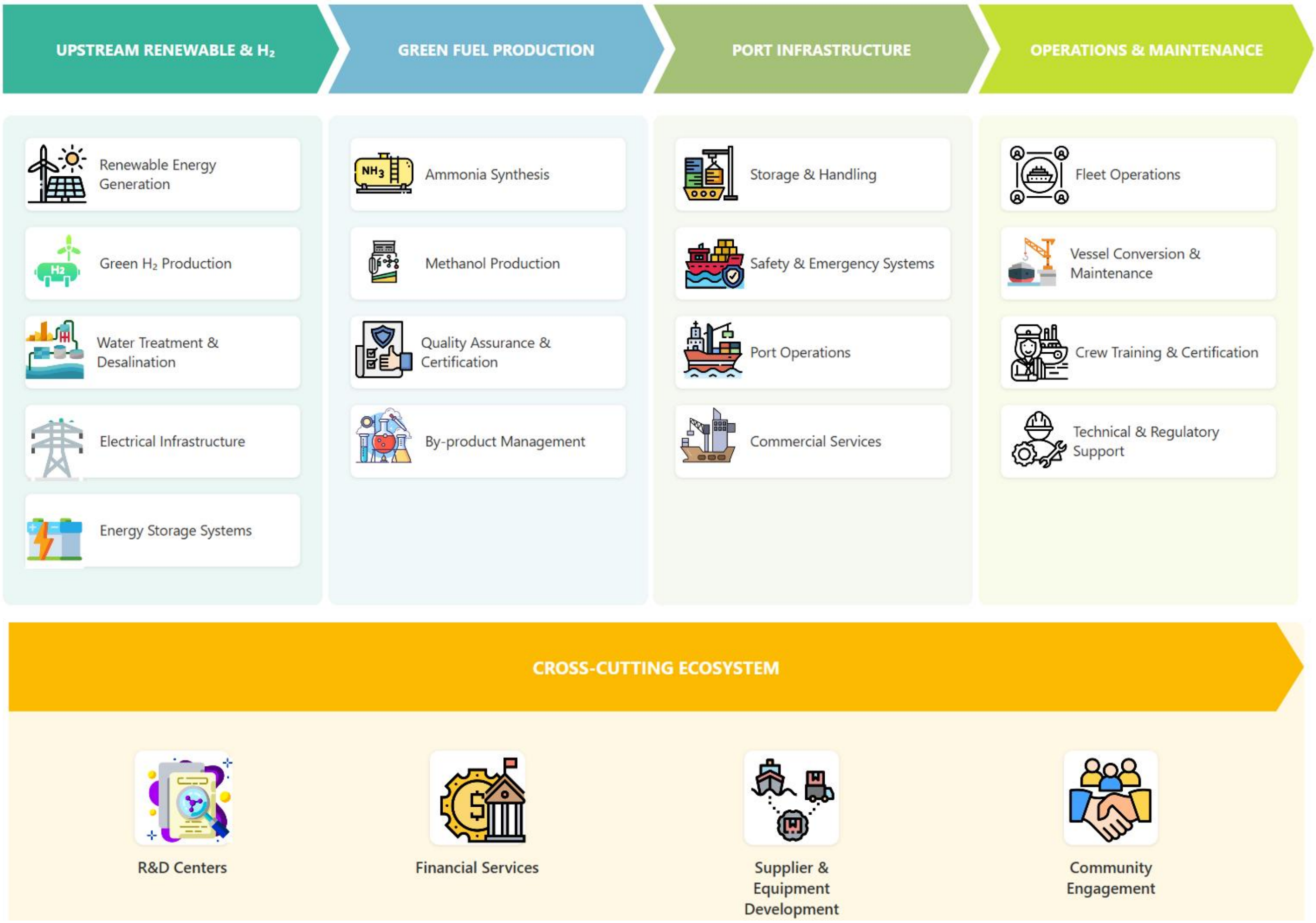

Figure 8: PtX Maritime value chain, adapted and modified from IRENA (2020), Green Hydrogen: A guide to policy making, International Renewable Energy Agency, Abu Dhabi

Stage 2: Green Fuel Production & Processing

This stage converts green hydrogen from Stage 1 into maritime-ready fuels through chemical synthesis. This stage is critical because pure hydrogen is impractical for shipping - it requires cryogenic storage at -253°C or extreme compression. Green ammonia and methanol, synthesised using nitrogen or captured carbon are preferred PtX products for maritime defossilisation because they produced in this stage, can be stored manageable temperature and pressure conditions, used to adapted versions of existing oil and gas handling infrastructure and offer high volumetric energy density and safety compared to liquefied hydrogen. This stage thus represents the bridge between renewable energy production and maritime fuel application, determining the overall economic viability of South Africa's green shipping supply chain.

Stage 3: Port Infrastructure & Bunkering services

This stage focuses on developing port-based infrastructure specialised for storing, handling and distribute green marine fuels across South Africa's eight commercial ports. It includes constructing cryogenic storage tanks for ammonia (-33°C) and methanol, installing bunkering infrastructure with loading arms and safety systems, upgrading port facilities at Richards Bay, Saldanha Bay, Durban, and Coega, and developing pipeline networks connecting production sites to storage terminals. The infrastructure enables South Africa to serve as a strategic refuelling hub on major shipping routes between the Atlantic and Indian Oceans.

The bunkering operations delivers green fuels to vessels through truck-to-ship, shore-to-ship, and ship-to-ship capabilities. This includes establishing commercial frameworks for fuel contracts and quality standards, implementing digital systems for bunker planning and customs clearance, and providing 24/7 emergency response services, international certification for the fuel quality and emissions reporting. Through establishing these capabilities, South Africa can position itself as a strategic refueling corridor on major East-West and North-South trade routes, linking Asia, Africa and Europe.

Stage 4: Operations & Maintenance, Spare Parts Supply Chain

This stage enables the maritime industry's transition to green fuels through vessel modifications and operational changes. This stage represents the demand side of the maritime PtX value chain - without vessels capable of using green fuels, the entire upstream investment becomes stranded. South Africa's strategic position on global shipping routes means vessels retrofitted or serviced here will carry green fuel capabilities worldwide. This creates a unique economic opportunity for hip repair industry to expand into green technology segment while also promoting skills transfer and local industrial diversification. The country's established ship repair and conversion industry, particularly in Cape Town and Durban, where dry-docking and marine engineering capacity already exists, to also establish spare part supply chain for fuel cells, compressors and safety valves, whilst provides a foundation for capturing value from the global fleet transition to green fuels.

Stage 5: Supporting Ecosystem & Community Integration

This cross-cutting stage supports the entire value chain through four pillars: research and development which are led by Universities, the Hydrogen South Africa HySA programme and innovation hubs focusing on hydrogen safety, storage and catalysis., financial services including green finance, insurance products, and blended funding mechanisms for project development such as GIZ, IDC, UK-IMPACT, local supplier and skills development (whereby building domestic manufacturing capacity for components such as storage tanks, valves, and electrolyser parts, and establishing SETAs skills programme (CHIETA) for technical and vocational education, and community and environmental integration whereby promoting environmental compliance, safety standards for hydrogen and ammonia handling and inclusive stakeholder engagement within port municipalities). Key elements include regulatory frameworks (Hydrogen Society Roadmap and Green Hydrogen Commercialisation Strategy), skills development through SETAs, environmental compliance and safety standards for hydrogen/ammonia handling. This integrated approach ensures coherent development, international competitiveness, and sustainable inclusive growth across the value chain.

6.3. Jobs and skills demand along the Maritime PtX value chain

South Africa's transition to green shipping fuels presents significant employment opportunities across the entire Maritime Power-to-X (PtX) value chain. The broader hydrogen economy, which encompasses all hydrogen applications including transport, industry, and power generation is expected to account for 3.6% of South Africa's GDP and generate 380,000 jobs by 2050 (The Presidency Republic of South Africa 2023). While these figures represent the entire hydrogen sector, the maritime component will contribute substantially to this growth given South Africa's strategic position on global shipping routes and port infrastructure. In particular, ports linked PtX activities can anchor new industrial clusters in coastal regions, supporting both direct and indirect employment. This fundamental shift in the energy landscape transforms employment patterns throughout all five stages of the maritime PtX value chain, from upstream renewable energy and green H_2 production through to cross-cutting support services. As the maritime industry evolves from fossil fuels to green alternatives, it creates diverse opportunities for workers at all skill levels while demanding new competencies and capabilities that will reshape South Africa's maritime workforce. The PtX transition therefore acts as both an employment generator and a skills transformation catalyst.
The maritime PtX transition generates three distinct categories of employment, which are:

New Jobs are professional roles that don't exist in today's maritime industry. These positions emerge directly from green fuel technologies and require workers to learn entirely new skills. Since these jobs involve technologies and processes not found in conventional shipping, workers need comprehensive training rather than simply updating existing skills. Most new jobs appear in the early stages of the value chain: Stage 1 (renewable energy and hydrogen production), Stage 2 (green fuel production and processing), and Stage 3 (port infrastructure and bunkering services).

Transition Jobs are existing maritime roles that must change significantly to work with green fuels. These workers have valuable experience in the maritime industry but need major retraining to handle new technologies and alternative fuels. While they don't need to start new careers, they must learn substantially different ways of doing their jobs. Transition jobs are most common in Stage 3 (port infrastructure and bunkering services), Stage 4 (operation and maintenance), and Stage 5 (cross cutting or supporting ecosystem) where current operations must shift from conventional to green fuels.

Scaled Jobs are existing maritime positions that require significant workforce expansion to meet green shipping fuel demands. These professionals perform established duties within the conventional maritime sector, with minimal adaptation needed for green fuel operations. Unlike workers in transition jobs, they don't need extensive retraining—their existing competencies remain largely applicable with only targeted orientation on green fuel safety protocols and regulations. Scaled jobs appear throughout the value chain but are particularly concentrated in operational areas such as renewable energy generation, fuel handling, port operations, safety inspection, and maintenance services.

The following sections examine each stage of the maritime PtX value chain in detail, breaking down the specific infrastructure and operations required at every stage of PtX value chain. For each stage, the analysis first explains what facilities and technologies South Africa currently has—such as existing wind farms or port infrastructure—and what new developments are planned. It then identifies exactly which jobs will be created, distinguishing between completely new positions that emerge from this transition to existing jobs that need significant changes, and current roles that simply need more workers. Each possible jobs listing includes a brief description of what the job requires, making it clear how these positions fit into South Africa's green fuel transition. This detailed approach of stage-by-stage mapping helps workforce planners, education providers, and policymakers understand not just how many workers are needed, but precisely what skills they require and where they will work within the maritime PtX value chain.

Stage 1: Upstream Renewable Energy & Green Hydrogen Production

Renewable Energy Generation (Solar/Wind Farms)

The production of green hydrogen through water electrolysis requires renewable electricity to meet international sustainability criteria for maritime fuel applications. South Africa's renewable energy sector has matured significantly through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). As of March 2024, the programme has successfully helped secure 9906 MW from 123 independent power producers across six bid windows, with 6,180 MW currently operational across 90 projects (IPPP, 2024). This established renewable capacity, which has created 78,075 job years for South African citizens during construction and operations, provides a strong foundation for green hydrogen production. The country has developed substantial expertise through large-scale projects including the 600 MW Concentrated Solar Power facilities in the Northern Cape and multiple wind farms totaling 3,605 MW of operational wind capacity across the Eastern and Northern Cape provinces.

These flagship projects demonstrate South Africa's renewable energy capabilities. The Redstone Concentrated Solar Power plant, which began operations in 2024, represents South Africa's largest renewable energy investment with advanced molten salt technology providing 12 hours of thermal storage (ESI-Africa, 2025). Similarly, the Roggeveld Wind Farm, operational since March 2022, stands as South Africa's largest wind facility with 147 MW capacity, generating approximately 613 GWh annually (Red Rocket Energy, 2022). Together, these facilities showcase the technical expertise and operational experience that South Africa has built in renewable energy generation.

However, transitioning this established renewable energy workforce and infrastructure from grid-connected operations to dedicated hydrogen production presents new challenges. Currently most renewable energy installations supply power to Eskom's national grid under standard power purchase agreements. In contrast, green hydrogen facilities typically prioritise direct renewable energy input to electrolysers, rather than supplying power to the grid. These green hydrogen facilities often maintain grid connectivity to ensure operational flexibility and to support continuous electrolyser operation during periods of low renewable generation. This shift requires workers to develop new competencies—shifting their focus from grid stability to optimising electrolyser performance in the face of fluctuating renewable energy input. They must also learn to coordinate multiple renewable sources (such as solar and wind) with energy storage systems to ensure consistent hydrogen production, understand electrolyser operational requirements and efficiency patterns, and integrate energy management systems specifically designed for hydrogen production. Therefore, the transition from grid-focused to hydrogen-focused operations represents a fundamental change in operational approach, requiring comprehensive retraining programs for South Africa's renewable energy workforce. Skills planning in this area will be critical to avoid capacity bottlenecks as hydrogen projects scale up.

The **Boegoebaai Green Hydrogen Project** in the Northern Cape plans to install 9 GW of dedicated solar and wind capacity to power 5 GW of electrolysers (Corporate Europe Observatory, 2024). This renewable capacity will not feed into the national grid but will directly supply hydrogen production facilities, ensuring maximum green hydrogen output. The project aims to produce 400,000 tons of green hydrogen per year for export to Europe (Corporate Europe Observatory, 2024). The project also plans to generate up to 6,000 permanent jobs and more than 50,000 temporary ones.

Possible Jobs Created

Scaled jobs:

- Solar PV Installer - *Install and mount solar panels on rooftops and ground-mounted systems.*
- Solar Plant Control Room Operator - *Monitor and control solar farm operations from centralised control rooms.*
- Wind Turbine Service Technician - *Perform routine maintenance and repairs on wind turbines.*
- Wind Farm Control Operator - *Monitor wind farm performance and coordinate turbine operations remotely.*
- Renewable Plant Manager - *Oversee daily operations and maintenance of renewable energy facilities.*
- Renewable Energy Maintenance Engineer - *Design and implement maintenance strategies for renewable energy equipment.*

Green Hydrogen Production Facilities

Green hydrogen production facilities use electrolysis to split water molecules into hydrogen and oxygen using renewable electricity. This hydrogen serves as the fundamental building block for all maritime PtX fuels - it's combined with nitrogen to make ammonia or with CO_2 to make methanol (IRENA, 2020). The efficiency and reliability of these facilities directly impact the cost and availability of green shipping fuels.

South Africa has limited commercial electrolysis experience. The only significant installations are small-scale research facilities at universities and pilot projects. HySA Infrastructure at North-West University operates small PEM electrolysers for research (HySA Infrastructure, 2024). Industrial hydrogen is currently produced from coal gasification at Sasol or as a by-product from chlor-alkali plants, not from water electrolysis. Sasol's plants in Secunda and Sasolburg gasify over 30 million tons per annum of bituminous coal to synthesis gas, which is converted to fuels and chemicals via the Fischer-Tropsch process (Van Dyk et al., 2006; Sasol, 2024).

The transition to large-scale green hydrogen production will require significant workforce development. Large-scale electrolyser facilities (100-500 MW) are designed to operate continuously, requiring round-the-clock teams of operators with expertise in both electrical systems (such as rectifiers, transformers) and chemical processes (including gas separation, compression). Workers must be capable of operating electrolysers that respond rapidly to fluctuations in renewable energy supply. To do this effectively, they must understand how to control temperature, maintain stable operating conditions, and monitor long-term efficiency and maintenance requirements (Cai et al., 2024; Zhang et al., 2023). This workforce will include chemical and electrical engineers focused on optimising system performance, maintenance engineers responsible for upkeep and reliability, and renewable energy professionals supporting hydrogen production and storage integration (Hydrogen Training Solutions, 2024). As the industry evolves, new specialised roles will emerge—ranging from catalyst performance management to coordinating real-time interactions with variable renewable power—marking a significant evolution from South Africa's current fossil-based hydrogen production methods. Consequently, higher education institutions and TVET colleges will need to update curriculum to include electrolysis, hydrogen system engineering, and associated safety.

Sasol is exploring green hydrogen production at Sasolburg, leveraging their existing hydrogen handling expertise from coal-based production. They have retrofitted an operational electrolyser to use renewable electricity, producing their first green hydrogen in June 2023 using electricity from a 3 MW solar photovoltaic facility (Engineering News, 2023). The facility is expected to produce up to 5 tons of green hydrogen daily once the 69 MW Msenge Emoyeni Wind Farm begins supplying power (Engineering News, 2023; Africa Oil & Gas Report, 2023). The Sasolburg facility features a 60 MW electrolyser, one of the biggest in South Africa (Northern Cape Government, 2024). The green hydrogen will initially be used for mobility applications, including partnerships with the mining industry for decarbonisation efforts.

Possible Jobs Created

New jobs:

- Electrolyser Technician - *Operate and monitor electrolysis equipment that produces hydrogen from water.*

- Hydrogen Plant Control Room Operator - *Monitor hydrogen production processes and respond to system alerts.*
- Hydrogen System Maintenance Technician - *Perform specialized maintenance on hydrogen production equipment*
- Hydrogen Quality Engineer - *Test and ensure hydrogen purity meets marine fuel specifications.*
- Hydrogen Safety and Hazard Specialist - *Develop and implement hydrogen-specific safety protocols and emergency procedures.*

Transition jobs:

- Chemical Engineer - *Adapt from coal-gasification to electrolysis processes*
- Electrical Engineer - *Transition from AC systems to DC power and electrolyser integration*

Water Treatment and Desalination Plants

Electrolysers require ultra-pure water (less than 1 microsiemens/cm conductivity) to prevent degradation of expensive catalysts and membranes. Approximately 9 litres of pure water are needed per kilogram of hydrogen produced through the stoichiometric splitting of water molecules (Decarbonisation Technology, 2024; Hydrogen Tech World, 2022). When including water for purification and process cooling, an additional 10-20 liters per kg is needed, resulting in approximately 200 litres per hour of ultrapure water required per MW of electrolyser capacity (Hydrogen Tech World, 2022). For maritime hubs producing millions of tonnes of green fuels, water treatment becomes a major industrial operation requiring sophisticated purification systems.

In water-scarce South Africa, this means seawater desalination followed by advanced purification. South Africa's current water treatment capabilities include several small-scale municipal desalination plants operating along the coast. The Mossel Bay desalination plant has a capacity of 15 million litres per day, making it one of South Africa's largest seawater desalination facilities (Veolia South Africa, 2024; Brand South Africa, 2024). Other coastal facilities include the Albany Coast Reverse Osmosis (Acro) plant (1.8 ML/day), Plettenberg Bay (2 ML/day), and Sedgefield plants operating in the Western Cape (Amatola Water, 2019). However, these produce potable water, not the ultra-pure deionised water required for electrolysis.

Industrial water treatment expertise exists in South Africa's power generation sector. Eskom operates sophisticated water treatment systems at its power stations, producing highly purified and demineralised feedwater for boilers operating at temperatures of 540°C and pressures of 17.1 MPa (Eskom Heritage, 2023; Power Technology, 2019). Nevertheless, this kind of expertise has not been scaled for hydrogen production, where facilities may need to process hundreds of cubic meters per hour of ultrapure water.

Looking into the future, water treatment facilities will be integrated with renewable energy to minimise costs, using excess solar power for energy-intensive reverse osmosis. New job roles will combine traditional water treatment with understanding of electrolyser requirements. Workers will need skills in advanced purification technologies like electrodeionisation, managing large-scale industrial water systems with zero liquid discharge targets, and coordinating water treatment operations with renewable energy availability. This creates a direct interface between the water sector and the emerging hydrogen industry, with skills and infrastructure increasingly co-designed to serve both.

The **planned Boegoebaai development** includes a proposed 30 million litre/day desalination plant specifically for hydrogen production. **At Saldanha Bay**, developers plan to expand the existing desalination capacity (currently serving the West Coast District Municipality) with an additional industrial-scale plant for electrolyser feed water.

Possible Jobs Created

New jobs:

- Ultra-pure water specialist - *Design systems to produce ultra-pure water required for electrolysis.*

Transition jobs:

- Water Treatment Process Engineer - *Shift from potable/industrial water standards to ultra-pure specifications for hydrogen production.*

Scaled jobs:

- Desalination Plant Operator - *Operate desalination equipment to provide water for hydrogen production.*
- Process Control Engineer - *Monitor and optimize water treatment processes through automated systems.*
- Membrane Maintenance Specialist/Technician - *Service and replace membrane filtration systems.*
- Water Quality Laboratory Technician - *Test water samples to ensure quality standards are met.*

Electrical Infrastructure and Grid Connections

Electrical infrastructure linking renewable generators to electrolysers requires high-capacity transmission lines, substations, transformers and power electronics. Unlike traditional grid connections, these systems must handle highly variable renewable input while ensuring that power electronics deliver a stable Direct Current (DC) supply to electrolysers. This infrastructure determines how efficiently renewable energy converts to hydrogen.

South Africa's current electrical infrastructure has limitations for renewable energy integration. Although Eskom operates extensive transmission infrastructure, it's designed for centralised coal power distribution, not distributed renewable energy collection. The grid faces constraints in renewable-rich areas like the Northern Cape and Western Cape (GreenCape, 2025). Private transmission development is new in South Africa, with first projects under the amended Electricity Regulation Amendment Act. Most electrical workers are experienced in Air Conditioner (AC) systems, while electrolyser operations require expertise in DC power conversion and management systems.

Looking ahead, the development of new transmission infrastructure for renewable energy integration will create diverse employment opportunities across the electricity sector. Workers will need skills in power electronics for converting variable AC from renewables to stable DC for electrolysers. Real-time control systems will optimise power flow based on renewable availability and hydrogen demand, requiring new competencies in energy management software and forecasting systems. South Africa's electrical workforce must rapidly develop expertise in power electronics, DC systems, and integrated renewable-hydrogen energy management to support the emerging green hydrogen economy. This shift turns ports and SEZs into integrated energy hydrogen nodes rather than simple grid off-takers.

The Saldanha Bay IDZ is upgrading electrical infrastructure to support planned industrial development, including new high-voltage substations and transmission connections. The port has already implemented 132kV infrastructure upgrades through Eskom (Khato Civils, 2020). At Coega, the development includes significant new transmission infrastructure with up to four 400kV transmission lines connecting inland wind farms to coastal hydrogen production facilities through the Dedisa Substation, potentially operating independently from Eskom's grid to ensure dedicated clean energy supply (NS Energy, 2024).

Possible Jobs Created

New jobs:

- Electrical Engineer - *Design and maintain DC electrical systems for electrolyser integration.*

Transition jobs:

- Grid Operation Specialist - *Adapt from centralised coal grid management to distributed renewable-hydrogen systems.*

Scaled jobs:

- High Voltage (HV) Substation/Electrical Technician - *Maintain and repair high-voltage electrical equipment.*
- Instrumentation Engineer - *Design control systems for electrical protection and automation.*

Energy Storage Systems

Energy storage systems, primarily large-scale batteries, buffer the variability of renewable energy to ensure consistent hydrogen production. While electrolysers can ramp up and down, they operate most efficiently at steady state. Batteries provide power during cloud cover or wind lulls, and absorb excess energy during peak generation, maximising electrolyser utilisation and hydrogen output. They therefore play a critical balancing role between intermittent generation and the continuous operating profile required for competitive hydrogen production.

South Africa has limited grid-scale battery experience, with notable installations including Eskom's 1440 MWh Battery Energy Storage System pilot (Eskom, 2023). Most battery expertise exists in telecommunications (backup power) and residential systems. The country lacks large-scale battery manufacturing, importing most systems. Technical skills exist but not at the scale required for hydrogen production support.

Looking forward, battery systems supporting hydrogen production will be 10-50 times larger than current installations, requiring fundamentally new operational approaches. Workers will manage complex algorithms balancing renewable forecasts, electrolyser efficiency curves, and battery degradation. Integration with hydrogen production adds more complexity – as operators must understand both electrical storage and chemical process requirements. New roles will emerge in predictive maintenance using artificial intelligence to maximise battery life in demanding cycling applications, where batteries may charge and discharge multiple times daily to smooth renewable variability. Workers will need expertise in energy management systems that can predict renewable generation patterns hours or days in advance, optimise battery state-of-charge to maximize electrolyser runtime, and minimize overall system degradation.
Large-scale hydrogen projects are expected to incorporate significant battery storage capacity to ensure stable electrolyser operation. South Africa's

Battery Energy Storage IPP Procurement Programme (BESIPPPP) has already procured 513 MW in its first window, with additional windows totaling over 1,200 MW planned (IPPPP, 2024). These utility-scale installations will require new approaches to thermal management and safety, particularly in harsh coastal environments where many hydrogen projects are planned. As a result, battery engineering and operations will become a core competency within coastal green hydrogen hubs rather than a peripheral grid service.

Possible Jobs Created

New jobs:

- Energy Storage Specialist - *Manage battery energy storage systems for grid stabilization and Optimise energy flows between renewable generation, storage, and hydrogen production.*

Scaled jobs:

- Battery Maintenance Technician - *Service and maintain battery storage systems.*
- Battery Safety Engineer - *Ensure safe operation of large-scale battery installations.*

Stage 2: Green Fuel Production & Processing

Ammonia Synthesis Facilities

Ammonia synthesis combines green hydrogen with nitrogen from air to produce NH_3 through the Haber-Bosch process. Green ammonia serves dual purposes: as a direct marine fuel for specially designed engines and as a hydrogen carrier 17.8% hydrogen by weight.

South Africa produces around 800–830 kt of ammonia per year, primarily from coal gasification at Sasol's Secunda and Sasolburg complexes (Centre for Environmental Rights, 2019; Sasol Chemicals, 2024). This capacity meets most domestic demand for fertilizer and industrial uses, but it is entirely fossil fuel–based and carries a high carbon footprint. Existing facilities operate in continuous mode with stable feedstock supply, optimised for steady-state Haber–Bosch synthesis. The current workforce is skilled in conventional ammonia production, including high-pressure operations, catalyst handling, and process optimisation (Sasol Chemicals, 2024). However, producing green ammonia from renewable hydrogen would require integrating electrolysers and air separation units with highly variable renewable electricity. This shift introduces operational challenges—such as ramping production up or down without compromising catalyst performance or product quality—that are not part of current practice. While South Africa's chemical industry has deep process expertise, it must now develop competencies in dynamic plant control, hybrid process design and digital energy management systems to stabilise variable renewable supply.

The **Hive Energy and Linde green ammonia plant** at Coega targets over 1 million tons/year production by 2029, powered by 3.31 GW of renewable energy (1.88 GW wind and 1.43 GW solar) with 1.12 GW electrolyser capacity (Hive Energy, 2025). The facility will use Air Separation Units (ASU) to extract nitrogen from air and combine it with green hydrogen in synthesis loops operating at 150-300 bar pressure and 400-500°C temperature conditions (Chemistry LibreTexts, 2023; PMC, 2024). Sasol is exploring the conversion of their existing Sasolburg ammonia plant (which currently uses coal-based hydrogen) to green hydrogen feedstock, leveraging decades of ammonia production expertise (Sasol, 2024).

Possible Jobs Created

Transition jobs:

- Ammonia Process Technician - *Shift from coal-based to green hydrogen feedstock in ammonia production.*
- Haber-Bosch Technician - *Adapt from steady-state to variable renewable-powered operations.*
- Nitrogen Plant Operator - *Integrate nitrogen production with fluctuating hydrogen supply.*
- Ammonia Safety and Hazard Specialist - *Develop new safety protocols for ammonia as marine fuel.*

Methanol Production Plants

Green methanol production combines green hydrogen with captured CO_2 to create a liquid fuel that offers significant advantages for maritime applications. Unlike ammonia, methanol remains liquid at ambient conditions, enabling use of existing petroleum infrastructure with minor modifications.

South Africa lacks commercial methanol production but possesses relevant expertise from Sasol's Fischer-Tropsch processes, which produce similar synthetic fuels from syngas. The country has multiple biogenic CO_2 sources including sugar mills, breweries, and biogas plants, but limited infrastructure exists for CO_2 capture, purification, and transport, especially at commercial scale (DTIC, 2023, CSIR, 2022). Workers in the petrochemical sector understand catalytic processes and syngas chemistry but require training in carbon management, carbon capture integration, and renewable feedstock operations. The absence of methanol production means no existing workforce trained in methanol-specific safety protocols or quality standards.

Methanol plants will require strategic placement near both hydrogen production and sustainable CO_2 sources, creating new logistical complexities. Workers will need to manage carbon supply chains - capturing, purifying, and transporting CO_2 from diverse sources including direct air capture, biomass facilities, and industrial emissions. Plants will also need to comply with carbon neutrality certification standards for maritime fuel classification, requiring detailed lifecycle carbon accounting and verification system throughout the supply chain. This will create new job categories in carbon logistics and sustainability verification.

In addition, there is also an opportunity to transition stranded fossil fuel assets to green fuel production. PetroSA's Mossel Bay gas-to-liquids facility, which has been out of operation for several years, is now being considered for conversion to green fuel production, including the potential to produce green methanol (PetroSA, 2023).

Possible Jobs Created

New jobs:

- Methanol Synthesis Technician - *Operate reactors that combine hydrogen with captured CO_2 to produce methanol.*
- CO_2 Capture Technicians - *Operate equipment that captures CO_2 for methanol synthesis.*
- Methanol Quality Engineer - *Test methanol to ensure it meets marine fuel specifications.*
- Process Engineer - Design systems to integrate CO_2 capture with *methanol production.*

Fuel Quality Assurance and Certification

Marine fuel quality directly impacts engine performance, emissions compliance, and vessel safety. For new fuels for instance ammonia and methanol, clear technical specifications and verification procedures are essential for safe handling and meeting regulations. Marine ammonia fuel standards are still being developed by international organisations. Current discussions focus on using commercial-grade ammonia, with special attention to water content levels that can improve storage safety (Ammonia Energy Association, 2024). The IMO approved safety guidelines for ammonia fuel in December 2024. While these guidelines are currently voluntary, they help prepare the industry for mandatory rules expected to enter into force in 2026 (IMO, 2024).

Methanol already has established standards through ISO 6583:2024, which defines three fuel grades. The highest grade requires at least 99.85% purity, maximum 0.1% water content, and sulfur below 0.5 mg/kg (IMPCA, 2024; ISO, 2024). Methanol has had IMO safety guidelines since 2020, making it further along in the regulatory process than ammonia. For both fuels to qualify as "green," producers must prove they come from renewable sources and calculate their carbon footprint using approved methods. This certification is becoming increasingly important as shipping companies work to meet stricter emissions targets.

South Africa's marine fuel testing currently focuses on petroleum products under ISO 8217 standards, with laboratories such as Société Générale de Surveillance (SGS), Bureau Veritas, and Intertek testing viscosity, sulfur, and flash point of conventional marine fuels (Bureau Veritas, n.d.; Intertek, n.d.; SGS, n.d.). However, testing capabilities for green marine fuels such as ammonia purity verification, methanol bio-content analysis, and advanced techniques such as cryogenic sampling remain limited or unavailable. National standards for green marine fuels are still under development, creating regulatory challenges for the emerging sector.

Quality assurance will expand beyond physical fuel testing to encompass sustainability and traceability verification throughout the supply chain. Laboratories require major equipment upgrades including specialised sampling systems for toxic and cryogenic fuels, advanced analytical instruments capable of parts-per-billion contamination detection, and digital systems for tamper-proof certification. New roles will emerge in sustainability auditing - professionals who verify renewable electricity consumption, track carbon intensity, and ensure compliance with international green fuel standards. South African facilities will require international accreditation and mutual recognition agreements to enable fuel exports, requiring technicians certified to global standards. The integration of digital technologies such as blockchain will create demand for professionals combining chemistry knowledge with digital systems expertise.

Possible Jobs Created

New jobs:

- Marine Fuel Laboratory Technician - *Test green marine fuels against new quality standards.*
- Sustainability Auditors / Specialist - *Verify carbon intensity and sustainability credentials of green fuels.*

- Fuel Certification Manager - *Issue certificates confirming fuel meets international green shipping standards.*

Transition jobs:

- Quality Assurance Manager - *Transition from ISO 8217 petroleum standards to new green fuel specifications.*

By-product Management

Green fuel production generates substantial by-products - electrolysis produces 8 kg of high-purity oxygen per kg of hydrogen, while ammonia synthesis releases ~90 MJ of heat per tonne NH_3 (Nayak-Luke et al., 2020). South Africa's announced green hydrogen projects, including Coega and Boegoebaai, could generate millions of tonnes of oxygen annually, creating opportunities to transform these by-products from waste streams into potential revenue sources and industrial linkages.

Currently, South Africa's industrial complexes such as Sasol Secunda demonstrate sophisticated by-product integration, with Air Liquide's facility producing 47,000 tonnes/day of oxygen across 17 units (Air Liquide, 2021). However, these existing systems were designed for steady-state operations with fixed offtake agreements. They lack the flexibility needed for renewable-powered maritime fuel production, where output varies with wind and solar availability. Most facilities still vent waste heat, missing energy recovery opportunities that could improve overall efficiency.

The transition to green maritime fuel production requires reimagining by-product management. Variable oxygen output from renewable-powered electrolysis demands flexible commercial arrangements, potentially including liquid oxygen storage for supply stability. Maritime fuel facilities at ports create unique opportunities - oxygen for ship repair operations, steelmaking, heat for cargo handling facilities, and integration with port industrial zones. Digital platforms could enable real-time matching of by-product supply with demand, creating spot markets that maximise value capture.

Emerging projects demonstrate this potential. The Coega facility's location within a port SEZ enables direct integration with regional industries. ArcelorMittal's exploration of green hydrogen for steel production at Saldanha could utilise oxygen from nearby maritime fuel facilities, reducing transport costs and improving project economics for both parties (Engineering News, 2023). Such industrial symbiosis could make South African green maritime fuels more competitive globally while supporting broader industrial defossilisation. Therefore, collaboration would improve overall project economies and strengthen South Africa's industrial decarbonisation ecosystem.

Possible Jobs Created

New jobs:

- By-product Coordinator - *Manage the sale and distribution of oxygen and other by-products.*
- Oxygen Supply Chain Specialist - *Coordinate oxygen storage and delivery to industrial customers.*

Transition jobs:

- Industrial Integration Engineer - Adapt from fixed industrial offtake to flexible by-product arrangements.
- Waste Heat Recovery Plant Operator - Manage heat recovery from variable renewable-powered processes.

Stage 3: Port Infrastructure and Bunkering Services.

Storage and Handling Infrastructure

Green maritime fuels require storage and handling infrastructure fundamentally different from conventional petroleum infrastructure. Ammonia must be stored either refrigerated at -33°C or pressurised at 10-18 bar, using specialised materials resistant to corrosion and stress cracking (Chellapandian et al., 2023; Kim et al., 2022). From these storage terminals, pipeline systems transport fuel to ship berths through stainless steel or treated carbon steel pipelines with continuous insulation and leak detection every 100 meters (Transnet Pipelines, 2024). Methanol, while simpler to handle, requires twice the storage volume due to its lower energy density of 15.6 MJ/L compared to 35.8 MJ/L for marine gas oil (Zhou et al., 2022).

South African ports currently operate petroleum-focused infrastructure unsuitable for green fuels. Existing mild steel storage tanks and carbon steel pipelines would corrode if used for ammonia, while industrial ammonia storage at Richards Bay lacks marine fuel specifications for rapid bunkering (DNV, 2023). The Durban-Johannesburg pipeline demonstrates long-distance capability but uses technology incompatible with cryogenic service (Transnet Pipelines, 2024). Critical gaps include leak detection systems that take 30-60 minutes to respond, response times that are acceptable for oil but far too slow for toxic ammonia, and workforce expertise limited to petroleum operations rather than cryogenic or toxic gas management. Accordingly, port infrastructure must shift from single fuel petroleum systems to dedicated or segregated storage transfer and safety systems for multiple green fuels. Future infrastructure will therefore need to transform South African ports into multi-fuel energy hubs, with purpose designed ammonia and methanol storage, rapid transfer systems, and embedded safety controls that meet emerging international standards for green maritime fuels.

Possible Jobs Created

New jobs:

- Leak Detection System Operator/ Safety Technician - *Monitor ammonia and hydrogen leak detection systems continuously.*
- Cryogenic Storage Operator - *Operate tanks storing liquefied hydrogen at -253°C.*
- Refrigeration System/Mechanical Engineer - *Design cooling systems for cryogenic fuel storage.*
- Vapor Recovery Technician - *Operate systems that capture and re-liquefy fuel vapors.*

Transition jobs:

- Pipeline Engineer - *Adapt from petroleum to ammonia/methanol compatible materials and designs.*
- Pipeline Integrity Specialist - *Shift from carbon steel to stainless/treated pipeline inspection methods.*
- Pipeline Technician - *Transition from petroleum to cryogenic/toxic gas pipeline operations.*
- Storage Operation Manager - *Manage multi-fuel green terminals instead of petroleum-only facilities.*
- Inventory Control/ Supply Chain Specialist - *Track fuels with different energy densities and storage requirements.*
- Safety and Hazard Specialist - *Implement ammonia-specific safety protocols replacing petroleum procedures.*

Scaled jobs:

- Corrosion Specialist - *Prevent pipeline corrosion through electrochemical protection systems.*
- Pipeline Maintenance Technician - *Perform routine pipeline inspections and repairs.*
- Pipeline Scheduler - *Coordinate pipeline construction projects and maintenance schedules.*
- Storage Maintenance Technician - *Service storage tanks and associated equipment.*

Safety and Emergency Systems

Safety and emergency systems for green marine fuels combine permanent infrastructure with rapid response capabilities to protect workers, communities, and the environment from ammonia's unique hazards. Fixed installations include gas sensors detecting toxic vapors at concentrations as low as 25 parts per million, water spray systems creating 50-meter protective curtains to suppress escaping ammonia, concrete blast walls shielding critical equipment, and emergency shutdown controls accessible within 30-second walking distances (American Bureau of Shipping [ABS], 2023; Indian Register of Shipping [IRClass], 2022). These systems connect to 24/7 emergency response teams trained in toxic gas procedures, equipped with specialised gear including cryogenic suits and extended duration breathing apparatus, and coordinated with municipal services for incidents that could impact communities kilometers from ports (HaskoningDHV, 2025).

Current South African capabilities focus on petroleum incidents and lack ammonia-specific readiness. Port gas detectors monitor oil vapors but miss toxic ammonia at dangerous concentrations, while foam-based fire systems cannot suppress ammonia vapor clouds (Dräger Safety, 2024). Emergency response centers at major ports handle oil spills effectively through SAMSA protocols, but teams lack training for ammonia's combination of toxicity, cryogenic burns, and dense vapor clouds that travel along ground level (IRClass, 2022). While municipalities operate disaster management centers in Cape Town, eThekwini, and Nelson Mandela Bay, strong, rehearsed coordination protocols for rapid evacuation during ammonia releases remain undeveloped.

Future integrated safety systems will create multiple protection layers from detection through response. Fiber-optic sensors throughout ports will feed real-time data to control rooms, automatically triggering water curtains and alerting emergency teams within seconds of detection (ABS, 2023). Regular joint exercises between ports, municipalities and emergency services will be essential or rather mandatory to operationalise these systems and build confidence amongst surrounding communities,

Possible Jobs Created

New jobs:

- Gas Detection System Installers - *Install ammonia and hydrogen gas detection sensors throughout facilities.*
- Fixed System Maintenance Technician - *Service specialised ammonia safety and suppression systems.*
- Safety Infrastructure Engineer - *Design ammonia-specific safety systems including water curtains and containment.*

- Drone Pilots for Emergency Assessment - *Operate drones to assess toxic gas releases from safe distances.*

Transition jobs:
- Safety and Hazards Specialist - *Lead emergency response teams trained in ammonia and hydrogen incidents; shift focus from oil spills to toxic gas release management.*
- Medical Emergency Paramedic - *Add ammonia exposure treatment to existing emergency medical skills.*
- Environmental Engineer - *Adapt from petroleum cleanup to ammonia/methanol incident response.*
- Communication Specialist - *Manage public warning systems for potential ammonia releases.*

Scaled jobs:

- Emergency System Electrician - *Install and maintain emergency electrical systems.*
- Technician Supervisor - *Oversee installation of safety equipment and systems.*

Port Operations

Port operations for green marine fuels require fundamental changes to both physical infrastructure and operational procedures. Ammonia's unique properties—toxicity, cryogenic temperature, and lower energy density—demand dedicated operational zones with safety buffers, strengthened berths for specialised loading equipment, and expanded electrical infrastructure for refrigeration systems (Jang et al., 2023; Kim et al., 2023). These modifications enable safe fuel delivery through coordinated management of vessel movements, berth assignments, and multi-party collaboration between terminal operators, shipping agents, and port authorities.

South African ports currently operate within significant constraints. Durban experiences vessel congestion that complicates scheduling, while manual coordination limits operational efficiency (TNPA, 2024). Existing petroleum bunkering relies on established suppliers but lacks digital integration between fuel systems and port operations (TNPA, 2023). Richards Bay offers deep-water advantages but faces spatial limitations near environmentally sensitive areas. The port's South Dunes development demonstrates how environmental considerations can guide sustainable infrastructure investment through long-term concessions (Engineering News, 2024). Electricity supply intermittency affects operations, prompting renewable energy integration including solar development at Richards Bay (Engineering News, 2024).

Future operations will transform through digital integration and predictive management. Integrated platforms will enable vessel compatibility checks before arrival, automated berth scheduling that considers safety requirements, and coordinated multi-fuel deliveries (Carpenter-Lomax et al., 2023). Weather forecasting and vessel tracking systems will anticipate disruptions, while ports could develop "green corridors" offering priority services for low-emission vessels. These green corridor concepts link operational incentives (such as reduced waiting time and preferential berthing) with decarbonisation outcomes, strengthening the business case for green fuel adoption. The Port of Ngqura's successful development provides evidence that rapid infrastructure transformation is achievable with proper planning (World Bank, 2024). By building on existing capabilities—including terminal operating systems and chemical handling experience—South African ports can develop efficient green fuel operations that balance commercial needs with safety requirements.

Possible Jobs Created

New jobs:
- Vessel Compatibility Assessor/ Marine Engineer - *Evaluate ships' readiness to receive green fuel bunkering.*
- Pipeline Scheduler - *Coordinate bunkering of different fuel types to minimize cross-contamination.*
- IT Specialist - *Analyse port data to optimise green fuel operations.*
- Logistics Optimisation Analyst - *Model and improve green fuel supply chain efficiency.*
- Operation Manager - *Develop contingency plans for green fuel supply interruptions.*
- Economic Modelling Specialist - *Optimise allocation of port resources across different fuel types.*
- Transportation Solutions Advisor - *Help vessels plan routes based on green fuel availability.*

Transition jobs:
- Environmental Compliance Officer / Engineer - *Shift from MARPOL petroleum rules to green fuel regulations.*
- Port Safety and Hazard Specialist - *Add ammonia/methanol protocols to existing safety management.*
- Port Planning Specialist - *Design ports with 200 - 500m safety buffers for ammonia operations.*
- Supply Chain Specialist - *Coordinate green fuel logistics instead of petroleum deliveries.*
- Operations Control Room Manager - *Manage integrated digital systems for multi-fuel operations.*

- Port-Vessel Liaison Officer/ Marine Engineer - *Communicate new safety and operational protocols for green fueling.*
- Inventory Planning Manager - *Plan storage for fuels with different energy densities and boil-off rates.*

Scaled jobs:
- Port Development Engineers / Civil Engineers - *Design and build port infrastructure expansion projects.*
- Marine Civil Works Supervisors / Civil Engineers - *Oversee construction of marine structures like jetties and berths.*
- Dredging Operations Manager - *Manage seabed dredging to maintain port depths.*

Commercial and Support Services

Commercial and support services for green marine fuels encompass the business frameworks and quality systems that enable safe, reliable fuel transactions. These services must create new market mechanisms that reflect renewable electricity costs, carbon values, and sustainability premiums while ensuring fuel quality meets strict specifications for both engine performance and safety (Kim et al., 2023). Unlike established petroleum markets with global benchmarks and standardised testing protocols, green fuel services require integrated commercial, technical and certification arrangements combining pricing models, contract structures, and verification systems that confirm both physical properties and renewable origin.

Current South African marine fuel services operate within petroleum-focused frameworks unsuitable for green fuels. Commercial structures follow international oil market pricing without mechanisms to value carbon reductions or renewable content. Quality testing laboratories focus on petroleum parameters like density and sulfur content, lacking capabilities for ammonia purity analysis or cryogenic sampling (Bureau Veritas, 2024). The absence of established green fuel standards and certification systems creates uncertainty for both suppliers and vessel operators considering fuel transitions.

Future commercial services will integrate multiple revenue streams through sophisticated digital platforms. Pricing mechanisms will dynamically incorporate renewable energy costs, carbon credit values, and market premiums for verified sustainable fuels (Global Maritime Forum, 2024). Long-term contracts with shipping lines will likely include take-or-pay provisions to secure infrastructure investments, while spot markets develop for voyage-specific compliance needs. Quality assurance will expand beyond physical testing to include continuous monitoring during transfer, isotopic verification of renewable origin, and blockchain-based certification ensuring supply chain transparency (DNV, 2023). These integrated commercial and quality systems will provide the confidence needed for vessels to adopt green fuels, knowing they can access competitively priced, verified sustainable fuel at South African ports.

Jobs Created

New jobs:
- Green Fuel Trading Manager - *Develop markets for green fuels without petroleum price benchmarks.*
- Carbon Credit Trader / Finance Specialist - *Trade carbon credits linked to green fuel usage.*
- Market Development Manager / Business Developer - *Build demand for new green marine fuel markets.*
- IT Specialist - *Manage blockchain-based green fuel certification systems.*

Transition jobs:
- Contract Negotiation Lawyer - *Adapt from petroleum to renewable-linked contract structures.*
- Pricing Analyst / Economic Modelling Specialist - *Model fuel prices including renewable costs and carbon values.*
- Credit Risk Manager / Finance Specialist - *Assess new market and technology risks in green fuel trading.*
- Laboratory Technician - *Learn new testing protocols for green marine fuels.*
- Quality Assurance Manager - *Audit against new green fuel standards instead of ISO 8217.*

Scaled jobs:
- Instrumentation Technician - *Calibrate measurement instruments to ensure accuracy.*

Stage 4: Operations & Maintenance

Fleet Operations and Management

Fleet operations for green fuel vessels fundamentally change how shipping companies manage their assets and routes. Unlike conventional operations where bunker fuel is available at most ports, green fuel availability will initially be limited to specific hubs, requiring strategic route planning, longer-term fuel procurement contracts and digital optimisation tools. Green corridors between major ports offer opportunities to concentrate infrastructure investment more efficiently than universal coverage (Global Maritime Forum, 2024). To adapt, digital fleet management systems must therefore evolve beyond basic tracking to integrate fuel availability databases, real-time pricing, weather routing optimisation, and emissions monitoring-reporting functions.

In South Africa, companies currently operate vessels internationally but lack green fuel management capabilities. The maritime sector handles approximately 8970 vessel movements annually through eight major ports (TNPA, 2024). Current operations rely on basic digital systems without the sophisticated optimisation required for dual-fuel operations. While established logistics expertise from mining and freight transport sectors provides transferable skills, no domestic companies currently offer specialised green fuel fleet management.

The transition therefore opens opportunities for specialised fleet management serving African trade routes. As regional ports develop capabilities at different rates, operators with local knowledge will gain competitive advantages in fuel procurement and voyage optimisation. Companies managing vessels on routes connecting South Africa with Europe or Asia could guarantee fuel availability through long-term contracts while optimising operations for the emerging carbon pricing regime.

Existing infrastructure could provide a foundation for this shift. The Maritime Domain Awareness Centres in Durban and Cape Town, originally designed for maritime security, already integrate real-time vessel tracking and data management (Vrey & Blaine, 2023). With adaptation, these systems could support fuel optimisation applications and help position South Africa as a regional leader in green fleet management.

Possible Jobs Created

New jobs:
- Green Fuel Fleet Operation Manager - *Coordinate vessels using alternative fuels across global routes.*
- Voyage Operation Optimisation Specialist - *Plan routes based on green fuel availability and efficiency.*
- Supply Chain Specialist - *Track green fuel availability at ports worldwide.*
- Marine Engines Expert - *Optimise switching between conventional and green fuels.*
- Operation Optimisation Specialist - *Monitor and improve green fuel consumption efficiency.*

Transition jobs:
- Predictive Maintenance Engineer - *Adapt predictive models from conventional to green fuel systems.*

Scaled Jobs:
- Systems Engineer (H) - *Integrate various digital systems for fleet management.*

Vessel Conversion and Maintenance services

Vessel retrofitting represents a critical component for enabling the existing fleet's transition to green fuels. Conversion costs vary with vessel age and remaining operational life, with container vessel retrofits often exceeding USD 30 million (Global Maritime Forum, 2024). These high capital costs, combined with the advanced engineering and safety requirements of handling green fuels, mean that conventional repair yards must evolve into certifies soecialised facilities. As a result, there is growing demand for specialised shipyards with the technical expertise, certified workforce, and infrastructure to deliver complex green fuel conversions at scale.

South Africa's ship repair industry is concentrated in Cape Town and Durban. Cape Town's Sturrock Dry Dock (369.6 m length, 45.1 m width) and Robinson Dry Dock (161.2 m length) provide significant capacity (Digital Logistics Capacity Assessments, 2024). Durban hosts two TNPA dry docks and several private floating docks, accommodating vessels up to 8,500 tons displacement (Dormac, 2023). These facilities already service vessels calling at South African ports, with established strengths in steel fabrication, engine overhauls, and structural modifications. However, expertise remains focused on conventional repairs. No facilities currently offer green fuel system retrofits, nor is the workforce trained in specialist skills such as cryogenic welding or handling ammonia-compatible materials.

Recognising the sector's importance, the Department of Trade and Industry's Operation Phakisa initiative identified shipbuilding and repair as strategic industries, linking them to broader marine transport and manufacturing objectives including coastal shipping, trans-shipment, and vessel refurbishment (Department of Environmental Affairs, 2024). Intergrated green fuel retrofit into this agenda would anchor South Africa's position as a regional retrofit hub for the African and Indian Ocean markets

Possible Jobs Created

New jobs:
- Marine Engineer - *Design fuel systems allowing ships to use both conventional and green fuels.*
- Safety Technician - *Inspect vessel-specific ammonia safety systems and procedures.*
- Retrofit Project Manager - *Manage conversion of existing vessels to green fuel capability.*

- Green Fuel System Designer Engineer - *Create detailed designs for vessel fuel system modifications.*
- Fuel Tank Welder - *Build specialized cryogenic and pressurized fuel tanks.*
- Green Fuel Naval Architect - *Design ship modifications to accommodate green fuel systems.*
- Component Manufacturing Technician - Manufacture specialised parts for green fuel systems.
- Utility Inspector - *Certify vessels meet green fuel safety standards.*
- Marine Equipment Designer Engineer - *Develop new fuel system components for marine use.*

Transition jobs:

- Vessel Conversion Supervisor - *Oversee green fuel conversion projects instead of conventional retrofits.*
- Vessel Plan Approval Surveyor - *Review vessel plans against new green fuel regulations.*

Crew Training and Certification

Maritime education must adapt to meet new international requirements for seafarer training on alternative fuels. In February 2025, the IMO's Human Element, Training and Watchkeeping (HTW) Sub-Committee agreed on draft interim guidelines, with final approval expected from the Maritime Safety Committee in June 2025 (IMO, 2025a; IMO, 2025b). Guidelines are also being developed for methanol, ammonia, hydrogen fuel cells, and LPG (IMO, 2025b). Meeting these standards requires significant investment in training infrastructure, including modern simulators capable of replicating alternative fuel operations and emergencies and virtual reality systems (Ship & Bunker, 2025; Safety4Sea, 2025).

South Africa demonstrates regional leadership through institutions such as Cape Peninsula University of Technology and the South African Maritime Training Academy (SAMTRA) in Simon's Town, which operates comprehensive simulation facilities (SAIMI, 2019; SAMTRA, 2024). However, South Africa's training system—like maritime education worldwide—faces challenges in preparing for green fuel operations. The maritime industry recognises major skills gaps in alternative fuel handling, with urgent need to develop competencies for ammonia, hydrogen, and other fuels (Lloyd's Register, 2023). Most existing simulators, in South Africa and globally, are designed for conventional fuels and require adaptation for alternative fuel scenarios. New training modules covering cryogenic fuels, bunkering procedures, and emergency response are also needed (Ammonia Energy, 2025; Maersk Training, 2025).

South Africa has started integrating decarbonisation priorities into maritime training. A national task force on maritime decarbonisation has identified workforce development as a priority area (IMO, 2025c). SAMTRA's facilities could be adapted for ammonia and hydrogen emergency scenarios, while the South African International Maritime Institute (SAIMI) coordinates skills development through the National Seafarer Development Programme and builds partnerships with international shipping companies—essential for providing cadets with sea-time on alternative fuel vessels (SAIMI, 2019; SAIMI, 2021).

Possible Jobs Created

New Jobs:

- Maritime Instructors and Trainers - *Teach seafarers safe handling of ammonia and hydrogen fuels.*
- Curriculum Development Specialists - *Create training materials for green fuel operations.*
- Practical Training Assessors - *Evaluate crew competency in green fuel handling.*
- E-Learning Content Creators - *Develop online training modules for global crew access.*
- Mobile Training Unit Operators - Deliver hands-on training at various port locations.
- Industry Liaison Officer/Business Developer - *Connect training programs with shipping company needs.*

Technical Support and Regulatory Services

Green fuel systems demand specialised expertise throughout the vessel lifecycle, creating new requirements for regulation and consultancy. Evidence from early alternative fuel adoption suggests that port state control inspections of alternative-fuel vessels face new challenges as inspectors adapt to unfamiliar technologies and safety systems. Investment decisions between fuels such as ammonia and methanol require complex analysis of fuel availability, infrastructure timelines, and ownership costs. Economic viability varies significantly by trade route, ship type, and regulatory frameworks such as FuelEU Maritime (Methanol Institute, 2024; Global Maritime Forum, 2024; Spathias, 2024).

South Africa's regulatory infrastructure provides a solid base for this transition. The South African Maritime Safety Authority (SAMSA) carries out port state control inspections under the Indian Ocean Memorandum of Understanding, which reported 5,062 inspections in 2022, rising to 5,785 in 2023 (SAMSA, 2023; Indian Ocean MoU, 2023). International classification societies such as Lloyd's Register, DNV, and Bureau Veritas maintain offices in Durban and Cape Town, acting as regional technical hubs for Sub-Saharan Africa. Despite this capacity, existing expertise is still focused on conventional vessel systems, with limited capabilities for alternative fuels certification and hazard assessment.

Safety oversight is also uneven across the continent. Smaller ports frequently lack specialised emergency response capacity for hazardous fuels, creating vulnerabilities. Digital inspection technologies—including drone-assisted surveys and remote verification systems—offer practical solutions to extend regulatory reach, reduce inspection costs, and address geographic challenges while maintaining compliance with international standards (Lloyd's Register, 2023; DNV, 2019; DNV, 2023).

Academic and research institutions in South Africa can strengthen these capabilities. Engineering programmes at universities, combined with applied maritime research, are well placed to develop skills in alternative fuel systems, risk assessment, digital inspection methods, lifecycle assessment and regulatory innovation for alternative fuels.

Jobs Created

New Jobs:

- Hydrogen Value Chain Expert - *Advise shipping companies on fuel transition strategies.*
- Safety and Hazards Specialist - *Analyse green fuel hazards for specific vessels and routes.*
- Lawyer - *Guide compliance with evolving green shipping regulations.*
- Safety Engineer - *Conduct detailed safety assessments for green fuel systems.*
- Lifecycle Assessment Practitioners - *Calculate environmental impacts of green fuel choices.*
- Green Fuel System Inspectors - *Conduct port state control inspections for green fuel compliance.*
- Digital Survey Technician - *Use remote inspection technologies for green fuel systems.*
- Regulatory Compliance Advisor - *Ensure adherence to international green shipping rules.*
- Administration Specialist - *Verify green fuel certificates and documentation.*

Stage 5: Cross cutting or supporting ecosystem

Research & Development Centers

Research and development centres drive innovation in green maritime fuel technologies, focusing on fuel production efficiency, storage safety, engine optimisation, and environmental impact reduction. Activities range from fundamental research and applied solutions to industry partnerships and demonstration projects, requiring collaboration among chemical engineers, naval architects, environmental scientists, and economists.

South Africa's hydrogen research capacity is anchored in the Hydrogen South Africa (HySA) programme, established in 2008, with three Centres of Competence: HySA Infrastructure at North-West University (hydrogen generation and storage), HySA Catalysis at the University of Cape Town (fuel cell catalysts), and HySA Systems at the University of the Western Cape (technology integration) (Pollet et al., 2014). The programme aims to secure 25% of the global catalyst market by leveraging South Africa's platinum resources (Department of Science and Innovation, 2021).

Future maritime R&D can build on this expertise to tackle shipping-specific challenges, including ammonia combustion efficiency for marine engines, port safety systems, and vessel fuel-cell applications on vessels. South Africa's existing research infrastructure provides strong foundations for these applications, with international collaboration accelerating technology transfer and local innovation ensuring solutions are adapted to African contexts (Pollet et al., 2014).

Possible Jobs Created

New Jobs:

- Research and Development Engineeer - *Develop new marine applications for green fuels.*
- Combustion system Mechanical Engineer - Optimise ammonia combustion in marine engines.
- Safety Systems Researcher - *Innovate new safety technologies for toxic fuel handling.*
- Technology Commercialisation Specialist- *Bring R&D innovations to market readiness.*

Transition Jobs:

- Environmental Impact Analyst/ Environmental Engineer - *Shift focus from general to maritime-specific environmental assessments.*
- Artificial Intelligence (AI) Specialist - *Apply AI to maritime fuel optimization problems.*

Scaled Jobs:

- Laboratory Technician - *Support research through testing and experimentation.*
- Research Project Manager - *Manage research projects and timelines.*

Financial Services

Financial services provide the capital and risk management tools essential for developing green shipping fuels. Key financial needs include project funding for infrastructure, operational capital, insurance for new technologies, and investment products for market growth. The transition to green fuels requires innovative financing solutions to manage technology risks, long development periods, and regulatory changes.

South Africa has strong foundations in sustainable finance. The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) attracted over R193 billion in investment, demonstrating the country's capacity to mobilize significant capital for clean energy projects (Eberhard & Naude, 2017). Research indicates growing stakeholder interest in green bonds as sustainable investment instruments (Ngobese & Makina, 2021). However, financial products specific to green shipping fuels bunkering still need development.

Future developments will likely include bkended finance model. Project funding will combine development banks, commercial lenders, and climate funds through blended finance models proven in South Africa's renewable energy sector (Eberhard & Godinho, 2017). New insurance products must cover risks specific to alternative fuel technologies and vessel operations. South Africa's renewable energy finance experience and mature capital markets create a solid platform for maritime green fuel investments.

Jobs Created

New Jobs:

- Green Shipping Finance Specialist - Structure financing for maritime Power-to-X projects.
- Project Finance Specialist - *Create complex financial structures for green fuel infrastructure.*
- Investment Product Developer - *Design green shipping investment funds.*
- Insurance Claims Assessor - *Process claims related to ammonia incidents.*
- Economic Modeling Specialist - *Model Power-to-X project economics and returns.*

Local Supplier and Equipment Supply Chain Development

South Africa must develop local suppliers and equipment supply chains to participate meaningfully in the green shipping fuel sector. This requires identifying companies with relevant capabilities, establishing reliable inventory systems, and creating partnerships with global technology providers.

The transition to green fuels demands specialised equipment different from conventional marine systems. Ammonia and hydrogen vessels require components such as cryogenic pumps, compatible valves, and advanced monitoring systems. These specialised parts often have longer lead times and fewer certified suppliers globally, creating supply chain challenges that must be addressed through strategic planning.

South Africa's manufacturing base in automotive, mining, and petrochemical industries provides capabilities that could be adapted for marine component production. Major ports in Durban and Cape Town offer established logistics infrastructure including warehousing and hazardous material handling facilities. However, current marine suppliers primarily serve conventional vessels and would need technical training and certification to handle green fuel equipment.

Building effective supply chains will require regional distribution networks to ensure spare parts availability across African ports. Partnerships with international equipment manufacturers can facilitate technology transfer and establish quality assurance systems. By leveraging existing industrial capabilities and port infrastructure, South Africa can develop competitive supply chains serving both domestic and regional green shipping markets.

Jobs Created

New Jobs:

- Supply Chain Specialist - *Build local supplier capabilities for green fuel equipment.*
- Safety and Hazards Specialist - *Manage safe transport of dangerous green fuel equipment.*
- Technical Inventory Manager - *Forecast and manage spare parts for green fuel systems.*
- Component Quality Engineer - *Verify authenticity and compliance of imported green fuel parts.*
- Cluster Coordinator - *Facilitate collaboration within the green fuel industry ecosystem.*
- Supply Chain Specialist - *Optimise distribution networks for green fuel components.*
- Business Developer - *Support SMEs to scale and access green fuel markets.*
- Warehouse Safety Technician - *Ensure safe storage of ammonia-compatible equipment.*

Community Engagement

Community engagement is essential for port cities and surrounding areas to benefit from maritime green fuel development while managing environmental and social impacts. Effective engagement goes beyond consultation to include skills training for local residents, opportunities for small businesses, improvements to local infrastructure, and transparent benefit-sharing arrangements. Because these projects involve large-scale facilities and potentially hazardous materials, maintaining strong community relationships is critical for social acceptance and long-term success.

South Africa already has frameworks for community participation. Environmental Impact Assessments require public consultation, and municipal planning systems incorporate community input into infrastructure projects. Yet responses differ by region: in long-industrialised areas such as Durban South Basin, community organisations are highly mobilised around environmental justice, while in less industrialised port regions engagement needs may centre on employment, health, or land-use concerns.

To succeed, engagement must shift from one-off consultations to genuine partnerships. This includes creating training pathways so residents can access employment across the green fuel value chain, enabling local SMEs to join supply chains, and ensuring surrounding communities benefit from port-linked infrastructure upgrades. The Coega Industrial Development Zone illustrates how industrial projects can integrate employment creation, training, and local procurement into their design, offering a model for replication in other port developments.
Finally, credible engagement requires transparent communication of both risks and opportunities, clear delivery of promised benefits, and responsive systems for addressing community concerns. Ongoing forums and participatory monitoring will help build trust, ensuring that port communities experience real benefits from South Africa's transition to sustainable maritime fuels.

Jobs Created

New Jobs:

- Public Relations Specialist - *Interface between green fuel facilities and local communities.*
- Skills Development Coordinator - *Develop local workforce for green fuel opportunities.*
- Enterprise Development Mentor - *Coach local businesses to participate in green fuel value chain.*
- Environmental Engineer - *Conduct community-based monitoring of facility emissions.*
- Sustainability Specialist - *Measure community benefits from green fuel development.*

6.4. Skills requirement along PtX Maritime Value Chain

The Organising Framework for Occupations (OFO) is South Africa's official classification system for jobs. Each occupation has a unique 6-digit code that links it to national labour market and skills planning. The OFO uses a hierarchical structure where the first digit indicates the major occupational group (1=Managers, 2=Professionals, 3=Technicians, etc.), and subsequent digits provide increasingly specific job classifications. The National Qualifications Framework (NQF) sets the minimum education or training level needed for these occupations, from entry level (NQF 1–4) through to professional and managerial roles (NQF 7–10).

In Table 11 the mapping of occupations across the PtX maritime value chain with their OFO codes (where available), job categories, required skills, and minimum qualifications were carried out. This mapping draws on 2024 Identification of Skills Needed for the Hydrogen Economy published by the Department of Higher Edication and Training (DHET), and aligns these occupantions with the five stages of the PtX maritime value chain (Department of Higher Education and Training, 2024).

Several maritime and engineering occupations essential for port operations are already recognised as high-demand positions in the 2024 Identification of Skills Needed for the Hydrogen Economy. These include Airport or Harbour Manager (132407), Marine Engineering Technologist (214406), and core engineering roles such as Chemical Engineer (214501), Electrical Engineer (215101), Civil Engineer (214201), and Environmental Engineer (214301). This recognition confirms the existing demand for technical expertise that will form the foundation for green shipping fuel development.

As shown in Table 11, many of these high-demand occupations are classified as "Transition" jobs, indicating they require reskilling to meet PtX maritime requirements. Civil engineers must learn port-specific infrastructure requirements for ammonia and methanol bunkering, chemical engineers need marine fuel handling and fuel quality assurance, and electrical engineers require knowledge of ship-to-shore power systems and electrolyser intergration. Similarly, project managers, environmental engineers, and supply chain specialists need upskilling in maritime regulations, port operations, and international shipping standards specific to green fuels.

This targeted maritime reskilling and upskilling is needed to transform existing professionals into PtX specialists, bridging the gap between South Africa's current expertise and green shipping fuel operational requirements.

Table 11: Skills requirements for jobs along PtX Maritime value chain

STAGE 1: UPSTREAM RENEWABLE ENERGY & GREEN HYDROGEN PRODUCTION

Sector/Industry	Job Type	OFO Code	Job Category	Skills Required	Education/Qualifications
Renewable Power Generation (Solar/ Wind Power Plants)	Solar PV Installer	2021-642602	Scaled	Solar panel installation, electrical systems, safety protocols	Technical certificate/diploma in electrical or renewable energy (NQF Level 4 -6)
	Solar Plant Control Room Operator		Scaled	SCADA systems, monitoring software, data analysis, emergency response	Technical diploma in electrical engineering or process control (NQF Level 6)
	Wind Turbine Service Technician		Scaled	Height work, mechanical maintenance, hydraulic systems, troubleshooting	Technical certificate in wind turbine technology, working at heights certification (NQF Level 4-5)
	Wind Farm Control Operator		Scaled	Wind farm monitoring, performance optimization, weather analysis	Technical diploma, SCADA certification (NQF Level 6)
	Renewable Plant Manager		Scaled	Operations management, team leadership, regulatory compliance, budget management	Engineering degree, management qualification, 5+ years experience (NQF Level 7-8)
	Renewable Energy Maintenance Engineer	2021-214401	Scaled	Predictive maintenance, fault diagnosis, equipment optimization	Mechanical/electrical engineering degree (NQF Level 7-8)
Green Hydrogen Production	Electrolyser Technician		New	Electrolyser operation, water chemistry, process control, safety protocols	Diploma in chemical/electrical engineering (NQF Level 6)

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	Hydrogen Plant Control Room Operator		New	Hydrogen production monitoring, process optimization, emergency procedures	Technical diploma, hydrogen safety certification (NQF Level 6)
	Hydrogen system Maintenance Technician	-	New	Specialised H2 equipment maintenance, leak detection, safety systems	Technical qualification with hydrogen-specific training (NQF Level 4-5)
	Hydrogen Quality Engineer		New	Hydrogen purity testing, quality standards, analytical methods	Chemical engineering degree, quality management certification (NQF Level 7-8)
	Hydrogen Safety and Hazards Specialist	-	New	Hydrogen safety protocols, risk assessment, emergency response planning	Engineering degree, safety management qualification (NQF Level 7-8)
	Chemical Engineer	2021-214501	Transition	Electrochemical processes, green hydrogen production, process optimization	Bachelor's degree in chemical or electrochemistry engineering (NQF Level 7-8)
	Electrical Engineer	2021-215101	Transition	DC power systems, electrolyser integration, grid connection	Bachelor's degree in electrical engineering (NQF Level 7-8)
Water Treatment and Desalination Plants	Ultra-pure Water Specialist		New	Ultra-pure water systems, membrane technology, water chemistry	Environmental/chemical engineering degree (NQF Level 7-8)
	Water Treatement Process Engineer	2021-214301	Transition	Water quality standards, environmental compliance, system design	Bachelor's degree in civil/environmental engineering (NQF Level 7-8)
	Desalination Plant Operator		Scaled	Process control systems, water treatment operations, quality monitoring	Certificate in power/stationary engineering (NQF Level 3-4)

	Process Control Engineer	2021-214101	Scaled	Automated control systems, process optimization, data analysis	Bachelor's degree in chemical/electrical engineering (NQF Level 7-8)
	Membrane Maintenance Specialist		Scaled	Membrane maintenance, pump systems, instrumentation	Technical diploma in mechanical engineering (NQF Level 6)
	Water Quality Laboratory Technician	2021-311101	Scaled	Water quality testing, analytical equipment, data recording	Diploma in chemistry/water sciences (NQF Level 6)
Electrical Infrastructure and Grid Connections	Electrical Engineer (DC Specialist)	2021-21501	New	DC electrical design, power electronics, system integration	Electrical engineering degree with DC specialization (NQF Level 7-8)
	Grid Operation Specialist		Transition	Distributed generation, renewable integration, grid stability	Bachelor's/ Master's in Electrical engineering (NQ Level 7-9)
	High Voltage (HV) Substation Technician	2021-311301	Scaled	HV equipment maintenance, safety procedures, testing	Electrical trade qualification (NQF Level 4)
	Instrumentation Engineer	2021-215201	Scaled	Control system design, automation, sensor technology	Bachelor's degree in instrumentation engineering (NQF Level 7-8)
Energy Storage Systems	Energy Storage Specialist		New	Battery management systems, grid integration, performance optimisation	Electrical engineering degree, battery technology certification (NQF Level 7-8)
	Battery Maintenance Technician		Scaled	Battery maintenance, thermal management, safety protocols	Technical diploma with battery systems training (NQF Level 6)

Battery Safety Engineer		Scaled	Battery safety systems, risk assessment, emergency procedures	Chemical/process engineering degree (NQF Level 7-8)

STAGE 2: GREEN FUEL PRODUCTION & PROCESSING

Sector/Industry	Job Type	OFO Code	Job Category	Skills Required	Education/Qualifications
Ammonia Synthesis	Ammonia Process Technician		Transition	Haber-Bosch process, green hydrogen feedstock, process control	Diploma in chemical engineering (NQF Level 6)
	Haber-Bosch Technician		Transition	Variable renewable operations, process monitoring, safety procedures	Certificate in process operations (NQF Level 3-4)
	Nitrogen Plant Operator		Transition	Nitrogen production, integration with hydrogen supply	Certificate in process operations (NQF Level 3-4)
	Ammonia Safety and Hazard Specialist		Transition	Ammonia safety protocols, marine fuel standards, risk management	Bachelor's degree, hazmat certification (NQF Level 7-8)
Methanol Production	Methanol Synthesis Technician		New	CO_2 capture, methanol synthesis, reactor operations	Diploma in chemical engineering (NQF Level 6)
	CO_2 Capture Technician		New	CO_2 capture equipment operation, purification processes	Diploma in chemical engineering (NQF Level 6)
	Methanol Quality Engineer		New	Methanol quality testing, marine fuel specifications	Chemical engineering degree (NQF Level 7-8)

	Process Engineer	2021-214101	New	Carbon integration, process design, optimisation	Bachelor's degree in process engineering (NQF Level 7-8)
Quality Assurance	Marine Fuel Laboratory Technician		New	Marine fuel testing, analytical methods, certification procedures	Shipbuilding management, project supervision, quality control, safety management
	Sustainability Auditor		New	Carbon intensity verification, lifecycle assessment	Specialised welding, marine fabrication, materials knowledge, quality assurance
	Fuel Certification Manager		New	Green fuel standards, ISO compliance, audit procedures	Engineering degree, quality management certification (NQF Level 7-8)
	Quality Assurance Manager	2021-121908	Transition	Green fuel standards, ISO compliance, audit procedures	Engineering degree, quality management certification (NQF Level 7-8)
By-product Management	By-product Coordinator		New	By-product logistics, market development, revenue optimization	Business/operations management degree (NQF Level 7)
	Oxygen Supply Chain Specialist		New	Oxygen distribution, industrial customer management	Supply chain management degree (NQF Level 7)
	Industrial Integration Engineer	2021-214101	Transition	Flexible process integration, by-product utilisation	Bachelor's degree in industrial engineering (NQF Level 7)
	Waste Heat Recovery Plant Operator		Transition	Heat recovery systems, variable operations	Certificate in power engineering (NQF Level 3-4)

STAGE 3: PORT INFRASTRUCTURE & BUNKERING SERVICES

Sector/Industry	Job Type	OFO Code	Job Category	Skills Required	Education/Qualifications
Storage & Handling	Leak Detection System Operator		New	Leak detection systems, ammonia monitoring, emergency response	Technical diploma, hazmat certification (NQF Level 6)
	Cryogenic Storage Operator		New	Cryogenic operations, vapor recovery, storage systems	Diploma in chemical engineering (NQF Level 6)
	Refrigeration System Engineer	2021-214401	New	Refrigeration design, cryogenic systems, safety engineering	Bachelor's degree in mechanical engineering (NQF Level 7-8)
	Vapor Recovery Technician		New	Vapor recovery systems, re-liquefaction processes	Diploma in chemical engineering (NQF Level 6)
	Pipeline Engineer		Transition	Ammonia-compatible materials, corrosion prevention	Chemical/civil/mechanical engineering degree (NQF Level 7-8)
	Pipeline Integrity Specialist		Transition	Non-destructive testing, corrosion monitoring	Engineering degree, pipeline certification (NQF Level 7-8)
	Pipeline Technician		Transition	Toxic gas operations, safety procedures	Certificate/diploma in instrumentation (NQF Level 4-6)
	Storage Operation Manager	2021-132102	Transition	Multi-fuel terminal management, safety protocols	Engineering/business degree, port operations experience (NQF Level 7-8)
	Inventory Control Specialist		Transition	Fuel inventory management, energy density calculations	Supply chain/business degree (NQF Level 7)

	Safety and Hazard Specialist	2021-121206	Transition	Ammonia safety protocols, emergency planning	Engineering degree, safety certification (NQF Level 6-8)
	Corrosion Specialist		Scaled	Cathodic protection, material selection, monitoring	Chemical/materials engineering degree (NQF Level 7-8)
	Pipeline Maintenance Technician		Scaled	Pipeline maintenance, equipment servicing	Technical diploma (NQF Level 6)
	Pipeline Scheduler		Scaled	Construction coordination, maintenance planning	Post-secondary training in business/engineering (NQF Level 5-6)
	Storage Maintenance Technician		Scaled	Storage tank maintenance, equipment servicing	Technical diploma (NQF Level 6)
Safety & Emergency	Gas Detection System Installer	2021-311401	New	Gas detection installation, sensor calibration	Technical diploma in instrumentation (NQF Level 6)
	Fixed System Maintenance Technician		New	Safety system maintenance, suppression systems	Technical diploma, hazmat certification (NQF Level 6)
	Safety Infrastructure Engineer	2021-214101	New	Ammonia safety system design, water curtains	Bachelor's degree in safety/chemical engineering (NQF Level 7-8)
	Drone Pilot for Emergency Assessment		Transition	Emergency assessment, toxic gas monitoring	Commercial drone license, hazmat training (NQF Level 5-6)
	Safety and Hazards Specialist	2021-121206	Transition	Emergency response, toxic gas release management	Engineering degree, safety certification (NQF Level 6-8)
	Medical Emergency Paramedic		Transition	Ammonia exposure treatment, hazmat medical response	Paramedic qualification, hazmat medical training (NQF Level 5-6)

	Environmental Engineer	2021-214301	Transition	Ammonia/methanol incident response, remediation	Environmental engineering degree (NQF Level 7-8)
	Communication Specialist	2021-243201	Transition	Public alert systems, emergency communication	Communications degree, emergency management certification (NQF Level 6-7)
	Emergency System Electrician	2021-671101	Scaled	Emergency electrical systems, safety equipment	Electrical trade qualification (NQF Level 4)
	Technician Supervisor	2021-312103	Scaled	Safety equipment installation, team management	Technical diploma, supervisory training (NQF Level 6-8)
Port Operations	Vessel Compatibility Assessor		New	Vessel assessment, green fuel systems	Bachelor's degree in marine engineering (NQF Level 7)
	Pipeline Scheduler		New	Multi-fuel scheduling, contamination prevention	Business/commerce training (NQF Level 5-6)
	IT Specialist	2021-252201	New	Digital operations, data analytics, system integration	IT/computer science degree (NQF Level 6-7)
	Logistics Optimisation Analyst	2021-132401	New	Green fuel logistics, route optimization	Supply chain management degree (NQF Level 7)
	Operation Manager	2021-132102	New	Disruption recovery, contingency planning	Business/operations degree (NQF Level 7)
	Economic Modelling Specialist	2021-263101	New	Resource allocation, cost optimization	Economics/engineering degree (NQF Level 7)
	Transportation Solutions Advisor		New	Voyage planning, fuel availability mapping	Maritime/logistics qualification (NQF Level 6-7)

	Environmental Compliance Officer	2021-214301	Transition	Green fuel regulations, MARPOL compliance	Environmental engineering degree (NQF Level 7-8)
	Port Safety and Hazard Specialist	2021-121206	Transition	Ammonia/methanol protocols, safety management	Engineering degree, safety certification (NQF Level 6- 8)
	Port Planning Specialist	2021-214201	Transition	Port design with safety buffers	Bachelor's degree in civil engineering (NQF Level 7)
	Supply Chain Specialist	2021-132401	Transition	Green fuel logistics, supply coordination	Supply chain management degree (NQF Level 7)
	Port-Vessel Liaison Officer		Transition	Safety protocols, green fueling communication	Marine engineering degree (NQF Level 7)
	Inventory Planning Manager	2021-132401	Transition	Fuel storage planning, inventory management	Supply chain/business degree (NQF Level 7)
	Port Development Engineer	2021-214201	Scaled	Port infrastructure, expansion projects	Bachelor's degree in civil engineering (NQF Level 7)
	Marine Civil Works Supervisor	2021-214201	Scaled	Marine structures, construction supervision	Civil engineering degree (NQF Level 7)
	Dredging Operations Manager	2021-132102	Scaled	Seabed dredging, port depth maintenance	Engineering/operations degree (NQF Level 7)
Commercial Services	Green Fuel Trading Manager		New	Green fuel market development, trading	Business degree (NQF Level 7)
	Carbon Credit Trader	2021-241301	New	Carbon credit trading, green fuel pricing	Finance/economics degree (NQF Level 6-7)
	Market Development Manager		New	Green fuel market building, demand creation	Business degree (NQF Level 7)

IT Specialist	2021-252201	New	Blockchain certification, digital systems	IT/computer science degree (NQF Level 6-7)
Contract Negotiation Lawyer	2021-261101	Transition	Renewable- linked contracts, green fuel regulations	Law degree, maritime law specialization (NQF Level 7-8)
Pricing Analyst	2021-263101	Transition	Fuel pricing models, carbon value integration	Economics/mathematics degree (NQF Level 7)
Credit Risk Manager	2021-241301	Transition	New market risks, technology risk assessment	Finance degree, risk management (NQF Level 6-7)
Laboratory Technician	2021-311101	Transition	Green fuel testing protocols, new standards	Technical diploma in chemistry (NQF Level 6)
Quality Assurance Manager	2021-121908	Transition	Green fuel audit procedures, compliance	Engineering degree, QA certification (NQF Level 7)
Instrumentation Technician	2021-311401	Scaled	Calibration, measurement accuracy	Technical diploma (NQF Level 6)

STAGE 4: OPERATIONS AND MAINTENANCE

Sector/Industry	Job Type	OFO Code	Job Category	Skills Required	Education/Qualifications
Fleet Operations	Green Fuel Fleet Operation Manager		New	Green fuel fleet coordination, global routing	Business/operations degree (NQF Level 7)
	Voyage Operation Optimisation Specialist		New	Route efficiency, fuel consumption analysis	Engineering/business degree (NQF Level 7-8)
	Supply Chain Specialist	2021-132401	New	Global fuel availability tracking, coordination	Supply chain management degree (NQF Level 7)

	Marine Engines Expert		New	Dual-fuel optimization, engine performance	Bachelor's degree in marine engineering (NQF Level 7)
	Operation Optimisation Specialist		New	Green fuel consumption efficiency, monitoring	Engineering/business degree (NQF Level 7-8)
	Predictive Maintenance Engineer	2021-214401	Transition	Predictive maintenance for green fuel systems	Mechanical engineering degree (NQF Level 7-8)
	Systems Engineer	2021-252301	Scaled	Digital integration, fleet management systeams	Bachelor's degree in systems engineering (NQF Level 6-7)
	Marine Engineer		New	Dual-fuel system design, vessel modification	Bachelor's degree in marine engineering (NQF Level 7)
Vessel Conversion	Safety Technician		New	Ammonia safety inspection, vessel compliance	Technical diploma, marine safety certification (NQF Level 6)
	Retrofit Project Manager	2021-121905	New	Retrofit project management, timeline coordination	Engineering degree, PMP certification (NQF Level 7)
	Green Fuel System Designer Engineer		New	Fuel system design, naval architecture	Engineering degree in relevant field (NQF Level 7-8)
	Fuel Tank Welder	2021-651202	New	Specialized tank fabrication, cryogenic welding	Welding certification, specialized training (NQF Level 4)
	Green Fuel Naval Architect		New	Ship modifications for green fuel systems	Naval architecture degree (NQF Level 7-8)
	Component Manufacturing Technician	2021-311501	New	Component manufacturing, system assembly	Diploma in mechanical engineering (NQF Level 6)

	Utility Inspector		New	Classification society standards, certification	Engineering degree, surveyor qualification (NQF Level 7-8)
	Marine Equipment Designer Engineer		New	Fuel system component development	Engineering degree (NQF Level 7- 8)
	Vessel Conversion Supervisor	2021-312103	Transition	Green fuel conversion supervision	Technical diploma, supervisory experience (NQF Level 6-8)
	Vessel Plan Approval Surveyor		Transition	Vessel plan review, green fuel regulations	Marine engineering degree, surveyor qualification (NQF Level 7)
Crew Training	Maritime Instructor	2021-235101	New	Maritime green fuel training, curriculum development	Teaching qualification, maritime experience (NQF Level 7)
	Curriculum Development Specialist	2021-235101	New	Training material creation for green fuel operations	Education degree, curriculum development (NQF Level 7)
	Practical Training Assessor	2031-235101	New	Crew competency evaluation, green fuel handling	Assessment qualification, maritime experience (NQF Level 7)
	E-Learning Content Creator	2021-252201	New	E-learning development, online platforms	IT degree, instructional design (NQF Level 6-7)
	Mobile Training Unit Operator	2021-235101	New	Mobile training delivery at ports	Teaching qualification, technical skills (NQF Level 7)
	Industry Liaison Officer	2021-242103	New	Industry liaison, training partnerships	Business degree, maritime knowledge (NQF Level 7)
Technical Support	Hydrogen Value Chain Expert		New	Fuel transition consulting, strategy development	Advanced degree in engineering/science (NQF Level 8-9)
	Safety and Hazards Specialist	2021-121206	New	Risk assessment, safety studies	Engineering degree, risk management certification (NQF Level 6-8)

	Lawyer	2021-261101	New	Regulatory compliance, green shipping law	Law degree, maritime specialization (NQF Level 7-8)
	Safety Engineer	2021-214101	New	Safety system assessment, design	Bachelor's degree in safety engineering (NQF Level 7-8)
	Lifecycle Assessment Practitioner	2021-121909	New	Lifecycle assessment, environmental impact	Environmental science degree (NQF Level Level 7-8)
	Green Fuel System Inspector		New	Port state control, green fuel inspection	Engineering degree, inspector certification (NQF Level 7-8)
	Digital Survey Technician	2021-252201	New	Remote inspection technology, digital surveys	IT/engineering degree (NQF Level 6-7)
	Regulatory Compliance Advisor	2021-261101	New	International green shipping rules adherence	Law degree, compliance certification (NQF Level 7-8)
	Administration Specialist	2021-334102	New	Documentation verification, certification	Business administration degree (NQF Level 6)

STAGE 5: CROSS CUTTING OR SUPPORTING ECOSYSTEM

Sector/Industry	Job Type	OFO Code	Job Category	Skills Required	Education/Qualifications
Research & Development Centers	Research and Development Engineer		New	Maritime fuel research, technology development	Master's/PhD in engineering (NQF Level 9-10)
	Combustion System Mechanical Engineer	2021-214401	New	Ammonia combustion optimization	Bachelor's degree in mechanical engineering (NQF Level 7-8)
	Safety Systems Researcher		New	Safety technology innovation for toxic fuels	Engineering degree, research experience (NQF Level 8-9)

	Technology Commercialisation Specialist		New	R&D commercialization, market readiness	Business/engineering degree (NQF Level 7-8)
	Environmental Impact Analyst	2021-214301	Transition	Maritime environmental assessment	Environmental engineering degree (NQF Level 7-8)
	Artificial Intelligence Specialist		Transition	AI for fuel optimization, data analysis	Computer science/AI degree (NQF Level 7-8)
	Laboratory Technician	2021-311101	Scaled	Research support, testing	Technical diploma (NQF Level 6)
	Research Project Manager	2021-121905	Scaled	Research project coordination	Engineering degree, project management (NQF Level 7)
Financial Services	Green Shipping Finance Specialist	2021-241301	New	PtX project finance, maritime focus	Finance/economics degree (NQF Level 6-7)
	Project Finance Specialist	2021-241301	New	Complex financial structures for green fuel infrastructure	Finance degree, project finance experience (NQF Level 6-7)
	Investment Product Developer		New	Green shipping investment funds	Finance degree, product development (NQF Level 7-8)
	Insurance Claims Assessor	2021-241301	New	Ammonia incident assessment	Finance degree, claims experience (NQF Level 6-7)
	Economic Modeling Specialist	2021-263101	New	PtX economics, financial modeling	Economics/finance degree (NQF Level 7)
Local Supplier and Equipment Supply Chain Development	Supply Chain Specialist	2021-132401	New	Supplier development, component sourcing	Supply chain management degree (NQF Level 7)
	Safety and Hazards Specialist	2021-121206	New	Hazmat logistics, safe transport	Safety certification, logistics qualification (NQF Level 6)

	Technical Inventory Manager	2021-132401	New	Spare parts forecasting and management	Supply chain degree (NQF Level 7)
	Component Quality Engineer	2021-214101	New	Component inspection, compliance verification	Engineering degree, quality certification (NQF Level 7-8)
	Cluster Coordinator	2021-242103	New	Industry ecosystem facilitation	Business degree (NQF Level 7)
	Supply Chain Specialist	2021-132401	New	Distribution network optimization	Supply chain degree, analytics skills (NQF Level 7)
	Business Developer	2021-242103	New	SME development, market access	Business degree, development experience (NQF Level 7)
	Warehouse Safety Technician		New	Warehouse safety, ammonia equipment storage	Technical diploma, safety certification (NQF Level 6)
Community Engagement	Public Relations Specialist	2021-122201	New	Community interface, stakeholder engagement	Communications/PR degree (NQF Level 7-8)
	Skills Development Coordinator	2021-235101	New	Local skills development, workforce training	Teaching qualification (NQF Level 7)
	Enterprise Development Mentor	2021-242103	New	Enterprise mentoring, local business support	Business degree, development experience (NQF Level 7)
	Environmental Engineer	2021-214301	New	Community monitoring, environmental assessment	Environmental engineering degree (NQF Level 7-8)
	Sustainability Specialist	2021-121909	New	Social impact assessment, benefit measurement	Social science/sustainability degree (NQF Level 7-8)

Source: Adapted from Identification of Skills Needed for the Hydrogen Economy by DHET (2024)

6.5. Impacts on Employment

Recent analysis of South Africa's green hydrogen economy demonstrates substantial employment creation potential across all five stages of the PtX maritime value chain (SAIIA et al., 2022). Under an export oriented green fuel scenario that includes beth domestic utilisation and international market participation, PtX value chain development becomes a major driver of long-term job creation. Table 12 presents the projected employment impacts for each stage of the value chain under an export-oriented scenario of green fuels that includes both domestic utilisation and international market participation.

Table 12: Skills requirements for jobs along PtX Maritime value chain

PtX Value Chain Stage	Total Jobs by 2050	TVET Jobs by 2050	Jobs at Risk/Transition Source	Intersectoral Migration Potential	Key Occupations	Timeline
Stage 1: Upstream Renewable Energy & Green H_2 Production						
Green Hydrogen Production	52,000	2,300	2,400 + from grey H_2 (Sasol)	High - Direct reskilling from grey to green H_2	Process Controllers, Electrical Engineers	Growth from 2030
Renewable Energy Generation	212,000	11,600	5,900 from coal mining	Medium - Requires location shift and retraining	Solar PV Installers, Wind Turbine Technicians	Immediate 2025-2050
Stage 2: Green Fuel Production & Processing						
Green Ammonia Production	66,000	3,000	2,000 from refineries	High - Similar process skills transferable	Chemical Plant Operators, Chemical Engineers	Post-2035
Stage 3: Port Infrastructure & Bunkering						
Port Power Generation & Infrastructure	212,000	16,600	1,000 from coal power stations	Medium - Infrastructure skills transferable	Marine Engineering Technologists, Harbour Managers	From 2030

Source: Adapted from SAIIA et al. (2022)
Note: Intersectoral Migration Potential rated as High (>70% skills transferable), Medium (40-70% skills transferable), Low (<40% skills transferable)

The analysis reveals that the stages of the green hydrogen value chain (Stages 1-3) could generate approximately 542,000 direct jobs by 2050, with 33,500 positions requiring Technical and Vocational Education and Training (TVET) qualifications, while approximately 11,300 TVET jobs in fossil fuel sectors face displacement within the maritime and related energy sectors (SAIIA et al., 2022). This confirms that green maritime fuels represent a net job creation opportunity, provided that skills development and retraining are proactively managed.

The transition to green shipping fuels requires both specialised technical competencies and transversal skills to ensure workforce adaptability. For the maritime sector, this means developing hydrogen-related capabilities such as managing ammonia and methanol bunkering operations, handling cryogenic storage, ship-to-ship transfer protocols, and complying with new maritime safety regulations. In parallel, digital skills are needed for automated bunkering systems, electronic documentation of green fuel certificates, and remote monitoring of storage and pipeline infrastructure, and integration of emissions-monitoring systems into fleet management platform (IMO Data Collection Systems, Ship Energy Efficiency Management Plan, Carbon Intensity Indicator). Safety protocols also become critical, including the safe handling of toxic ammonia, emergency response readiness at ports, and alignment with International Maritime Organization (IMO) standards.

Pathways for retraining and upskilling depend on how transferable existing skills are. Workers in conventional hydrogen production, bunkering operations, and retroleum refineries show high skills transferability, with over 70% overlap, meaning that process control, safety, and chemical handling competencies can be adapted to green fuel contexts with structured retraining. Medium transferability (40–70%) applies were workers in coal or power generation shift to renewables or port infrastructure, requiring additional training in new technologies.

Labour market dynamics further complicate this transition. According SAIIA et al., (2022), between 2022 and 2030, refinery workers—estimated at around 2,000 TVET jobs—face job losses as fossil marine fuels decline. Bridge opportunities arise through port infrastructure development (2025–2035), which can absorb part of the displaced workforce. The long-term transition (2035–2050) is expected to create large-scale employment in green ammonia and methanol production to serve maritime markets. Overall, South Africa's maritime defossilisation will depend not only on technical and digital training but also on proactive retraining pathways and policies to smooth intersectoral migration, ensuring that the workforce is prepared for the structural shifts in the maritime fuel economy.

6.6. Impact on local communities

The development of green shipping infrastructure presents both opportunities and risks for economic diversification in South African port communities. Analysis by the Council for Scientific and Industrial Research indicates that green hydrogen production could provide alternative economic pathways for industrial zones such as Saldanha Bay and Ngqura, particularly important for regions transitioning from fossil fuel dependence (Roos et al., 2022). The establishment of green shipping corridors positions South African ports as strategic nodes in global green supply chains, with potential for foreign direct investment and skills transfer, and the localisation of high value industrial activities (Global Maritime Forum, 2023). These developments have direct implications for local communities in port cities, influencing employment opportunities, land use, water security, health and safety conditions and the distribution of economic benefits.

6.6.1. Local Enterprise Development

The transition creates specific opportunities for small and medium enterprises (SMEs) in port communities. Green hydrogen development can stimulate local participation through five main channels namely; component manufacturing and assembly services, maintenance and technical support services, environmental monitoring and compliance services, logistics and transportation support; and training and skills development provision. These diverse opportunities enable SMEs to integrate into various stages of the green shipping value chain, from upstream renewable energy services to downstream port operations and monitoring, creating employment multiplier effects and building local technical capacity that can support long-term economic sustainability in port communities (Carpenter-Lomax, Wilkinson, & Ash, 2021).

6.6.2. Social and Environmental Concerns

Land Use and Community Rights

The implementation of large-scale renewable energy projects for green hydrogen production raises concerns regarding land use and community displacement. In the Northern Cape, the proposed Boegoebaai project has generated community concerns about consultation processes and potential impacts on traditional land use (Food for Mzansi, 2022). These concerns highlight the need for clear benefits sharing mechanisms, transparent information and legally strong consultation processes that recognise customary land rights and existing livelihood strategies.

Water Resource Management

Water requirements for green hydrogen production present challenges in water-scarce regions. For example, estimates indicate that large-scale hydrogen production could require significant annual water inputs for electrolysis, necessitating desalination and integrated water resource management to balance industrial and community needs (Uhorakeye, Kopp-

Moini, & Cohen, 2023). Without deliberate planning, there is a risk that new industrial water demand could comptete with municipal supply, agriculture and ecological requirements particularly in stressed catchments areas.

Community Engagement and Participation

Effective community consultation mechanisms are critical for project acceptance and success. Studies on South African port development emphasise that insufficient information sharing and limited participation by local stakeholders can undermine legitimacy and long-term sustainability of maritime infrastructure projects (Carpenter-Lomax et al., 2021). For green shipping projects, this implies a shift from once off public meetings to ongoing, structured engagement processes with clear feedback loops and decision making influence for affected communities.

Health and Safety Management

The handling and storage of ammonia and other alternative maritime fuels introduce new risk profiles for port communities. Key considerations include the development of emergency response protocols, community awareness programmes, regular risk assessments for densely populated port areas, and establishment of buffer zones between storage facilities and residential areas. These safety measures must be integrated into port planning from the outset to protect vulnerable populations and ensure preparedness for potential risks (DNV, 2023). Special attention is required for schools, clinics and informal settlemets located near port industrial zones.

6.6.3. Recommendations for Community Integration

To ensure equitable distribution of benefits and mitigation of negative impacts highlighted above, South Africa needs comprehensive community integration strategies. These strategies should treat communities as partners and rights-holders rather than passive recipients of corporate social investments.

Creating Real Community Participation

Experience with major projects such as Boegoebaai has shown that consultation processes often fall short of community expectations. The South African International Maritime Institute's work on Operation Phakisa demonstrates that successful multi-stakeholder coordination requires structured engagement platforms involving government, industry, and communities (SAIMI, 2024).

Community liaison committees should include voting rights for local representatives on key decisions affecting their areas. This means quarterly forums with authority over local content requirements, environmental monitoring, and benefit distribution. To address information asymmetries, communities should also have access to independent technical advisors funded through project budgets but appointed by community structures.

Supporting Local Business Development

The opportunities for small and medium enterprises in green shipping are significant, but require structured support beyond simple procurement targets. The Coega Industrial Development Zone (Coega IDZ) demonstrates how combining training, supplier development, and enterprise-support initiatives can build lasting local capacity. The Coega Development Corporation integrates skills training through its Skills Development Centre with SMME procurement and incubation programmes that have supported thousands of workers and hundreds of small firms (Coega Development Corporation, 2022; DTIC, 2021b).

Building on this approach, a practical model for new green-port developments could include three stages: (1) Entry-level Integration, engaging local SMEs in entry-level service contracts (catering, security, transport, cleaning etc.), (2) Capability deepening, developing specialised maintenance and monitoring enterprises through targeted technical and business support programmes, and (3) Advanced participation, forming joint ventures for advanced technical operations (for example, cryogenic equipments maintenance or fuel quality testing) with majority local ownership in line with South Africa's empowerment principles.

Fair Benefit Sharing Based on Impact

Under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), project operators contribute at least 1 % of revenue to socio-economic development (SED) and 0.8 % to enterprise development, with a target of 1.5 % SED (IPP Office, 2021; Intellidex, 2021). These mechanisms have mobilised about ZAR 1.2 billion for community initiatives since 2012.

For green maritime fuel projects, a similar approach applies but with more spatially targeted measures. Communities located closest to hazardous operations (within 2 km) should receive enhanced support through priority employment, regular health monitoring, and additional infrastructure investments. These benefits should be administered through community-majority trusts with clear governance rules—rather than company-managed programmes—to strengthen transparency and local ownership.

Water Security Through Smart Industrial Investment

Green hydrogen production consumes about 9 litres of purified water per kilogram of hydrogen (CSIR, 2022; IRENA, 2021). Industrial users can offset this by investing in local water-saving projects—rainwater harvesting, grey-water reuse, and wetland rehabilitation—to achieve at least 1.5 times their own consumption as verified savings. This converts industrial water demand into a source of community benefit and resilience and helps maintain social licence in water-scarce regions.

Skills Development Aligned with Job Creation

The 542 000 potential jobs identified in South Africa's hydrogen economy (SAIIA et al., 2022) call for training aligned with skill-transfer potential. Workers with transferable skills may need short bridging courses, while others require 12- to 24-month reskilling programmes.

To improve outcomes beyond the current ≈ 40 % employment rate for TVET graduates (Bambili Advisory, 2021), training contracts should include guaranteed placements commitments with participating industries—targeting around 80% placement for high-transferability workers and 70% for reskilled cohorts. This would align with public and private training investments with real labour market demand in port regions.

Accountability Through Community-Controlled Monitoring

Monitoring systems should be community-led, giving public access to data on employment, environment, and benefits. Community scorecards can prompt automatic reviews when satisfaction or employment outcomes fall below set thresholds.

This aligns with REIPPPP's quarterly socio-economic reporting requirements (IPP Office, 2021). Persistent non-compliance could trigger penalties, such as directing up to 2% of annual project revenue to affected communities.

These recommendations require coordinated implementation across government departments, port authorities, industry, and community organizations. A dedicated Port Community Integration Office, established within each major green port, should oversee implementation with clear mandates, ring-fenced funding, and quarterly progress reviews, ensuring that green shipping development not only advances decarbonisation objectives, but also delivers tangible, inclusive benefits for all port communities.

7. REFERENCES

Abhold, K., & Shaw, A. (2022). Shipping's energy transition: Strategic opportunities in South Africa. Report for P4G–Getting to Zero Coalition Partnership project. World Economic Forum.

ABS. (2023). Requirements for ammonia-fueled vessels (Guide 325). American Bureau of Shipping. https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/325_guide_ammonia_fueled_vessels/ammonia-fueled-vessels-reqts-e-sept21.pdf

ABS. (2025, May 16). ABS publishes safety insights for ammonia as a fuel. Safety4Sea. https://safety4sea.com/abs-publishes-safety-insights-for-ammonia-as-a-fuel/

Aerni, P. (2021). Business as part of the solution: SDG 8 challenges textbook views on sustainable development. In Transitioning to decent work and economic growth. Basel, Switzerland: MDPI Books.

Africa Oil & Gas Report. (2023, September 26). Sasol: Pilot successful, green hydrogen production starts early 2024. https://africaoilgasreport.com/2023/09/energy-transition/sasol-pilot-successful-green-hydrogen-production-starts-early-2024/

Air Liquide. (2021). Air Liquide finalizes the acquisition of the biggest oxygen production site in the world in Secunda, South Africa. https://www.airliquide.com/group/press-releases-news/2021-06-24/air-liquide-finalizes-acquisition-biggest-oxygen-production-site-world-secunda-south-africa

Air Liquide. (n.d.). Our offices | Air Liquide South Africa. https://za.airliquide.com/our-offices

Air Products. (2021). Home - Air Products - South Africa. https://airproducts.co.za/

All Atlantic Ocean. (2023). Maritime education and training cooperation in South Africa. All-Atlantic Ocean Research Alliance.

All Atlantic Ocean. (2023, April 4). Maritime studies and maritime engineering – Cape Peninsula University of Technology. All Atlantic Ocean. https://allatlanticocean.org/initiatives/maritime-studies-and-maritime-engineering-cape-peninsula-university-of-technology/

Amatola Water. (2019, September 2). Desalination an alternative solution to SA's water supply challenges. https://amatolawater.co.za/talking-water/details/desalination-an-alternative-solution-to-sas-water-supply-challenges

American Bureau of Shipping. (2023). Guide for ammonia fueled vessels. ABS Plaza.

Ammonia Energy Association. (2024, March 20). World-scale green ammonia production in Egypt. Retrieved from https://ammoniaenergy.org/articles/world-scale-green-ammonia-production-in-egypt/

Ammonia Energy Association. (2024, March 20). World-scale solar ammonia plant planned for South Africa. Ammonia Energy Association. https://ammoniaenergy.org/articles/world-scale-solar-ammonia-plant-planned-for-south-africa/

Ammonia Energy Association. (2025). Training requirements for safe ammonia bunkering and fuel use. Ammonia Energy Association.

Ammonia Energy Association. (2025, March 21). Paving the way for ammonia as a marine fuel: Insights into the IMO's interim guidelines. https://ammoniaenergy.org/articles/paving-the-way-for-ammonia-as-a-marine-fuel-insights-into-the-imos-interim-guidelines/

Aramco & Methanol Institute. (2024). Accelerating the net-zero transition: E-fuels for sustainable mobility. https://www.methanol.org/wp-content/uploads/2024/06/240607AramcoMI-Joint-Report-release.pdf

Assad, M. E., AlMallahi, M. N., & Abdelsalam, M. A. (2022). Desalination technologies: Overview. ASET Conference Proceedings, doi:10.1109/ASET53988.2022.9734991

Atlanthia Green Hydrogen (Pty) Ltd. (2024). *Atlanthia Green Hydrogen Project*. Retrieved from https://www.atlanthiagreenhydrogen.com

Augier, C., Engel, H., Girancourt, F., & Onyekweli, O. (2023). Green energy in Africa presents significant investment opportunities. McKinsey & Company. https://www.mckinsey.com/

Aurecon. (2020). 2020 costs and technical parameter review. Australian Energy Market Operator (AEMO).

Bayssi, O. (2024). Green hydrogen landscape in North African countries: Strengths, challenges, and future prospects. International Journal of Hydrogen Energy, 84, 822–839.

Bambili Advisory. (2021). The South African hydrogen economy: A TVET-industry skills gap analysis. South African Institute of International Affairs (SAIIA) – UK PACT Green Hydrogen Programme.

Berger Maritiem. (2025, June 26). HVO in inland shipping: Up to 90% CO2 reduction without retrofit. Berger Maritiem. https://www.bergermaritiem.nl/en/hvo-inland-shipping

Brand South Africa. (2024, April 23). South Africa's biggest desalination plant opens. https://brandsouthafrica.com/113258/news-facts/mossel-211111/

Brand, D., Mahabir, K., & Mthembu-Salter, G. (2021). Green technology opportunities for South African ports and ship manufacturers. Journal of Maritime Economics, 18(1), 32–47.

Britannica. (2024, July 20). Haber-Bosch process. Encyclopedia Britannica. https://www.britannica.com/technology/Haber-Bosch-process

Bullock, S., Mason, J., & Larkin, A. (2022). The urgent case for stronger climate targets for international shipping. Climate Policy, 22(3), 301–309. https://doi.org/10.1080/14693062.2022.2030071

Bureau Veritas. (2024). How infrastructure will lay the foundations for alternative fuels. Marine & Offshore Division. https://marine-offshore.bureauveritas.com/insight/how-infrastructure-will-lay-foundations-alternative-fuels

Bureau Veritas. (n.d.). Contact us | South Africa. https://www.bureauveritas.co.za/contact-us

C-Job Naval Architects. (2023). Ammonia-fuelled tankers could transport and operate on green ammonia by 2030. ShippingWatch. https://shippingwatch.com/regulation/article11448244.ece

Caetano, T., Merven, B., Hartley, F., & Ahjum, F. (2017). Decarbonisation and the transport sector: A socio-economic analysis of transport sector futures in South Africa. Journal of Energy in Southern Africa, 28(4), 10–24. https://doi.org/10.17159/2413-3051/2017/v28i4a2605

Cai, S., Zhang, Q., & Li, X. (2024). A review of electrolyzer-based systems providing grid ancillary services: Current status, market, challenges and future directions. Frontiers in Energy Research, 12, Article 1358333. https://doi.org/10.3389/fenrg.2024.1358333

Carpenter-Lomax, O., Haskell, C., Gaddo, F., & Button, M. (2023). Port infrastructure adaptation for green shipping corridors. Lloyd's Register Maritime Decarbonisation Hub.

Carpenter-Lomax, O., Wilkinson, G., & Ash, N. (2021). South Africa: Fueling the future of shipping. South Africa's role in the transformation of global shipping through green hydrogen-derived fuels. Environmental Defense Fund. https://www.edf.org/

Centre for Environmental Rights. (2019). Sasol operates two ammonia production facilities in Sasolburg and Secunda. In SASOL PPP – May 2019. https://cer.org.za/wp-content/uploads/2019/12/SASOL-PPP-May-2019.pdf

Chellapandian, M., Ranjbar, S., & Maheswari, M. (2023). Safety evaluation of using ammonia as marine fuel by analysing gas dispersion in a ship engine room using CFD. Process Safety and Environmental Protection, 170, 1072-1092. https://doi.org/10.1016/j.psep.2022.12.049

Chemistry LibreTexts. (2023, January 30). The Haber process. Chemistry LibreTexts. https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Equilibria/Le_Chateliers_Principle/The_Haber_Process

Chen, L., Wang, P., & Zhang, T. (2023). Research on digital twin based temperature field monitoring system for LNG storage tanks. Measurement, 215, 112864. https://doi.org/10.1016/j.measurement.2023.112864

CIMAC. (2025). FAQ on ISO 6583:2024 – Methanol as a fuel for marine applications. Retrieved from https://www.cimac.com

ClassNK. (2023). Pathway to zero emission in international shipping. Nippon Kaiji Kyokai. https://www.classnk.or.jp/hp/pdf/info_service/ghg/PathwaytoZero-EmissioninInternationalShipping_ClassNK_EN.pdf

Clean Energy Wire. (2024, July 24). German government adopts import strategy for green hydrogen. Clean Energy Wire. https://www.cleanenergywire.org/news/german-govt-adopts-import-strategy-green-hydrogen

CMB.TECH. (2024, February 12). CMB.TECH to build world's first ammonia-powered container ship in partnership with NCL and Yara. CMB.TECH. https://cmb.tech/news/cmbtech-to-build-worlds-first-ammonia-powered-container-ship-in-partnership-with-ncl-and-yara

Coega Development Corporation (CDC). (2022). Annual report 2021/22. Gqeberha: CDC. https://www.coega.co.za.

Corporate Europe Observatory. (2024). The scramble for hydrogen in South Africa: How frontline communities are impacted by the EU's green extractivism (pp. 13-14). https://www.corporateeurope.org/sites/default/files/2024-12/ScrambleH2SouthAfricaFinalWeb.pdf

Council for Scientific and Industrial Research (CSIR). (2022). Powerfuels 2: Stimulating domestic hydrogen consumption opportunities in South Africa. CSIR Energy Centre / European Union Delegation to South Africa. https://researchspace.csir.co.za/handle/10204/12163

CSIR. (2023). Green Hydrogen in South Africa: Policy, Projects and Opportunities. [Section 3.2]

CSIR. (2024). Identification of skills needed for the hydrogen economy: Research report. Labour Market Intelligence Research Programme. Pretoria: Department of Higher Education and Training.

Daily Maverick. (2023, October 16). Cape provinces sign green hydrogen cooperation deal. Daily Maverick. https://www.dailymaverick.co.za/article/2023-10-16-cape-provinces-sign-green-hydrogen-cooperation-deal/

Decarbonisation Technology. (2024). Ultrapure water for electrolysis. https://decarbonisationtechnology.com/article/228/ultrapure-water-for-electrolysis

Deloitte. (2024, June). Green hydrogen: Incentives to support decarbonization and attract investments. Deloitte Tax at Hand.

Department of Environmental Affairs (DEA). (2014). Operation Phakisa: Ocean economy. Department of Environmental Affairs (DEA).

Department of Higher Education and Training. (2024). National list of occupations in high demand: 2024 (Government Gazette No. 50510). Republic of South Africa. https://www.gov.za/sites/default/files/gcis_document/202404/50510gen2414.pdf

Department of Mineral Resources and Energy (DMRE). (2023, December 1). How much renewable has REIPPPP put on the SA grid? ESI Africa. https://www.esi-africa.com/renewable-energy/how-much-renewable-has-reipppp-put-on-the-sa-grid/

Department of Trade, Industry and Competition. (2023). Green hydrogen (GH_2) commercialisation strategy (GHCS). Pretoria, South Africa: Department of Trade, Industry and Competition.

Department of Transport. (2023, December 6). Policy paper COP26: Clydebank Declaration for green shipping corridors. Department of Transport. https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors

Digital Logistics Capacity Assessments. (2024). South Africa Port of Cape Town. Retrieved from https://lca.logcluster.org/212-south-africa-port-cape-town

DNV. (2019, June 25). Drones herald in new era of inspections. DNV Maritime Impact. https://www.dnv.com/expert-story/maritime-impact/Drones-herald-in-new-era-of-inspections/

DNV. (2023). Alternative fuels for maritime sector: Infrastructure requirements. DNV GL.

DNV. (2023). Remote drone-based ship hull survey. DNV Research Review 2023. https://www.dnv.com/research/review-2023/featured-projects/remote-drone-based-ship-huii-survey/

DNV. (2024, April 7). MRV – Monitoring, reporting and verification (EU and UK). *DNV Maritime*. https://www.dnv.com/maritime/insights/topics/mrv/

DNV. (2024, September 23). Strategies for meeting the earliest decarbonization targets: one key finding is that the well to wake (WtW) emissions ... electrofuels must be produced using electricity with very low GHG intensity. DNV. sciencedirect.com+15dnv.com+15theicct.org+15proman.org+4publications.tno.nl+4arxiv.org+4

DNV. (2024a). Energy transition outlook 2024: A global and regional forecast to 2050. https://www.dnv.com/energy-transition-outlook/

DNV. (2024b). Maritime forecast to 2050. https://www.dnv.com/maritime/publications/maritime-forecast-2050.html

DNV GL. (2019). Alternative Marine Fuels Study: Collection of well to wake GHG emission data for marine fuel pathways (Report No. 2019 0567, Rev. 4). DNV GL.

Domashenko, E. (n.d.). Why shipping could still use fuel oil even with additional EU ETS costs. Market opinion and analysis blog. Argus Media. Retrieved June 14, 2025, from https://www.argusmedia.com/pt/news-and-insights/market-opinion-and-analysis-blog/why-shipping-could-still-use-fuel-oil-even-with-additional-eu-ets-costs

Dormac. (2023). Dormac Marine & Engineering. Retrieved from https://www.dormac.net/

Dräger Safety. (2024). Gas detection systems for ammonia applications in ports. Dräger Safety AG & Co.

DTIC. (2021a). South African Special Economic Zones Programme. [pp. 7, 11, 15]

DTIC. (2021b). Industrial Policy Action Plan review.

Duong, P. A., Ryu, B., Kim, C., Lee, J., & Kang, H. (2023). Regulatory gap analysis for risk assessment of ammonia-fuelled ships. Ocean Engineering, 287, 115751. https://doi.org/10.1016/j.oceaneng.2023.115751

Dwyer, N., & Bauroth, E. (2021). Emerging issues in ocean and coastal law: MARPOL Annex VI—Air pollution from ships. Ocean and Coastal Law Journal, 26(1), 68–76.

Eberhard, A., & Godinho, C. (2017). A review and exploration of the status, context and political economy of power sector reforms in Sub-Saharan Africa, South Asia and Latin America. Energy Policy, 111, 722-734.

Eberhard, A., & Naude, R. (2017). The South African renewable energy IPP procurement programme: Review, summary and recommendations. University of Cape Town Graduate School of Business. https://www.gsb.uct.ac.za/files/EberhardNaude_REIPPPReview_2017_1_1.pdf

Engineering News. (2023). Study under way to produce green directly reduced iron at mothballed Saldanha Works. https://www.engineeringnews.co.za/article/study-under-way-into-producing-green-direct-reduced-iron-at-mothballed-saldanha-works-2023-10-11

Engineering News. (2023, August 23). Sasol produced first green hydrogen from Sasolburg electrolyser in June. https://www.engineeringnews.co.za/article/sasol-produced-first-green-hydrogen-from-sasolburg-electrolyser-in-june-2023-08-23

Engineering News. (2023, December 11). Transnet issues RFP for terminal operators to operate green fuel terminals at South Dunes Precinct. IOL Business Report. Retrieved from https://www.iol.co.za/business-report/economy/transnet-issues-rfp-for-terminal-operators-to-operate-green-fuel-terminals-at-south-dunes-precinct-ab7a23c0-0c34-4dfc-9900-81067d4ba1ca

Engineering News. (2024, January 15). Richards Bay port advances renewable energy initiatives with solar PV development. https://www.engineeringnews.co.za/article/richards-bay-port-solar-pv-2024-01-15

Engineering News. (2024, January 15). Richards Bay port renewable energy development programme.

Engineering News. (2024, March 20). TNPA boosts energy hub status in the Port of Richards Bay. Retrieved from https://www.engineeringnews.co.za/article/tnpa-boosts-energy-hub-status-in-the-port-of-richards-bay-2024-03-20

Engineering News. (2024, April 12). Saldanha Bay ideal for green hydrogen production. https://www.engineeringnews.co.za/article/saldanha-bay-ideal-for-green-hydrogen-production-2022-04-19

Engineering News. (2024, July 24). Port of Richards Bay moves to diversify beyond bulk exports while bolstering climate resilience. Retrieved from https://www.engineeringnews.co.za/article/port-of-richards-bay-moves-to-diversify-beyond-bulk-exports-while-bolstering-climate-resilience-2024-07-24

Environmental Change Institute. (2024). Green ammonia could decarbonize 60% of global shipping when offered at just 10 regional fuel ports. University of Oxford. Retrieved from https://www.eci.ox.ac.uk/news/green-ammonia-could-decarbonize-60-global-shipping-when-offered-just-10-regional-fuel-ports

ESI-Africa. (2025, January 13). SSA's first concentrated solar thermal power (CSP) plant. https://www.esi-africa.com/elites/redstone-ssas-first-concentrated-solar-thermal-power-csp-plant/

Eskom Heritage. (2023, November 30). Lethabo Power Station. https://www.eskom.co.za/heritage/lethabo-power-station/

European Commission. (2023). *Regulation (EU) 2023/1805 on the use of renewable and low-carbon fuels in maritime transport* (FuelEU Maritime). Official Journal of the European Union.

EXMAR. (2023, March). Additional order for two ammonia-fuelled 46,000 m³ LPG/ammonia gas carriers. EXMAR. https://exmar.com/en/milestones/additional-order-for-two-ammonia-fuelled-46000-m%C2%B3-lpg-ammonia-gas-carriers-2/

Gaddo, F., Haskell, C., & Button, M. (2021). Port infrastructure requirements for alternative marine fuels: A socio-technical perspective. Transportation Research Part D: Transport and Environment, 98, 102981. https://doi.org/10.1016/j.trd.2021.102981

Global Africa Network. (2022). Green hydrogen economy: Boegoebaai port development feasibility study.

Global Africa Network. (2022). The Boegoebaai Port and Green Hydrogen Cluster. Retrieved from https://www.globalafricanetwork.com/manufacturing/boegoebaai-port-and-green-hydrogen-cluster/

Global Centre for Maritime Decarbonisation (GCMD). (2025, January 15). Phase 1: Ammonia bunkering pilot safety study. Retrieved from https://www.gcformd.org/projects/ammonia-bunkering-pilot-safety-study/

Global Maritime Forum. (2021). Global Maritime Forum Annual Summit 2021: Summary from virtual to in-person. Global Maritime Forum.

Global Maritime Forum. (2022, March 21). Methanol as a scalable zero-emission fuel. Global Maritime Forum. https://globalmaritimeforum.org/insight/methanol-as-a-scalable-zero-emission-fuel/

Global Maritime Forum. (2023). The implications of the IMO Revised GHG Strategy for shipping. https://globalmaritimeforum.org/insight/the-implications-of-the-imo-revised-ghg-strategy-for-shipping/

Global Maritime Forum. (2024). Alternative fuels: Retrofitting ship engines. Retrieved from https://globalmaritimeforum.org/insight/alternative-fuels-retrofitting-ship-engines/

Global Maritime Forum. (2024). Annual progress report on green shipping corridors 2024. Retrieved from https://globalmaritimeforum.org/report/annual-progress-report-on-green-shipping-corridors-2024/

Global Maritime Forum. (2024, March 7). Zero-emission shipping fuels: A guide to methanol and ammonia. Global Maritime Forum. https://globalmaritimeforum.org/news/zero-emission-shipping-fuels-methanol-and-ammonia/

GreenCape. (2025). Large-scale renewable energy 2025. https://greencape.co.za/wp-content/uploads/2025/04/Large-Scale-Renewable-Energy-2025.pdf

Hansson, J., Brynolf, S., Fridell, E., & Lehtveer, M. (2020). The potential role of ammonia as marine fuel—Based on energy systems modeling and multi-criteria decision analysis. Sustainability, 12(8), 3265. https://doi.org/10.3390/su12083265

HaskoningDHV. (2025). Port master planning for ammonia integration. https://www.haskoning.com/en/newsroom/blogs/2025/port-master-planning-for-ammonia-integration

Hirdaris, S. E., et al. (2024). Safe and efficient storage of ammonia within ships - List of identified classification rule requirements. Marine Structures, 94, 103556. https://doi.org/10.1016/j.marstruc.2024.103556

Hive Energy. (2024). Coega Green Ammonia Project. https://www.hiveenergy.co.uk/clean-futures/green-hydrogen/coega-green-ammonia-project/

Hive Energy. (2024, February 27). Hive Hydrogen and Genesis Eco-Energy Developments sign wind power agreement for $5.8bn Coega green ammonia plant. https://www.hiveenergy.co.uk/2024/02/27/hive-hydrogen-and-genesis-eco-energy-developments-sign-wind-power-agreement-for-5-8bn-coega-green-ammonia-plant/

Hive Energy. (2025, June 12). Hive Hydrogen completes South Africa's largest solar PV plant development phase. Retrieved from https://www.hiveenergy.co.uk/2025/06/12/hive-hydrogen-completes-south-africas-largest-solar-pv-plant-development-phase/

Hove, P., & Masocha, R. (2014). Interaction of technological marketing and Porter's five competitive forces on some competitiveness in South Africa. Mediterranean Journal of Social Sciences, 5(4), 254–262.

Hydrogen Tech World. (2022, October 31). Water treatment for green hydrogen: What you need to know. https://hydrogentechworld.com/water-treatment-for-green-hydrogen-what-you-need-to-know

Hydrogen Tech World. (2023, November 28). Electrodeionization processes for ultrapure water production in green hydrogen generation. https://hydrogentechworld.com/electrodeionization-processes-for-ultrapure-water-production-in-green-hydrogen-generation

Hydrogen Training Solutions. (2024). Principles of PEM electrolyser operation. https://www.hydrogentrainingsolutions.co.uk/principles-of-pem-electrolyser-operation

HySA Infrastructure. (2024). Special demonstration projects. https://hysainfrastructure.com/info/

ICCT. (2023, April). Key issues in LCA methodology for marine fuels. International Council on Clean Transportation (ICCT). theicct.org

IFPEN. (2025). Life cycle assessment of e-/bio-methanol and e-/grey-/blue-ammonia for maritime transport. Commissioned by CMA-CGM. https://www.ifpenergiesnouvelles.fr/sites/ifpen.fr/files/inline-images/20250310_IFPEN_CMACGM_LCA%20and%20Regulations_NH3_MeOH_VF%20(003).pdf

IIoT World. (2023). Elevating predictive maintenance: The transformative impact of IIoT. Industrial Internet of Things World.

IMO. (2020). Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel (MSC.1/Circ.1621). International Maritime Organization.

IMO. (2024). Interim guidelines for the safety of ships using ammonia as fuel (MSC.1/Circ.1687). International Maritime Organization.

IMO. (2024). Report of the Marine Environment Protection Committee on its eighty-first session. MEPC 81/16.

IMPCA. (2024). IMPCA Reference Specifications for Methanol. International Methanol Producers and Consumers Association.

Indian Ocean MoU. (2023). Indian Ocean MoU annual report 2023. PMDS. https://panamamaritime.com/pmds/2024/04/24/indian-ocean-mou-annual-report-2023/

Indian Register of Shipping. (2022). Guidelines for risk-based design of fuel containment systems for ammonia as marine fuel. IRClass Systems and Solutions. https://www.irclass.org/media/7356/guidelines-on-ammonia-fueled-vessels_december-2022.pdf

Industrial Development Corporation (IDC) of South Africa. (2023, October 17). Green Hydrogen Commercialisation Strategy for South Africa: Full report (public submission) [PDF]. IDC. Retrieved June 14, 2025, from https://www.idc.co.za/wp-content/uploads/2023/11/GHCS-Full-Report-17Oct23-Public-Submission.pdf

Institute for Sustainable Process Technology (ISPT). (2017). Power to ammonia: Feasibility study for the value chains and business cases to produce CO_2-free ammonia suitable for various market applications. Amersfoort, The Netherlands: Institute for Sustainable Process Technology.

International Association of Ports and Harbours. (2024). Study on investment requirements of developing countries for port decarbonisation and adaptation to climate change. IAPH.

International Council on Clean Transportation (ICCT). (2022). The effectiveness of the IMO's GHG strategy: A technical review. ICCT. https://theicct.org

International Energy Agency. (2024). Ammonia technology roadmap - Executive summary. IEA. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary

International Energy Agency (IEA). (2024). Electrolysers - Energy system. https://www.iea.org/energy-system/low-emission-fuels/electrolysers

International Energy Agency (IEA). (2024). Global Hydrogen Review 2024. https://www.iea.org/reports/global-hydrogen-review-2024

International Maritime Organization. (2020). Fourth IMO greenhouse gas study. International Maritime Organization.

International Maritime Organization (IMO). (2018, April 23). IMO adopts an initial strategy on the reduction of greenhouse gas emissions from ships, with a vision which aims to phase them out, as soon as possible in this century. International Maritime Organization. https://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

International Maritime Organization (IMO). (2022). Interim guidelines on the use of biofuels under regulations 26, 27 and 28 of MARPOL Annex VI (DCS and CII) (MEPC.1/Circ.905). London: IMO.

International Maritime Organization (IMO). (2023). 2023 IMO Strategy on Reduction of GHG Emissions from Ships. https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx

International Maritime Organization. (2023, September 29). Progress on safety guidelines for hydrogen- and ammonia-fuelled ships. https://www.imo.org/en/MediaCentre/Pages/WhatsNew-1968.aspx

International Maritime Organization (IMO). (2023, July 7). Revised GHG reduction strategy for global shipping adopted. International Maritime Organization. https://www.imo.org/en/MediaCentre/PressBriefings/Pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx

International Maritime Organization (IMO). (2024). 2024 Guidelines on life cycle GHG intensity of marine fuels (Resolution MEPC.391(81)). IMO.

International Maritime Organization. (2025a, February 14). Sub-Committee on Human Element, Training and Watchkeeping (HTW 11) - 11th session. IMO Meeting Summaries. https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/HTW-11th-session.aspx

International Maritime Organization. (2025a, February 19). Interim generic guidelines agreed for training seafarers on ships using alternative fuels. IMO News. https://www.imo.org/en/MediaCENTRE/Pages/WhatsNew-2225.aspx

International Maritime Organization. (2025b, February 14). Sub-Committee on Human Element, Training and Watchkeeping (HTW 11) - 11th session. IMO Meeting Summaries. https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/HTW-11th-session.aspx

International Maritime Organization (IMO). (2025c). Report of the National Task Force on Maritime Decarbonisation: South Africa case study. London: International Maritime Organization.

International Renewable Energy Agency (IRENA). (2020). Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5°C climate goal. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

International Renewable Energy Agency (IRENA). (2021). A pathway to decarbonise the shipping sector by 2050. Abu Dhabi, United Arab Emirates: International Renewable Energy Agency.

International Renewable Energy Agency (IRENA). (2020). Green Hydrogen: A Guide to Policy Making. [Sections 4.3, 5.2]

International Renewable Energy Agency (IRENA). (2023). Socio-economic footprint of the energy transition: South Africa. Abu Dhabi, United Arab Emirates: International Renewable Energy Agency.

International Renewable Energy Agency (IRENA). (2024). Renewable energy and jobs annual review 2024. IRENA.

International Renewable Energy Agency (IRENA). (2024). World energy transitions outlook 2024. Abu Dhabi, United Arab Emirates: International Renewable Energy Agency.

International Renewable Energy Agency (IRENA) & International Labour Organization (ILO). (2022). Renewable energy and jobs annual review 2022. IRENA/ILO.

Intertek. (n.d.). South Africa petroleum, fuel, and chemical testing. https://www.intertek.com/petroleum/south-africa/

Intellidex. (2021). An assessment of economic development under South Africa's REIPPPP. Johannesburg: Intellidex Research. https://www.intellidex.co.za

Independent Power Producer Office (IPP Office). (2021). REIPPPP Economic Development Annual Report 2019/20. Department of Mineral Resources and Energy (DMRE), Republic of South Africa. https://www.ipp-projects.co.za

IPP Office. (2024). Independent Power Producers Procurement Programme (IPPPP): An overview as at 31 March 2024 (Quarterly Report, Quarter 4 2023/24). Department of Mineral Resources and Energy, Republic of South Africa. https://www.ipp-projects.co.za/Publications

ISO. (2024). ISO 6583:2024 – Methanol as a fuel for marine applications – General requirements and specifications. International Organization for Standardization.

Jang, H., Jeong, B., Zhou, P., Ha, S., Park, C., Nam, D., & Rashedi, A. (2023). Safety assessment of the ammonia bunkering process in the maritime sector: A review. Energies, 16(10), 4019. https://doi.org/10.3390/en16104019

Kathu Solar Park. (2019). Kathu Solar Park: Concentrated solar power. https://www.kathusolarpark.co.za/

Khato Civils. (2020, July 1). Transnet Saldanha Bay bulk power supply. https://www.khatocivils.com/project/transnet-saldanha-bay-bulk-power-supply-khato-civils-pty-ltd/

Kim, K., Roh, G., Kim, W., & Chun, K. (2023). Operational and economic evaluation of ammonia bunkering – Bunkering supply chain perspective. Transportation Research Part D: Transport and Environment, 117, 103666. https://doi.org/10.1016/j.trd.2023.103666

Kyriakarakos, G., Swartbooi, A., Snyman-van der Walt, L., & Uehlecke, H. (2024). Pre-feasibility study on lighthouse technology methanol. Pretoria, South Africa: GFA Consulting Group, CSIR, and H2Global Advisory.

Lekela Power. (2020). South Africa, Kangnas. https://lekela.com/projects/south-africa-kangnas/

Lim, S., Yoo, S., Ha, S., & Kim, J. (2023). Risk assessment of ammonia bunkering operations: A consequence-based approach. Journal of Hazardous Materials, 451, 131157. https://doi.org/10.1016/j.jhazmat.2023.131157

Lloyd's Register. (2021, April 14). Potential of ammonia as a shipping fuel. Retrieved from https://www.lr.org/en/knowledge/horizons/april-2021/decarbonising-shipping--could-ammonia-be-the-fuel-of-the-future/

Lloyd's Register Group Services Limited. (2024, June). Marine biofuels: Alternative shipping fuel. Lloyd's Register. https://www.lr.org/en/knowledge/research/fuel-for-thought/biofuel/

Longden, T., Jotzo, F., Prasad, M., & Andrews, R. (2020). Green hydrogen production costs in Australia: Implications of renewable energy and electrolyser costs. CCEP Working Paper 20-07. Crawford School of Public Policy, Australian National University.

MAERSK. (2023, June 13). Maersk secures green methanol for maiden voyage of the world's first methanol-enabled container vessel. MAERSK. https://www.maersk.com/news/articles/2023/06/13/maersk-secures-green-methanol

Maersk Training. (2025). Cryogenic fuels training and safety modules for seafarers. Copenhagen: Maersk Training.

Marcelo, H. (2022). Potential synergies between industrial carbon emitters and the maritime transportation sector: A path towards decarbonisation (Masters' thesis).

Maritime AI Consortium. (2024). Artificial intelligence in maritime transportation: A comprehensive review. Applied Sciences, 14(18), Article 8420.

Maritime Executive. (2023, November 17). Durban warns it could take 15 weeks to clear backlog as 60 ships wait. Retrieved from https://maritime-executive.com/article/durban-warns-it-could-take-15-weeks-to-clear-backlog-as-60-ships-wait

Matola Gas Company. (2024). About Matola Gas Company. Retrieved from https://www.mgc.co.mz/en/about-us/about-matola-gas-company/

McKinsey & Company. (2020). The mining value chain: A hidden gem. McKinsey Metals & Mining Practice Report.

McKinsey & Company. (2024). The power of predictive maintenance with IoT. McKinsey Global Institute.

Methanol Institute. (2024, September). Economic value of methanol for shipping under FuelEU Maritime and EU ETS. Methanol Institute. https://www.methanol.org/wp-content/uploads/2024/09/ECONOMIC-VALUE-OF-METHANOL-FOR-SHIPPING-PAPER_final.pdf

Millennium Institute. (2022). The green hydrogen economy: Challenges and opportunities for national development. Cases for Namibia, South Africa, and Brazil. Green Hydrogen Business Alliance (H2A) on behalf of the German Federal Ministry for Economic Cooperation.

Monaisa, L., & Maimele, S. (2023). The European Union's Carbon Border Adjustment Mechanism and implications for South African exports. Pretoria, South Africa: Trade and Industrial Policy Strategies.

MTBS & IAPH. (2024). Port climate investments: Global developments and outlook 2024 (Corrected version). International Association of Ports and Harbors (IAPH). https://www.iaphworldports.org/n-iaph/wp-content/uploads/2024/09/2024-09-26-MTBS-IAPH-Port-Climate-Investments-Report-corrected.pdf

Mthembu, S. P. (2023). An assessment of the capacity and the performance of marine services in South Africa's ports. Journal of Transport and Supply Chain Management, 17, Article a879.

mtu Solutions. (2019, September 29). E-diesel and HVO make mtu engines (almost) climate-neutral. mtu Solutions. https://www.mtu-solutions.com/eu/en/stories/company/hvo-makes-mtu-engines-almost-climate-neutral.html

Naidoo, G. (2022). Strategies for a sustainable bunker fuel in South Africa. Cape Town, South Africa: Linsen Nambi Bunkering Services.

National Energy Technology Laboratory. (n.d.). Commercial use of Fischer-Tropsch synthesis. https://netl.doe.gov/research/carbon-management/energy-systems/gasification/gasifipedia/sasol

News24. (2024, March 1). Durban Port stabilised as Transnet removes 30 000 containers from backlog. Retrieved from https://www.news24.com/business/economy/durban-port-stabilised-as-transnet-removes-30-000-containers-from-backlog-20240301

NexantECA. (2024). Making money out of thin air: Valorizing the oxygen byproduct of green hydrogen production. https://www.nexanteca.com/blog/202401/making-money-out-thin-air-valorizing-oxygen-byproduct-green-hydrogen-production

Ngobese, T., & Makina, D. (2021). Understanding the determinants of the development of the green bond market in South Africa. South African Journal of Business Management, 52(1), a2769. https://sajbm.org/index.php/sajbm/article/view/4065/2769

North-West University (NWU). (2024). Hydrogen South Africa (HySA). https://engineering.nwu.ac.za/research/hydrogen-south-africa-hysa

Northern Cape Department of Economic Development and Tourism. (2022). Northern Cape's proposed green hydrogen hub can help open region's full energy potential. Mining Weekly. Retrieved from https://www.miningweekly.com/article/northern-capes-proposed-green-hydrogen-hub-can-help-open-regions-full-energy-potential-2022-09-22

Northern Cape Economic Development Agency. (2022). Boegoebaai green hydrogen hub: Infrastructure master plan. NCEDA.

Northern Cape Government. (2024). Northern Cape delegation visits Sasol operations as Boegoebaai green hydrogen project moves forward. http://www.northern-cape.gov.za/index.php/about-us/nc-dg/152-media-room/office-of-the-premier/news-and-speeches/1746-northern-cape-delegation-visits-sasol-operations-as-boegoeberg-green-hydrogen-project-moves-forward

NS Energy. (2024, November 17). Coega Green Ammonia Project, South Africa. https://www.nsenergybusiness.com/projects/coega-ammonia-project-south-africa/?cf-view

Occupational Safety and Health Administration. (2024). Storage and handling of anhydrous ammonia (Standard No. 1910.111). Retrieved from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.111

Offshore Energy. (2022, November 15). Egypt ramping up efforts to make SCZONE clean fuel production hub. Retrieved from https://www.offshore-energy.biz/egypt-ramping-up-efforts-to-make-sczone-clean-fuel-production-hub/

Oliveira, A. M., Veríssimo, P. H. A., et al. (2024). Oxygen liquefaction economical value in the development of the hydrogen economy. International Journal of Hydrogen Energy, 61, 721-732. https://doi.org/10.1016/j.ijhydene.2024.02.244

Omnia & WKN Windcurrent. (2023, February 2). Omnia, WKN Windcurrent sign MoU to evaluate green ammonia production at Sasolburg plant. Bizcommunity. https://www.bizcommunity.com/Article/196/648/235590.html

Ovrum, E. (2023, June). Exploring the potential of biofuels for shipping. DNV. https://www.dnv.com/expert-story/maritime-impact/Exploring-the-potential-of-biofuels-in-shipping/

Pacific Island States Coalition. (2024). Proposal for carbon levy on international shipping. Submission to IMO MEPC 81.

PetroSA. (2022). Our history | PetroSA. https://www.petrosa.co.za/history.html

PetroSA. (2023). Annual Report 2022/23. Cape Town: The Petroleum Oil and Gas Corporation of South Africa SOC Limited. Retrieved from http://www.petrosa.co.za

PMC. (2024). Operating envelope of Haber–Bosch process design for power-to-ammonia. PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC9087324/

Power Engineering International. (2016, March 24). Conserving water at the world's largest air-cooled coal plant. https://www.powerengineeringint.com/coal-fired/conserving-water-at-the-world-s-largest-air-cooled-coal-plant/

Power Technology. (2019, September 23). Duvha Power Station. https://www.power-technology.com/projects/duvha-power-station/

Procurement Resource. (n.d.). Ammonia price trends. https://www.procurementresource.com/resource-center/ammonia-price-trends

Red Rocket Energy. (2022, March 16). Red rocket advances with launch of one of South Africa's biggest wind farms. Energy Capital & Power. https://energycapitalpower.com/red-rocket-advances-with-launch-of-one-of-south-africas-biggest-wind-farms/

Republic of Mozambique Pipeline Company. (2024). Cross-border pipeline operations: Lessons from the Mozambique-South Africa gas pipeline. ROMPCO Technical Series.

Republic of Mozambique Pipeline Investments Company (ROMPCO). (2024). Maintaining an 800km pipeline through two countries is no mean feat. Retrieved from https://www.rompco.co.za/2024/08/28/maintaining-an-800km-pipeline-through-two-countries-is-no-mean-feat/

Ricardo & EDF. (2021). South Africa: Fuelling the future of shipping – Feasibility study. P4G Getting to Zero Coalition. https://www.globalmaritimeforum.org/content/2021/11/South-Africa-Fuelling-the-future-of-shipping.pdf

Roelf, W. (2025, June 12). South Africa's $5.8 billion Hive project aims to lead low cost ammonia output. Reuters. Retrieved from https://www.reuters.com/sustainability/south-africas-58-billion-hive-project-aims-lead-low-cost-ammonia-output-2025-06-12/

Roos, T., & Wright, J. (2021). Powerfuels and green hydrogen. European Commission.

Roos, T., Chauke, M., Oloo, F., & Mbatha, L. (2022). Powerfuels 2: Stimulating domestic hydrogen consumption opportunities in South Africa. Brussels, Belgium: European Commission.

S&P Global. (2024, April 26). Hydrogen markets progress towards price transparency. https://www.spglobal.com/commodity-insights/en/news-research/latest-news/energy-transition/042624-hydrogen-markets-progress-towards-price-transparency

Safety4Sea. (2025). IMO alternative fuel training requirements: Industry prepares for next steps. Retrieved from https://safety4sea.com

Safety4Sea. (2025, April 23). IMO rolls out training on alternative fuels. Safety4Sea. https://safety4sea.com/imo-rolls-out-training-on-alternative-fuels/

SAIMI (South African International Maritime Institute). (2021). Annual report 2021: Building capacity for South Africa's maritime sector. Port Elizabeth: SAIMI.

SAIMI – South African International Maritime Institute. (2024). Skills audit and needs analysis for the marine transport sector in South Africa. Gqeberha: SAIMI / Department of Higher Education and Training.

SAIIA, Energy & Water SETA, Department of Science and Innovation, & UK PACT. (2022). The South African green hydrogen TVET ecosystem: Just transition strategic framework. Johannesburg: South African Institute of International Affairs.

SAMSA (South African Maritime Safety Authority). (2024). Maritime training and seafarer development in South Africa. Pretoria: SAMSA.

SAMTRA (South African Maritime Training Academy). (2024). Training catalogue and simulator facilities. Simon's Town: SAMTRA.

Sasol. (2021, October 6). Sasol and IDC to lead feasibility study for green hydrogen project in Boegoebaai. https://www.sasol.com/media-centre/media-releases/sasol-and-idc-lead-feasibility-study-green-hydrogen-project-boegoebaai

Sasol. (2023). *Sasolburg Green Hydrogen Pilot*. Retrieved from https://www.sasol.com/sites/default/files/2023-12/Fact%20Sheet%20Sasolburg%20Green%20Hydrogen%20Pilot.pdf

SASOL LIMITED. (2024). *HyshiFT Consortium*. Retrieved from https://www.sasol.com/sites/default/files/2022-11/SASOL_CC%20Report%202022_12112022%20reduced_2.pdf

Sasol. (2024). Integrated Report 2023 (p. 27). Retrieved from https://www.sasol.com/sites/default/files/2024-08/SASOL%20Integrated%20Report%202023_0.pdf

Sasol. (2024). Sasol - Wikipedia. https://en.wikipedia.org/wiki/Sasol

Sasol Chemicals. (2024, February 28). Sasol Chemicals produces and sells more than 540,000 t/y of ammonia. Engineering News. https://www.engineeringnews.co.za/article/sasol-to-fund-tfrs-maintenance-of-128-ammonia-tankers-2024-02-28

Schuller, O., Bopp, J., & Rapp, J. (2024). 1st life cycle GHG emission study on the use of ammonia as marine fuel. Society for Gas as a Marine Fuel Limited (SGMF).

ScienceDirect. (2024). Anhydrous ammonia - An overview. Retrieved from https://www.sciencedirect.com/topics/engineering/anhydrous-ammonia

SGS. (n.d.). Fuel oil testing | SGS South Africa. https://www.sgs.com/en-za/services/fuel-oil-testing

Ship & Bunker. (2023). Engen to turn Durban refinery into storage terminal. Retrieved from https://shipandbunker.com/news/emea/595179-engen-to-turn-durban-refinery-into-storage-terminal

Ship & Bunker. (2025). Simulator investment needed to meet IMO training guidelines. Retrieved from https://shipandbunker.com

Ship & Bunker. (2025, February 20). IMO moves forward with alternative fuel training guidelines for seafarers. Ship & Bunker. https://shipandbunker.com/news/world/438289-imo-moves-forward-with-alternative-fuel-training-guidelines-for-seafarers

Ships Education. (n.d.). Maritime English and training resources for international seafarers. Retrieved from https://shipseducation.org

Ships Education. (n.d.). South African Maritime Training Academy (SAMTRA). Ships Education Directory. https://shipseducation.com/training/directory/south-african-maritime-training-academy-samtra/

Singh, R., & Jephias, S. S. (2020). Evaluating South Africa's legal framework for green foreign capital partnerships in shipping corridors towards 2030. Maritime Economics and Logistics, 22(8), 810–828. https://doi.org/10.1057/s41278-019-00130-x

Snyman-van der Walt, L., Schreiner, G., & Lochner, P. (2023). Towards an evidence base to support Power-to-X (PtX) decision-making in South Africa. Stellenbosch, South Africa: Council for Scientific and Industrial Research (CSIR), Environmental Management Services.

SolarQuarter. (2025, June 16). Hive Hydrogen's Coega Green Ammonia Project secures $20 million investment, advancing South Africa's green hydrogen ambitions. SolarQuarter. https://solarquarter.com/2025/06/16/hive-hydrogens-coega-green-ammonia-project-secures-20-million-investment-advancing-south-africas-green-hydrogen-ambitions/

South African Institute of International Affairs (SAIIA). (2022). The South African Green Hydrogen TVET Ecosystem Just Transition Strategic Framework. Pretoria, South Africa: South African Institute of International Affairs.

South African International Maritime Institute. (2019, September 30). National Seafarer Development Programme. SAIMI. https://saimi.co.za/article/national-seafarer-development-programme/

South African International Maritime Institute. (2021, July 28). SAIMI | South African International Maritime Institute | Blue Economy. SAIMI. https://saimi.co.za

South African International Maritime Institute (SAIMI). (2024). Skills audit and needs analysis with implementation plan for the marine transport sector in South Africa. Port Elizabeth, South Africa: South African International Maritime Institute.

South African Maritime Safety Authority. (2023). Port state control. SAMSA. http://www.samsa.org.za/Pages/Portstate-Control.aspx

South African Maritime Safety Authority. (2024). Cape Peninsula University of Technology. The 10th Province. https://blog.samsa.org.za/tag/cape-peninsula-university-of-technology/

South African Maritime Training Academy. (2024, December 10). South African Maritime Training Academy: SAMTRA. SAMTRA. https://www.samtra.co.za

Spathias, G. (2024). A comprehensive analysis of marine alternative fuels and price forecasting. Erasmus University Rotterdam. https://thesis.eur.nl/pub/75554/Spathias-Georgios.pdf

Statista. (2023, December 19). Average age of vessels scrapped worldwide from 2013 to 2022. Statista. https://www.statista.com/statistics/1102659/average-age-of-vessels-scrapped-worldwide/

Statista. (2025, February 25). Platinum-group metal reserves worldwide 2024, by country. https://www.statista.com/statistics/273624/platinum-metal-reserves-by-country/

Statistics South Africa (Stats SA). (2024). South Africa gross domestic product (GDP). Pretoria, South Africa: Statistics South Africa.

Steyn, G. (2023). South Africa's carbon tax policy: Opportunities to transition to low-carbon shipping. Carbon and Climate Law Review, 17(1), 55–64. https://doi.org/10.21552/cclr/2023/1/11

The Marine Environment Protection Committee (MEPC). (2024, March 22). Resolution MEPC.391(81) (adopted on 22 March 2024): 2024 guidelines on life cycle GHG intensity of marine fuels.

The Presidency Republic of South Africa. 2023. "Just Energy Transition Implementation Plan."

TNO. (2023). Green Deal validation: Sustainability and applicability of biodiesel from waste cooking oil (MDF1) (Report TNO 2023 R10862V2). TNO. https://publications.tno.nl/publication/34641639/rOGTRY/TNO-2023-R10862.pdf

Transition Petro Chemicals. (2024). Production at Sasolburg. Meridian Economics. https://transitionpetrochemicals.meridianeconomics.co.za/production-at-sasolburg/

Transnet. (2023). Boegoebaai Deep-Water Port Project Announcement.

Transnet. (2024). New multi-product pipeline project: Technical specifications and capabilities. Transnet SOC Ltd.

Transnet National Ports Authority (TNPA). (2022). National Ports Authority annual report 2022. Transnet.

Transnet National Ports Authority. (2023). Port of Richards Bay infrastructure development master plan 2023-2048. TNPA Strategic Planning Division.

Transnet National Ports Authority (TNPA). (2023, December 13). TNPA issues RFP for Port of Richards Bay's South Dunes Precinct development. African Petrochemicals & Energy. Retrieved from https://africanpetrochemicals.co.za/tnpa-issues-rfp-for-port-of-richards-bays-south-dunes-precinct-development/

Transnet National Ports Authority. (2024). Annual port statistics and performance report 2023/24. TNPA Operations Division.

Transnet Pipelines. (2024). National petroleum pipeline network: Operations and maintenance standards. Transnet Pipelines Division.

U.S. Department of Energy. (2023). Hydrogen production: Electrolysis. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

Uhorakeye, T., Kopp-Moini, A., & Cohen, B. (2023). PtX business opportunities in South Africa: Renewable hydrogen market potential and value chain analysis. Pretoria, South Africa: Green Hydrogen South Africa, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Uhorakeye, T., Roos, T., Snyman-van der Walt, L., & Uehlecke, H. (2023). Pre-feasibility study on lighthouse technology ammonia South Africa. Pretoria, South Africa: GFA Consulting Group, CSIR, and H2Global Advisory.

United Nations Conference on Trade and Development (UNCTAD). (2023). Review of maritime transport 2023: Towards a green and just transition. New York, NY: United Nations.

United Nations Industrial Development Organization (UNIDO). (2022). Global programme for green hydrogen in industry. United Nations Industrial Development Organization.

Van Dyk, S., Keyser, J., & Coertzen, M. (2006). Syngas production from South African coal sources using Sasol-Lurgi gasifiers. International Journal of Coal Geology, 65(3-4), 243-253. https://doi.org/10.1016/j.coal.2005.05.007

Veolia South Africa. (2024). Seawater desalination. https://www.veolia.co.za/seawater-desalination

Vrey, F., & Blaine, D. (2023). Maritime domain awareness and the South African maritime security environment. African Security Review, 32(2), 145-162.

World Bank. (2023). Green shipping fuels made in South Africa. Transport for Development Blog. https://blogs.worldbank.org/en/transport/green-shipping-fuels-made-south-africa

World Bank. (2024). Creating a green marine fuel market in South Africa. Washington, DC: World Bank.

World Bank. (2024). Green shipping fuels in South Africa: Infrastructure assessment. World Bank Group.

World Bank. (2024). Green shipping fuels made in South Africa. Retrieved from https://blogs.worldbank.org/en/transport/green-shipping-fuels-made-south-africa

World Economic Forum. (2024). Decarbonizing South Africa's shipping and trucking sectors. Geneva, Switzerland: World Economic Forum.

World Economic Forum. (2024, April 10). Hydrogen is developing fast in Japan, edging nearer to wider use in society. World Economic Forum. https://www.weforum.org/stories/2024/04/hydrogen-japan/

World Platinum Investment Council. (2024). Platinum perspectives: Policy certainty is accelerating hydrogen electrolyser approvals and supporting platinum's investment case.

Xie, Y., Liu, Z., Li, K., Liu, J., Zhang, Y., Dan, D., Wu, D., & Zhu, C. (2023). Digital twin applications in the extractive industry—A short review. Engineering Applications of Artificial Intelligence, 126, 107034. https://doi.org/10.1016/j.engappai.2023.107034

Young, B. D., & McGregor, C. (2024, September 13). SA's green hydrogen hub will cost billions, not millions. Wits University Opinion. Retrieved June 14, 2025, from https://www.wits.ac.za/news/latest-news/opinion/2024/2024-09/sas-green-hydrogen-hub-will-cost-billions-not-millions.html

Zhang, H., Wang, L., & Chen, Y. (2023). Optimization of alkaline electrolyzer operation in renewable energy power systems: A universal modeling approach for enhanced hydrogen production efficiency and cost-effectiveness. International Journal of Hydrogen Energy, 48(99), 39120-39135. https://doi.org/10.1016/j.ijhydene.2023.05.123

Zhang, S., & Feng, C. (2024). Evolutionary game model for decarbonization of shipping under green shipping corridor. International Journal of Low-Carbon Technologies, 19, 2502–2511.

Zhou, Y., Meng, X., Yang, J., Liu, H., & Liu, Z. (2022). A comparative study on energy efficiency of the maritime supply chains for liquefied hydrogen, ammonia, methanol and natural gas. Carbon Neutrality, 1(1), 12. https://doi.org/10.1007/s43979-022-00012-w

[i] The Fischer–Tropsch (FT) process is a catalytic chemical reaction that converts syngas—a mixture of carbon monoxide and hydrogen—into liquid hydrocarbons, typically for fuel production. It is commonly used in coal-to-liquids (CTL) and gas-to-liquids (GTL) applications, with feedstocks derived from coal, natural gas, or biomass through gasification.

[ii] Projects designated as SIPs under the Infrastructure Development Act (as amended in 2014) must be of significant economic or social importance to the Republic; contribute substantially to any national strategy or policy relating to infrastructure development; or be above a certain monetary value determined by the PICC. The primary benefit of a project being declared an SIP is that the processes relating to any application for approval, authorisation, licence, permission, or exemption are streamlined.