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Comparative Analysis of Global Hydrogen Policies and Strategies with Recommendations for Nigeria:

Focusing on Green Hydrogen Regulation, Value Chain Development, and Power-to-X

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01. List of Abbreviations

ADNOC	Abu Dhabi National Oil Company
ARENA	Australian Renewable Energy Agency
AU	African Union
BMWF	Ministry of Education and Research
BMWi	Ministry of Education and Research
BMWi	Bundesministerium für Wirtschaft und Energie
BMWK	The Ministry of Economic Affairs and Climate Action
CCS	Carbon Capture and Storage
CEFC	Clean Energy Finance Corporation
CSIR	Council for Scientific and Industrial Research
DAAD	Deutscher Akademischer Austauschdienst
DISER	Department of Industry, Science, Energy, and Resources
DOE	The Department of Energy
ECN	Energy Commision of Nigeria
ECN	Energy Commission of Nigeria
ECOWAS	Economic Community of West African States
EIB	European Investment Bank
FCVs	Fuel Cell Vehicles
FMIST	Federal Ministry of Innovation, Science and Technology
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HFC	Hydrogen Fuel Cell
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
JETP	Just Energy Transition Plan
LCOH	Levelized Cost of Hydrogen
MASEN	Ministry of Energy, Moroccan Agency for Sustainable Energy
MIIT	Ministry of Industry and Information Technology
MoA	Ministry of Aviation
MoAFS	Ministry of Agriculture and Food Security
MoBEP	Ministry of Budget and Economic Planning
MoE	Ministry of Environment
MoF	Ministry of Finance
MoITI	Ministry of Industry, Trade, and Investment
MoMBL	Ministry of Marine and Blue Economy
MoP	Federal Ministry of Power

MoPR	Ministry of Petroleum Resources - Gas
MoSD	Ministry of Steel Development
MOST	Ministry of Science and Technology
MoT	Ministry of Transport
MoWR	Ministry of Water Resources
NCCC	The National Council for Climate Change
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NHREC	Nigerian Hydrogen and Renewable Energy Commission
NMDPRA	Nigerian Midstream and Downstream Petroleum Regulatory Authority
NNPC	Nigerian National Petroleum Corporation
NPA	Nigerian Ports Authority
NREA	National Renewable Energy Agency
NREL	National Renewable Energy Laboratory
NUPRC	Nigerian Upstream Petroleum Regulatory Commission
NWR	National Hydrogen Council
PPP	Public Private Partnership
PtG	Power-to-Gas
PtX	Power-to-X
R&D	Research and Development
SANEDI	South African National Energy Development Institute
STEM	Science, technology, engineering, and mathematics
TWh	Terawatt-hours
UAE	United Arab Emirate

02. Executive Summary

The global transition toward a hydrogen-based economy has led countries to develop distinct hydrogen policies shaped by their unique geographical, economic, and energy contexts. This document examines Germany's hydrogen strategy as a foundational case study, benchmarking it against the approaches of ten other nations: the United States, China, Australia, South Korea, Japan, the United Arab Emirates, Chile, Saudi Arabia, Morocco, and South Africa. Each country has adopted distinct hydrogen pathways, focusing on, green and blue hydrogen production, fuel cell development, energy storage solutions, transport infrastructure, and the integration of renewable energy.

This study identifies key drivers, policy frameworks, and technological priorities that are guiding national hydrogen agendas. The findings present a roadmap of best practices and adaptable policy measures that Nigeria can leverage to establish a robust hydrogen economy, tailored to its vast renewable and natural gas resources. The proposed policy also aligns the broader goals of the ECOWAS Green Hydrogen Strategy, emphasizing regional collaboration, and the African Union's Green Hydrogen Strategy, which envisions Africa as a global leader in green hydrogen production and export.

Additionally, these insights inform recommendations and provide clear measures for the development of Power-to-X (PtX) technical standards across the hydrogen value chain: covering production, storage, transport, distribution, handling, and conversion. Specific recommendations outline both medium- and long-term regulatory adaptations to support Nigeria's PtX and hydrogen policy, ensuring a sustainable and integrated energy future.

03. Introduction

The growing concerns about climate change and the need for sustainable energy transition have spurred global interest in hydrogen as a versatile and clean energy carrier. Hydrogen has emerged as a crucial component of the decarbonization strategies of many nations, especially in sectors where direct electrification is challenging, such as heavy industry, long-haul transport, and large-scale energy storage (Menefee & Schwartz, 2024). Among various forms of hydrogen, green hydrogen, produced through renewable energy-driven electrolysis, and blue hydrogen, derived from natural gas with carbon capture and storage (CCS) stand out due to their potential to significantly reduce greenhouse gas emissions (Sachdeva & Chaudhry, 2024). Therefore, numerous countries have adopted targeted policies to accelerate its development, establish infrastructure, and integrate it across national energy systems. Each country's approach is shaped by unique factors such as its economic goals, available resources, and existing infrastructure, leading to a wide array of policy frameworks and strategic initiatives around the world (Yusida et al., 2022).

Japan was the first country to launch a national hydrogen strategy, releasing its Basic Hydrogen Strategy in 2017. This pioneering move positioned Japan as a global leader in hydrogen, particularly focusing on fuel cell technology, hydrogen imports, and hydrogen-based power generation. Following Japan, South Korea and Australia released their own hydrogen policies shortly after, with South Korea's Hydrogen Economy Roadmap in 2019 and Australia's National Hydrogen Strategy in 2019 as well (Nallapaneni & Kshirsagar, 2024).

Germany, although only initiated its National Hydrogen Strategy in June 2020 and updated it in July 2023, with specification on hydrogen import again in July 2024, has rapidly positioned itself as a leader in the hydrogen sector. The country's strategy emphasizes green and low-carbon hydrogen[1], industrial decarbonization, and robust R&D investments, establishing Germany as a central player in the global hydrogen economy alongside pioneers like Japan, South Korea, and Australia. Germany's approach aligns closely with its renewable energy expansion goals, as the country aims to phase out coal and reduce reliance on fossil fuels[2,3]

Furthermore, hydrogen strategies vary across the globe, shaped by countries' unique resource endowments, energy priorities, and regional contexts. For example, the United States and China,

[1] Import Strategy for hydrogen and hydrogen derivatives released in July, 2024 recognized the potential of low-carbon hydrogen produced from non-renewables energy sources.
[2] Statement on Germany's updated National Hydrogen Strategy of 24th July 2023 (wasserstoffrat.de)
[3] Germany | European Hydrogen Observatory (europa.eu)

with their enormous natural gas reserves, have leaned toward blue hydrogen as a transitional solution, while simultaneously investing in green hydrogen research and development (Pingkuo & Junqing, 2024). In contrast, countries like Australia and Chile, endowed with abundant solar and wind resources, are prioritizing green hydrogen production for both domestic use and export markets (Garcia G. & Oliva H., 2023). Similarly, the UAE and Saudi Arabia are leveraging their fossil fuel wealth to produce both green and blue hydrogen, aiming to become key players in the global hydrogen market (Schoonover et al., 2024).

In Asia, Japan and South Korea have placed significant emphasis on hydrogen fuel cell (HFC) technology for mobility and industrial applications, with national strategies focusing on building hydrogen-powered societies through innovations in fuel cell vehicles (FCVs) and infrastructure (Kim et al., 2024). Meanwhile, African nations such as Morocco and South Africa, with their rich renewable energy resources, are positioning themselves as emerging hubs for green hydrogen production and export, particularly to Europe (Ourya et al., 2023). Nigeria, with abundant renewable resources, particularly solar energy, has significant potential to develop a green hydrogen sector. However, developing an effective national hydrogen policy requires understanding how leading hydrogen economies address key challenges such as hydrogen production, storage, transport, and end-use applications (Khzouz & I. Gkanas, 2020)

Given the diversity of approaches, there is a growing need to analyze these hydrogen policies comprehensively, considering regional resource availability, technological focus areas, and policy frameworks, building existing reports, such as the study[4] on 'the policy and regulation framework for the build-up of a hydrogen market in Nigeria', commissioned by the German-Nigerian Hydrogen Office, which is part of the Global H2-Diplo programme, as well as the study[5] on 'hydrogen opportunities for Saudi Arabia', commissioned by Global H2-Diplo programme in Saudi Arabia, also in 2023.

This review document uses Germany as a case study to explore how different countries' strategies align with their specific energy landscapes and economic priorities. By comparing the hydrogen policies of the identified countries, this study aims to draw lessons for Nigeria's emerging hydrogen economy. This comparative analysis will lay the groundwork for Nigeria to adopt best practices and create a hydrogen policy that is not only aligned with its energy transition goals but also tailored to its unique regional context and resource landscape. Additionally, this report will present specific measures for developing Power-to-X (PtX) technical standards for each stage of the hydrogen value chain encompassing production, storage, transport, distribution, handling, and conversion for both the medium and long-term in Nigeria. These recommendations aim to guide Nigeria's regulatory adaptation to facilitate a robust and resilient hydrogen economy.

[4]https://h2diplo.de/wpcontent/uploads/2023/10/Synthesis_report_Study_policy_and_reg_framework_H2DiploNG-1.pdf

[5] Hydrogen Opportunities for KSA

04. Global Overview of Hydrogen Policies

Global organizations, including the International Energy Agency (IEA)and International Renewable Energy Agency (IRENA) project that hydrogen could meet up to 18% of global energy demand by 2050, provided that countries adopt supportive policies, invest in infrastructure, and reduce production costs. As a result, hydrogen policies have become integral to national energy strategies (Bouacida, 2024).

Hydrogen can be produced through various methods, each with differing environmental impacts. Green hydrogen is considered the most sustainable option due to its low carbon footprint while Blue hydrogen, is considered a transitional solution for countries with significant natural gas reserves (Qin et al., 2024). Understanding these distinctions is essential to contextualizing each country's hydrogen policies, as the choice of hydrogen production type often reflects a nation's resource availability and economic goals.

Hydrogen policies often encompass various stages of the hydrogen value chain shown in Figure 1. These stages shape each country's hydrogen strategy, with specific policies and technical standards addressing each element to facilitate hydrogen's role within their national energy mix.

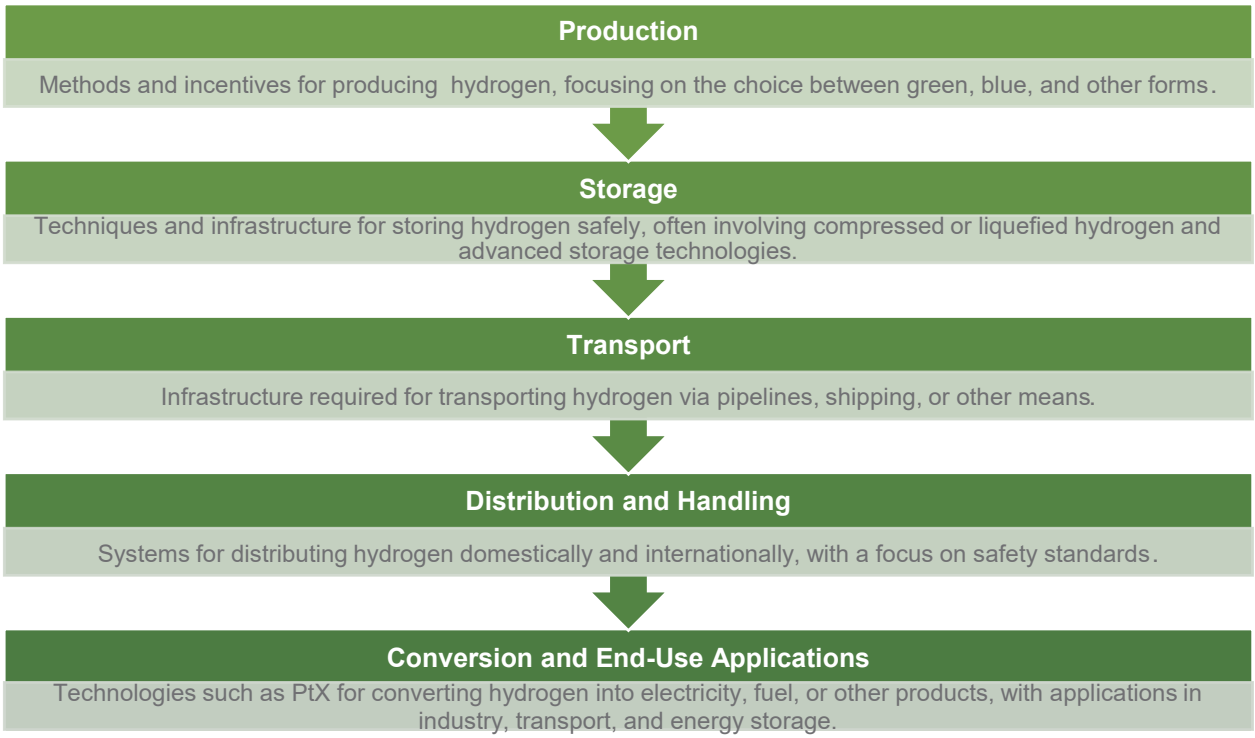


Fig. 1 Key Elements of the Hydrogen Value Chain

It is worth noting that among the hydrogen value chain; conversion processes such as Power-to-X (PtX) technologies have emerged as a transformative solution in hydrogen strategies, enabling hydrogen to be converted into various other forms of energy or products, such as electricity, heat, synthetic fuels, and chemicals. Many countries are also investing in PtX technologies, expanding the versatility of hydrogen as a clean energy source (Kumar & Singh, 2024). For instance, Germany and the Netherlands have actively promoted Power-to-gas (PtG) as part of their hydrogen strategies, focusing on integrating hydrogen into their existing natural gas grids to create a more flexible, decarbonized gas system. PtG also offers seasonal storage solutions, enabling renewable energy to be stored long-term and used during high-demand periods (Litheko et al., 2023). PtX is especially valuable in applications where hydrogen alone may not be the optimal solution, such as in synthetic fuels for aviation, chemicals for industry, and energy storage for grid balancing. Key PtX pathways in hydrogen strategies as shown in Figure 2 include Power-to-Gas, Power-to-Liquids, and Power-to-Chemicals, each of which facilitates hydrogen's integration into different energy systems and industrial processes. The implementation of PtX technologies requires standards and infrastructure to support safe production, storage, and transportation (Wells et al., 2016).

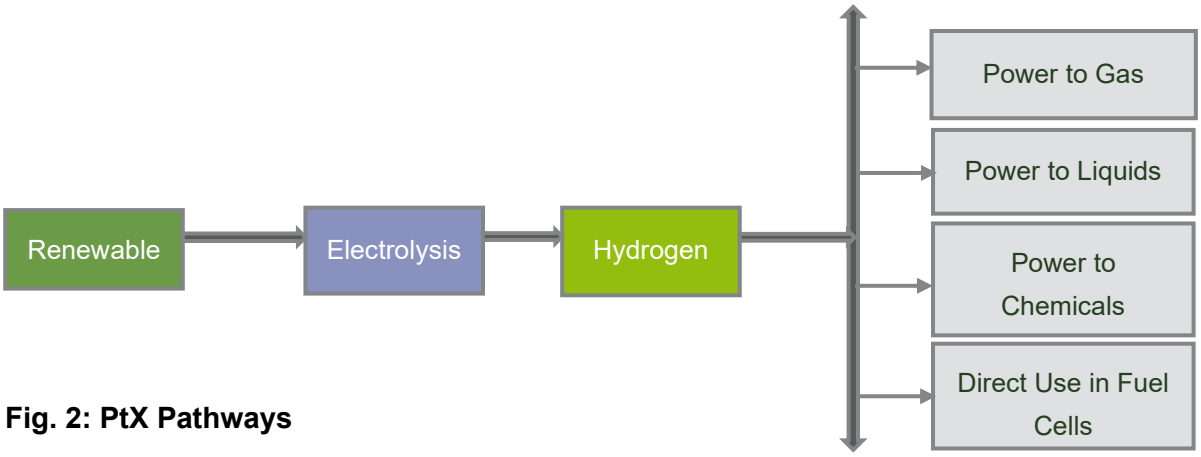


Fig. 2: PtX Pathways

05. Germany: a Case Study

Overview of Germany's National Hydrogen Strategy

Germany has positioned itself as a frontrunner in the global hydrogen economy, developing a comprehensive policy framework to support hydrogen as a cornerstone of its energy transition. Central to Germany's strategy is the National Hydrogen Strategy (Nationale Wasserstoffstrategie, NWS), introduced in 2020 (Quitzow et al., 2024). The framework outlines ambitious goals for green hydrogen production and lays the groundwork for establishing Germany as a leader in hydrogen technologies. However, the strategy was updated in 2023 to address gaps in the original 2030 vision, which, while foundational, was deemed insufficient for achieving a fully liquid hydrogen market in terms of necessary technologies, infrastructure, and commodities (BMWK, 2023). The National Hydrogen Council (NWR) identified several areas for immediate expansion and refinement[6]. Key enhancements include:

- **Detailed Post-2030 Planning**: Setting clearer goals through 2030 with improved monitoring and planning for market development beyond 2030. For instance, changes in production target from 5GW to 10GW by 2030.
- **Storage and Import Strategies**: Adding strategies for hydrogen storage, financing mechanisms, and an import framework with long-term contracts, certifications, and infrastructure funding.
- **Policy Integration and Regulatory Streamlining**: Aligning with broader energy policies, expediting approvals, and prioritizing carbon contracts to drive industrial demand.

The updated strategy reflects Germany's more ambitious climate neutrality goals for 2045, the impact of the Ukraine conflict on energy security, and the intensifying global competition for hydrogen technology leadership. Alongside the National Hydrogen Strategy, Germany has implemented complementary initiatives, such as the Hydrogen and Fuel Cell Technology Strategy and various Energy Transition Acts, which collectively aim to promote hydrogen's role in decarbonizing industry, transportation, and energy storage.[7]

[6] https://www.cleanenergywire.org/factsheets/germanys-national-hydrogen-strategy
[7] National Hydrogen Strategy: Green hydrogen as energy source of the future - BMBF

Key Policy Elements

Germany's approach to hydrogen includes a significant focus on production capacity targets, extensive funding allocations, and targeted sectoral applications that span industry, transportation, and energy storage. Key elements of this strategy, highlighted in Table 1, also cover the development of advanced infrastructure, including hydrogen storage and distribution networks, alongside stringent safety, and handling protocols. Furthermore, Germany's investment in PtX technologies positions it at the forefront of converting renewable energy into valuable energy carriers like synthetic fuels and industrial feedstocks (Martin et al., 2023).

Table 1: Germany's Hydrogen Strategy 2023

Policy Element	Details
Policy Focus	Green hydrogen production, with additional targets and infrastructure support for scaling beyond 2030, 50% GHG reduction by 2030; accelerated 2045 climate neutrality goal
Production Target	10 GW production capacity by 2030
Financial Incentives	Over €12 billion (€9 billion for Domestic Funding and €3 billion for International Partnerships)
Infrastructure	Expanded H2 core network[8], underground storage, development of ammonia terminals for import/export
PtX Technologies	Synthetic fuels, ammonia, industrial feedstocks, with focus on advanced PtX technologies
Key Institution(s)/Government Agencies	The National Hydrogen Council (NWR) is commissioned, and steered by the four ministries: Federal Ministry of Economic Affairs and Climate Action (BMWK), Federal Ministry of Education and Research (BMBF), Federal Ministry of Economic Cooperation and Development (BMZ), Federal Ministry for Digital and Transport (BMDV). Until the end of 2023, the Federal ministry of environment, nature conversation, nuclear safety and consumer production were also part of the steering committee.
International Collaboration	Algeria, Chile, Australia, Egypt, India, Morocco, Namibia, etc. See[9]
Key Challenges	Scaling up, High production costs, securing offtake agreements (FIDs), Infrastructure Limitations, Supply chain uncertainty and Coordination challenges

[8] Bundesnetzagentur - Hydrogen core network
[9] Import Strategy for hydrogen and hydrogen derivatives

New Additions	Comprehensive storage strategy, hydrogen import strategy, streamlined regulatory framework, and Carbon Contracts for Difference (CCfD) for industrial hydrogen applications

Policy focus

Germany's strategy prioritizes green hydrogen as the primary pathway to reduce greenhouse gas emissions at the onset, but in the recent update to the strategy, the word "green" has mostly been replaced by low-carbon. The country has set a target to produce up to 10 GW of green hydrogen capacity by 2030, with an eye toward expanding this capacity to meet long-term energy needs. By emphasizing green hydrogen, Germany aims to achieve a 50% reduction in greenhouse gas emissions by 2030 and 80% renewable energy target by 2050 through decarbonization of sectors where direct electrification is challenging, such as heavy industry, long-haul transportation, and large-scale energy storage. While green hydrogen is the primary focus (Waite et al., 2020), Germany acknowledges blue hydrogen, as a transitional option. However, Germany's long-term goal is to transition entirely to green hydrogen by 2050, aligning with its commitment to reducing fossil fuel dependency (Asiegbu et al., 2023)

Production targets and financial incentives

To drive innovation and scale up hydrogen production, the German government has committed substantial funding to hydrogen research, development, and deployment. Over €12 billion has been allocated to support the hydrogen sector, including €9 billion for domestic projects and €3 billion for international partnerships aimed at technology exchange and green hydrogen imports [10]. This financial support includes grants and subsidies for research and development (R&D), pilot projects, and industrial-scale green hydrogen production, reflecting Germany's commitment to a robust hydrogen ecosystem[11].

Infrastructure

Germany is investing in infrastructure to support large-scale hydrogen production and distribution. Key components of this infrastructure include underground hydrogen storage solutions such as the use of salt caverns, to store hydrogen securely and meet demand fluctuations. Additionally, plans are underway to retrofit parts of the existing natural gas pipeline network for hydrogen and to develop a dedicated hydrogen pipeline network (H2 core network) for long-distance transportation by 2030[12]. Integrating hydrogen into the natural gas grid is also being explored, enabling hydrogen blending in areas where it is feasible and safe. Germany's infrastructure investments are part of a larger effort

[10] https://www.dw.com/en/germany-and-hydrogen-9-billion-to-spend-as-strategy-is-revealed/a-53719746
[11] https://hydrogeneurope.eu/2024-innovation-fund-grants-hydrogen-projects-account-for-30-of-total-awards/
[12] https://www.deloitte.com/de/de/issues/sustainability-climate/impact-of-eu-low-carbon-hydrogen-regulation

to ensure that hydrogen can be safely stored and transported on a national scale, addressing one of the critical challenges of hydrogen adoption. (Kumar et al., 2024)

Safety, Handling, and Distribution Protocols

Safety is paramount in Germany's hydrogen strategy. The country has established stringent safety standards for hydrogen production, storage, transport, and handling, which are regularly updated to reflect the latest technological advancements and industry needs. Special handling and distribution protocols are being developed to ensure hydrogen's safe integration into existing infrastructure, minimizing risks associated with storage and transportation. (Rigas, 2024)

PtX Technologies and Applications

Germany is also a global leader in PtX technologies, which involve converting renewable energy into hydrogen for use in synthetic fuels, ammonia, and industrial feedstocks. This approach enables Germany to produce low-carbon fuels that can replace fossil-based alternatives in sectors like aviation, shipping, and chemical manufacturing. PtX technologies are a strategic component of Germany's hydrogen policy, allowing for versatile applications of hydrogen across various industries and supporting the country's broader decarbonization goals (Martin et al., 2023). The Ministry of Economic Affairs and Climate Action (BMWK) and the Ministry of Education and Research (BMBF) are responsible for implementing and overseeing hydrogen and PtX policies. Through these ministries, Germany coordinates PtX-related projects and provides funding for innovative applications of hydrogen[13].

International Collaboration and Hydrogen Imports

Recognizing that domestic production alone will not meet future demand, Germany is actively engaging in international partnerships to secure a reliable supply of green hydrogen. Collaborations with countries like Norway, Chile, and Australia focus on importing green hydrogen and facilitating technology exchange, particularly in regions with abundant renewable resources (Jiménez & Zheng, 2024). Plans are in place to import green hydrogen from Chile and Morocco, among others, to address Germany's anticipated hydrogen demand and diversify its energy sources. Germany's approach to international collaboration demonstrates its commitment to creating a sustainable global hydrogen market, positioning itself as both a consumer and a potential hub for hydrogen innovation (Barra Novoa, 2024)

Sectoral Applications and Transport

Germany has identified several key sectors for hydrogen deployment, including heavy industry (steel, cement, and chemicals, transportation) for decarbonization, and supporting hydrogen-powered heavy-duty trucks and buses, which are well-suited for long-distance routes (Anderhofstadt & Spinler, 2020). Also, hydrogen is used to balance the grid and store surplus renewable energy,

[13] https://explore.mission-innovation.net/wp-content/uploads/2023/03/H2RDD-Germany-FINAL.pdf

ensuring stable power supply even during low renewable production periods. These applications reflect Germany's strategic focus on sectors that are difficult to electrify, allowing hydrogen to play a crucial role in achieving carbon neutrality. The sectors identified are captured in Figure 4.

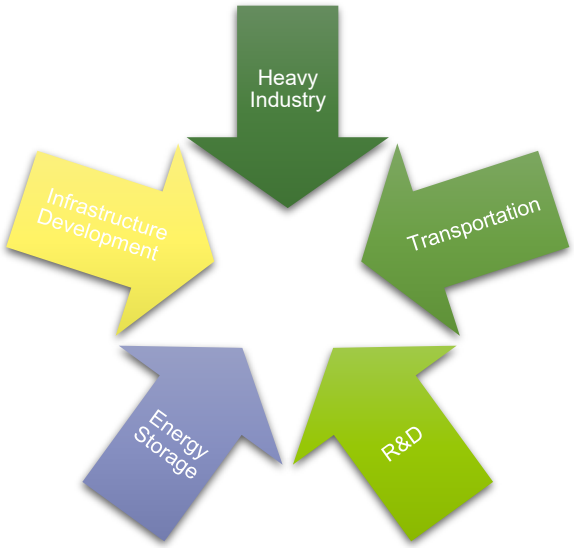


Fig 4: German's Hydrogen Strategy Sectoral Application

Challenges and Future Considerations

Despite its extensive hydrogen strategy, Germany faces several challenges such as scaling up production, high production costs, infrastructure limitations, supply chain uncertainty and coordination challenges. These challenges underscore the need for continued innovation, investment, and policy adaptation to achieve Germany's hydrogen targets. For instance, the current domestic production falls short of meeting the projected demand of 95–130 TWh by 2030, necessitating substantial imports to bridge the gap[14,15] The cost of producing green hydrogen is influenced by the expenses associated with electrolysis and renewable energy. As of 2020, the levelized cost of hydrogen (LCOH) from electrolysis was estimated between €3.50 and €5.00 per kilogram. The German government aims to reduce this cost to approximately €2.00 to €3.00 per kilogram by 2030 through technological advancements and economies of scale. Achieving these cost reductions is crucial for Germany to meet its hydrogen production targets and ensure the competitiveness of green hydrogen in both domestic and international markets[16]. The details of these challenges are given in Table 2 below.

[14] Germany's National Hydrogen Strategy | Clean Energy Wire
[15] Import Strategy for hydrogen and hydrogen derivatives
[16] presseinformationen/2022/2021-11-17_CATF_Report_Electrolysis

Table 2: Germany's Hydrogen Challenges

Challenge	Details
Scaling Up Production	Current production is 55–60 terawatt-hours (TWh) annually, primarily from fossil fuel, doesn't meet demand. Projections indicate that by 2030, hydrogen demand will rise to between 95-130 TWh
High production Costs	Electrolysis and renewable costs are high: As of 2020, the levelized cost of hydrogen (LCOH) from electrolysis was estimated between €3.50 and €5.00 per kilogram
Infrastructure Limitations	Retrofitting pipelines and new networks are costly and complex
Supply Chain Uncertainty	Reliance on international hydrogen imports
Coordination Challenges	Need for cohesive action between national and regional authorities

06. Overview of Policies/Strategies of Selected Countries

Countries around the world are implementing diverse hydrogen strategies and policies tailored to their unique energy needs and resources. This section provides an overview of hydrogen policies or/and strategies (as the case may be) from selected countries against Germany's established hydrogen framework. By examining these strategies/policies, we can identify best practices, innovative approaches, and lessons that can inform and enhance the development of hydrogen policy in Nigeria. The selected countries were chosen for their significant roles in advancing hydrogen technologies and policies:

- United States and China: Leaders in hydrogen production and integration into industry.
- Australia and Chile: Prioritizing green hydrogen production leveraging their renewable energy resources.
- Japan and South Korea: Pioneers in hydrogen fuel cell technology for transport.
- UAE and Saudi Arabia: Investing in both green and blue hydrogen to diversify their energy portfolios.
- Morocco and South Africa: Emerging players harnessing renewable energy for green hydrogen production, with export potential.

The comparison criteria align with Germany's comprehensive approach, examining policies across the hydrogen value chain: production, storage, transportation, distribution and handling, conversion (power-to-x), end-use applications, R&D and innovation and international collaboration.

United State

The United States is a key player in the global hydrogen economy, leveraging both green and blue hydrogen to meet its decarbonization targets by 2050. The Department of Energy (DOE) leads the nation's hydrogen initiatives, implementing policies such as the Hydrogen Energy Earthshot and the Hydrogen Energy Act. These initiatives aim to reduce the cost of green hydrogen to $1 per kilogram by 2030 (DOE, 2023)[17].

The key policy includes its decarbonization goal via widespread hydrogen adoption across industries to meet 2050 climate targets, financial support in form of tax credits, grants, and loans for hydrogen projects, covering both green and blue hydrogen, hydrogen fuel use and hydrogen-powered vehicle adoption. The fundings are governed by Infrastructure Investment and Jobs Act (IIJA), Inflation

[17] https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf?Status=Master

Reduction Act (IRA)[18],H2 Fuel Tax Credit and Alternative Fuel Vehicle Incentives. Significant funding is also allocated to R&D for advancing hydrogen technologies and exploring cost-effective production methods (U.S. Department of Energy, 2022).

In terms of Infrastructure and Storage Solutions, the U.S. has over 600 hydrogen refueling stations and continues to develop hydrogen transportation corridors while research into large-scale hydrogen storage using salt caverns and compressed hydrogen, and expansion of the pipeline network for hydrogen blending with natural gas and development of dedicated hydrogen pipelines is ongoing (Kannan & Srivastava, 2024).

Similarly, the US has made investments in PtX technologies for decarbonizing industrial sectors, with a focus on steel and ammonia production and exploration of hydrogen conversion into synthetic fuels and industrial feedstocks. This activities and policy implementation is monitored by the DOE[19], collaborating with various national laboratories and private sector stakeholders in various countries like Japan and Canada to advance hydrogen technologies, focusing on innovation, safety standards, and commercial viability (Hikima et al., 2020). The U.S. has stringent safety codes and standards for hydrogen, managed by organizations like the National Renewable Energy Laboratory (NREL) and the DOE.

However, while Germany battles import dependency and infrastructure scaling, the U.S. faces regulatory inconsistencies and infrastructure scaling difficulties. Despite these hurdles, both nations are advancing hydrogen technology and international partnerships to strengthen their hydrogen economies. A summary of the U.S. strategy is given in Table 4.

Table 3: U.S. hydrogen strategy

Policy Element	Details
Policy Focus	Balanced approach with both green and blue hydrogen
Production Target	Not specified
Financial Incentives	Funding through IIJA and IRA; tax credits, grants, and loans
Infrastructure	600+ hydrogen refueling stations; expanding pipeline for hydrogen blending
PtX Technologies	Investment in PtX for industrial sectors like steel and ammonia
Key Institution(s)/Government Agencies	Department of Energy (DOE), National Renewable Energy Laboratory (NREL)
International Collaboration	Collaborations with Japan and Canada for technology exchange
Key Challenges	Regulatory inconsistencies, high production costs, scaling infrastructure

[18] In January 2025, the Federal Government paused funds disbursement for some programs under this laws, especially programs that discourage fossil fuel development or boost electric vehicles. White House says order pausing IRA disbursements only applies to some programs | Reuters

[19] https://www.schroders.com/en-us/us/individual/3d-reset/decarbonization

China

China's hydrogen strategy, outlined in the 14th Five-Year Plan for Hydrogen Energy Development (2021–2025), is overseen by the National Development and Reform Commission (NDRC), along with the Ministry of Industry and Information Technology (MIIT), Ministry of Science and Technology (MOST), National Energy Administration (NEA), and local provincial governments. The plan as shown in Figure 5 initially emphasizes blue hydrogen, derived from natural gas with carbon capture and storage (CCS), transitioning to green hydrogen as the country's renewable capacity grows. This focus on green hydrogen is integral to China's ambition to achieve carbon neutrality by 2060 (Yang et al., 2024). The policy highlights the following:

- ***Financial Incentives and Subsidies***: China provides subsidies and tax breaks for hydrogen production, particularly targeting blue hydrogen projects. Provincial governments also offer incentives for green hydrogen pilot initiatives and zero-emission vehicle programs to promote the adoption of hydrogen fuel cell vehicles (FCVs).
- ***Infrastructure Development***: China is heavily investing in hydrogen storage infrastructure, which includes pressurized gas storage, hydrogen liquefaction technology, and underground storage. The country is expanding its pipeline network to support both natural gas and hydrogen distribution and plans to develop a national hydrogen pipeline network. Hydrogen hubs are being established in key industrial regions, aiming to integrate hydrogen into existing natural gas grids. Efforts are also underway to build a robust network of hydrogen refueling stations to support the growing fleet of FCVs (Ghadiani et al., 2024).
- ***Industrial Applications and PtX:*** China is exploring hydrogen use in various industrial applications, including synthetic fuels and chemical production, to decarbonize these sectors. The focus on PtX technologies aligns with its plans to become a major exporter of hydrogen technologies, particularly in the fuel cell and hydrogen-powered vehicle markets.
- ***International Collaboration***: The policy is heavily reliant on blue hydrogen, and China's transition to green hydrogen may face delays due to technological and economic constraints, however China collaborates with Saudi Arabia and Russia on blue hydrogen production and import strategies, while also working with the EU on green hydrogen technology to improve its capabilities in this area [20].

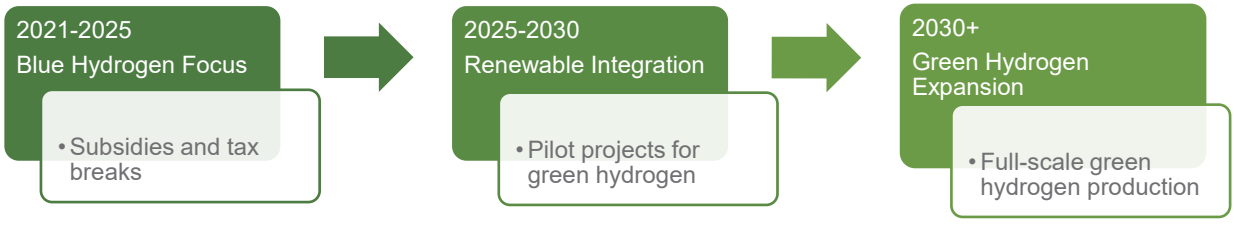


Fig. 5. China's Hydrogen Development Plan

A summary of China's hydrogen strategy is highlighted in Table 4. The key challenges encountered, especially in implementation of the strategy, include scaling green hydrogen production, managing the environmental impacts of blue hydrogen production such as the carbon footprint of CCS.

[20] https://www.cat.com/en_ZA/by-industry/electric-power/electric-power-industries/renewable-liquid-fuels

Table 4: China's Hydrogen Strategy

Policy Element	Summary
Policy Focus	Initial focus on blue hydrogen with plans to transition to green hydrogen as renewable capacity expands.
Production Target	Undefined
Financial Incentives	Government subsidies, tax breaks, and provincial incentives for blue and pilot green hydrogen projects.
Infrastructure	Approximately 300+ stations, primarily supporting fuel cell vehicles (FCVs) with plans for rapid expansion. Developing hydrogen storage and expanding blending in natural gas pipelines, with dedicated pipelines under consideration.
PtX Technologies	Investing in PtX for synthetic fuels and ammonia to decarbonize heavy industries.
Key Institution(s) /Government Agencies	National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology (MIIT), Ministry of Science and Technology (MOST), National Energy Administration (NEA), and local provincial governments
International Collaborations	Partnerships with Saudi Arabia and Russia for blue hydrogen, and with the EU and Japan for green hydrogen technology.
Key Challenges	High production costs for green hydrogen, lack of large-scale infrastructure, and environmental concerns with blue hydrogen production.

Australia

Australia's National Hydrogen Strategy, established in 2019, emphasizes green hydrogen, leveraging the country's abundant renewable resources like solar and wind, while supporting blue hydrogen as a transitional option. The strategy aims to decarbonize heavy industries and transportation by 2050 (Australian Government, 2021) [21]. Financial incentives include tax credits, grants, and subsidies, supported by organizations like the Clean Energy Finance Corporation (CEFC) and the Australian Renewable Energy Agency (ARENA). State-level incentives are also significant, especially in Queensland and Western Australia, which aim to become hydrogen hubs.

Australia is investing in hydrogen storage solutions such as compressed gas and liquefied hydrogen and is exploring ammonia as a transportation carrier to address the logistical challenges of long-distance hydrogen transport. (Alexander, 2022). The country is building hydrogen refueling stations and piloting hydrogen blending into natural gas networks, particularly in South Australia and New South Wales. Hydrogen applications in ammonia production, synthetic fuels, and energy storage are key to Australia's export ambitions and decarbonization of sectors like mining and agriculture (Boretti, 2020).

The Department of Industry, Science, Energy, and Resources (DISER) oversees the strategy, with support from state governments and organizations like ARENA and CEFC. Australia is developing export infrastructure, including ports capable of handling hydrogen in liquefied form or as ammonia,

[21] https://www.dcceew.gov.au/energy/publications/australias-national-hydrogen-strategy

targeting key markets in Asia and Europe. Major collaborations with countries like Japan, Germany, and South Korea focus on green hydrogen exports and technology exchange. Japan is a particularly significant partner in building hydrogen supply chains. [22]

However, Australia faces challenges such as high production costs and limited domestic infrastructure, making it difficult to scale hydrogen production and establish a robust domestic market. The strategy is heavily export-oriented, creating reliance on global demand. The high cost of production and infrastructure development further complicates scaling efforts, necessitating more comprehensive regulatory frameworks and infrastructure investment (Andeobu et al., 2024). A summary of Australia's hydrogen strategy is summarized in Table 5.

Table 5: Australia's Hydrogen Policy

Policy Element	Details
Policy Focus	Green hydrogen with blue hydrogen as a transitional option
Production Target	N/A
Financial Incentives	Tax credits, grants, and subsidies via CEFC and ARENA
Infrastructure	Hydrogen refueling stations, compressed and liquefied storage, export ports
PtX Technologies	Emphasis on ammonia and synthetic fuels for transport and storage
Key Institution(s) /Government Agencies	Department of Industry, Science, Energy, and Resources (DISER), Clean Energy Finance Corporation (CEFC) and the Australian Renewable Energy Agency (ARENA) and State governments
International Collaboration	Strong ties with Japan, Germany, and South Korea for exports and technology exchange
Key Challenges	High production costs, limited domestic market, infrastructure barriers

South Korea

South Korea's hydrogen strategy, guided by the Hydrogen Economy Roadmap (2019) and policies like the Seoul Hydrogen Fuel Cell Plan and the Hydrogen Economy Activation Plan, focuses on building a "hydrogen society" by 2040. This vision includes a strong emphasis on fuel cell vehicles (FCVs), hydrogen-based power generation, and industrial applications. The plan prioritizes both green and blue hydrogen, with a long-term goal of fully transitioning to green hydrogen to align with its Carbon Neutrality 2050 pledge (Chu et al., 2022).

South Korea has set ambitious targets, including achieving 15 GW of hydrogen production capacity and building 1,200 refueling stations by 2040. The government envisions a $40 billion hydrogen economy by this time, supported by financial measures such as subsidies and tax credits for

[22] https://www.dcceew.gov.au/energy/hydrogen

hydrogen production and fuel cell innovation. These incentives encourage industrial and technological advancements to foster a robust hydrogen ecosystem.[23]

Infrastructure development is a significant focus of South Korea's strategy, involving the creation of a national network of hydrogen refueling stations to meet the needs of an estimated 1.8 million hydrogen-powered vehicles by 2040. The country is also investing in hydrogen storage technologies, such as compressed and liquid hydrogen systems, and developing pipeline networks to facilitate distribution. South Korea's PtX (Power-to-X) technologies are prioritized for power generation and industrial sectors like steel production to decarbonize energy-intensive industries. (Choi & Bhakta, 2024)

The Ministry of Trade, Industry, and Energy (MOTIE) leads the implementation of hydrogen policies, supported by institutions like the Korea Institute of Energy Research (KIER). To ensure safety, the government has established stringent standards for hydrogen production, storage, and transportation, with particular attention to urban areas.[24]

International collaboration is essential to South Korea’s hydrogen ambitions. The country partners with Australia, the U.S., and Japan for hydrogen technology development and imports, with Australia being a key supplier of green hydrogen. South Korea also aims to export its hydrogen technologies, focusing on fuel cells to strengthen its position as a technological leader in the sector (Kim et al., 2024).

South Korea faces challenges, including scaling up infrastructure, the high cost of hydrogen production, and an initial reliance on blue hydrogen that raises environmental impact concerns. The government is working to address these issues to create a sustainable hydrogen economy (Rohilla & Kumar, 2024). The summary of the hydrogen policy highlighting its strategy, targets, financial incentives, infrastructure plans, and challenges is given in Table 6.

Table 6: South Korea’s Hydrogen Policy

Policy Element	Details
Policy Focus	Green and blue hydrogen; transitioning to fully green hydrogen by 2040
Production Target	15 GW production capacity; $40 billion hydrogen economy by 2040
Financial Incentives	Subsidies and tax credits for production and fuel cell development
Infrastructure	1,200 refueling stations; comprehensive pipeline network; 1.8 million hydrogen-powered vehicles by 2040, etc.
PtX Technologies	Focus on power generation and industrial use, particularly in steel
International Collaboration	Partnerships with Australia, U.S., and Japan for imports and tech development
Key Institution(s)	Ministry of Trade, Industry, and Energy (MOTIE), Korea

[23] https://h2council.com.au/wp-content/uploads/2022/10/KOR-Hydrogen-Economy-Roadmap-of-Korea_REV-Jan19.pdf

[24] https://resourcehub.bakermckenzie.com/en/resources/hydrogen-heat-map/asia-pacific/south-korea/topics/hydrogen-developments

/Government Agencies	Institute of Energy Research (KIER)
Key Challenges	High production costs, infrastructure scaling, environmental impact of blue hydrogen

Japan

Japan's hydrogen strategy, outlined in the Basic Hydrogen Strategy released in 2017, emphasizes the development of a hydrogen-based society by 2050, leveraging renewable hydrogen production from solar and wind, as well as fuel cell technology. Initially, the strategy focuses on blue hydrogen, with plans to transition to green hydrogen as renewable energy capacity increases. [25]. While specific large-scale GW targets may not be clearly outlined in every policy document, they do have significant projects contributing to an estimated capacity of 3GW.

The Japanese government provides subsidies for hydrogen production, particularly for blue hydrogen projects, and offers financial incentives to promote the development of fuel cell vehicles (FCVs) and hydrogen infrastructure. To support domestic and international transport, Japan is investing in hydrogen storage solutions, including compressed hydrogen storage and liquefied hydrogen technology. The country has developed a network of hydrogen refueling stations and implemented pilot projects for blending hydrogen into existing natural gas pipelines. [26]

Japan invested heavily in Power-to-X (PtX) technologies, with a focus on using hydrogen in synthetic fuel production, ammonia, and industrial applications such as steel and chemical production. The Ministry of Economy, Trade, and Industry (METI) oversees the hydrogen strategy, collaborating with private sector companies and international partners. [27]

Internationally, Japan has built partnerships with Australia, Saudi Arabia, and the U.S. to develop hydrogen supply chains and import both blue and green hydrogen. Japan plays a significant role in global hydrogen forums and initiatives, aiming to strengthen its expertise and influence in hydrogen technology. It is also investing in maritime hydrogen transport solutions and has established strict safety regulations for hydrogen storage and handling, particularly for liquefied hydrogen, with plans to update these standards as technology evolves (Wouters, 2024).

Japan's reliance on imported hydrogen poses energy security challenges, and the country faces difficulties in scaling up green hydrogen production due to limited domestic renewable energy resources (Rohilla & Kumar, 2024). The summary of the hydrogen policy highlighting its strategy, targets, financial incentives, infrastructure plans, and challenges is given in Table 7.

Table 7: Japan's Hydrogen Policy

Policy Element	Details
Policy Focus/Production Target	Initial focus on blue hydrogen; transition to green hydrogen by 2050
Financial Incentives	Subsidies for hydrogen production; support for FCVs and infrastructure

[25] 10.1016/b978-0-323-95553-9.00081-9
[26] https://www.renewable-ei.org/pdfdownload/activities/REI_JapanHydrogenStrategy_EN_202209.pdf
[27] https://www.weforum.org/stories/2024/04/hydrogen-japan/

Infrastructure	Network of hydrogen refueling stations; investments in compressed and liquefied hydrogen storage
Power-to-X (PtX) Technologies	Emphasis on synthetic fuel production, ammonia, and industrial applications
International Collaboration	Partnerships with Australia, Saudi Arabia, U.S.; participation in global hydrogen initiatives
Safety Standards	Strict regulations for storage and handling; continuous updates as tech evolves
Key Institution(s) /Government Agencies	Ministry of Economy, Trade, and Industry (METI)
Key Challenges	Reliance on imported hydrogen, scaling up due to limited domestic renewable energy resources

United Arab Emirates (UAE)

The UAE's hydrogen policies and strategy are outlined in the UAE Hydrogen Leadership Roadmap established in 2021. This roadmap incorporates the UAE Energy Strategy 2050, the Dubai Clean Energy and Green Hydrogen Plan, and the HFCV Development Plan. The UAE aims to position itself as a major global hydrogen producer and exporter, leveraging both green and blue hydrogen ("UAE Energy Strategy 2050," 2023). This aligns with the country's broader decarbonization goals under its "Net Zero by 2050" initiative, combining existing fossil fuel infrastructure with expanding renewable energy capabilities [28].

Key targets include a 1.4 GW hydrogen production capacity, a 44% renewable energy target, a goal of capturing 30% of the global hydrogen export market, and building a $100 billion hydrogen economy by 2030. The UAE provides financial incentives such as investment funds, government-backed loans, tax breaks for hydrogen production, and subsidies for green hydrogen initiatives to foster public-private partnerships. (Andrade & Thiringer, 2023)

Key Institutions: The Abu Dhabi National Oil Company (ADNOC) plays a significant role in blue hydrogen development, while Masdar leads green hydrogen initiatives. The Ministry of Energy and Infrastructure oversees policy implementation and supports infrastructure development. [29]

The UAE invests in hydrogen storage solutions, with a focus on liquid hydrogen and ammonia as transport mediums due to their logistical advantages. The country is also developing hydrogen distribution networks in industrial hubs and export infrastructure, including port facilities at Jebel Ali for hydrogen shipping. The UAE's efforts in Power-to-X (PtX) technologies include using hydrogen for synthetic fuel and ammonia production, which are critical for decarbonizing shipping and aviation sectors. Similarly, the country is developing national safety standards for hydrogen, focusing on handling, storage, and transportation, aligning with international best practices (Nallapaneni & Kshirsagar, 2024).

The UAE has partnerships with Japan, South Korea, and Germany for technology development and export supply chains, particularly in green hydrogen. These collaborations aim to establish a robust global export network, targeting markets in Europe and Asia. However, existing challenges are scaling up green hydrogen production due to high costs and limited renewable energy availability in

[28] https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/environment-and-energy/national-hydrogen-strategy

[29] https://www.adnoc.ae/en/sustainability-and-energy-transition/2030-sustainability-strategy

some regions, environmental impact of blue hydrogen production, which still involves carbon emissions, poses an obstacle to full decarbonization and other hurdles like technical issues with hydrogen transport and competition from other hydrogen-exporting nations. [30]

The summary of the hydrogen policy highlighting its strategy, targets, financial incentives, infrastructure plans, and challenges is given in Table 8.

Table 8: UAE's Hydrogen Policy

Policy Element	Details
Policy Focus	Both green and blue hydrogen; aiming for major global export share
Production Target	1.4 GW hydrogen production; $100 billion hydrogen economy by 2030
Financial Incentives	Investment funds, government-backed loans, tax breaks, subsidies
Infrastructure	Port facilities for export (Jebel Ali), hydrogen distribution networks
PtX Technologies	Focus on synthetic fuel and ammonia for shipping and aviation
Key Institution(s) /Government Agencies	Ministry of Energy and Infrastructure, Abu Dhabi National Oil Company (ADNOC)
International Collaboration	Partnerships with Japan, South Korea, Germany for green Hydrogen tech and exports
Key Challenges	Scaling up due to high costs, limited renewable energy, environmental impact of blue H2 production

Chile

Chile's hydrogen policy, established under the National Hydrogen Strategy and Electric Mobility Law in 2020, focuses on green hydrogen production, leveraging the country's significant renewable energy resources, particularly solar and wind. The strategy aims to position Chile as one of the top three hydrogen exporters globally by 2040, with an emphasis on decarbonization and integrating renewable energy into various sectors, including public transportation and industrial applications (Armijo & Philibert, 2020).

Key targets include a 2 GW hydrogen production capacity, a 60% renewable energy mix, capturing 20% of the global hydrogen export market, and building a $50 billion hydrogen economy by 2030. The Ministry of Energy and CORFO (Production Development Corporation) are responsible for implementing the strategy, fostering public-private partnerships (PPP) and supporting pilot projects to scale up production. [31]

In terms of infrastructure development, Chile is investing in underground hydrogen storage, including compressed gas and liquid hydrogen. The country is exploring ammonia as a hydrogen carrier to facilitate long-distance transport due to its remote location from major markets. Hydrogen distribution

[30] https://energypartnership-korea.org/fileadmin/korea/media_elements/cooperation-hydrogen_studie_final.pdf

[31] https://www.iea.org/reports/global-hydrogen-review-2023/executive-summary

infrastructure is being developed, especially within the mining and industrial sectors, which are significant energy consumers. Efforts to integrate hydrogen into natural gas grids are also underway. (Boretti, 2024)

Likewise, the country prioritizes PtX technologies for producing ammonia and synthetic fuels, which are essential for decarbonizing the mining, agriculture, and transport sectors. This supports its ambition to become a key player in the global hydrogen supply chain. Chile is also developing national safety standards for hydrogen production, handling, and transportation, aligning with international standards. (Halder et al., 2024)

Chile maintains strong partnerships with Europe (particularly Germany and the EU) and Asia (Japan and South Korea), focusing on green hydrogen exports and technology development. The country is developing port facilities for liquefied hydrogen and ammonia exports, identifying Germany and Japan as major markets. But several challenges, including the high capital investment requirements and costs associated with large-scale hydrogen production, the need for significant infrastructure development, and technological advancements exist. The country's remote location also presents logistical challenges for hydrogen exports. [32]

The summary of the hydrogen policy highlighting its strategy, targets, financial incentives, infrastructure plans, and challenges is given in Table 9.

Table 9: Chile's Hydrogen Policy

Policy Element	Details
Policy Focus	Green hydrogen production, decarbonization, top three global exporter by 2040
Production Targets	2 GW hydrogen production; $50 billion hydrogen economy by 2030
Financial Incentives	Grants and subsidies for green hydrogen projects, public Private partnerships
Infrastructure	Port facilities for exports, hydrogen storage solutions, pilot pipelines
PtX Technologies	Focus on ammonia and synthetic fuels for decarbonizing mining and transport
Key Institution(s) /Government Agencies	Ministry of Energy, Production Development Corporation (CORFO)
International Collaboration	Partnerships with Europe (Germany, EU) and Asia (Japan, South Korea) for exports and technology
Key Challenges	Require high capital cost for large scale production, Infrastructure development & technological advancement, logistic challenges due to its remote location

Saudi Arabia

Saudi Arabia's hydrogen strategy, established under the National Hydrogen Strategy and Green Initiative in 2021, is an integral part of Saudi Vision 2030. The policy focuses on both green and blue

[32] https://international-partnerships.ec.europa.eu/policies/global-gateway/developing-chiles-green-hydrogen-potential_en

hydrogen, leveraging the country's vast fossil fuel resources and high solar radiation levels, which provide a significant cost advantage for solar-based hydrogen production compared to regions like Europe (Hassan et al., 2024). The Ministry of Energy, Saudi Aramco, and the Public Investment Fund (PIF) are the key institutions responsible for implementing hydrogen strategies and policies. (Islam & Ali, 2024)

The strategic goal is to diversify Saudi Arabia's energy mix and position the country as a global leader in hydrogen production and renewable energy solutions. This aligns with broader Vision 2030 objectives to reduce economic dependence on oil and advance sustainable energy. [33]

Key Targets include producing 2.9 GW of hydrogen capacity, achieving 2.9 million tonnes of hydrogen production per year by 2030, and 4 million tonnes by 2035. The strategy also aims for 50% of the global hydrogen market share, a 50 GW renewable energy target, and building a $150 billion hydrogen economy by 2030 [34].

Major Projects and Investments: Saudi Arabia offers substantial government funding and incentives for hydrogen projects. Key initiatives include:

- NEOM Hydrogen Project: A $5 billion venture between Air Products and ACWA Power to produce 1.2 million tonnes of green ammonia per year.
- Saudi Aramco's Hydrogen Project: A $10 billion initiative to produce 1.2 million tonnes of blue hydrogen annually by 2030. (Sarwar, 2022)
- Red Sea Development Company's Hydrogen Plant: A project with a production capacity of 650 tonnes per day [35].

Saudi Arabia's infrastructure and storage solutions plan is focused on developing large-scale hydrogen storage solutions, emphasizing liquid hydrogen and ammonia for transportation, alongside national safety standards for hydrogen production, storage, and transportation, aligned with international best practices. The country is also investing in port facilities and shipping infrastructure to support hydrogen exports and developing domestic pipelines for industrial hydrogen distribution (Islam & Ali, 2024). Likewise, the country is investing in PtX technologies, using hydrogen to produce ammonia and synthetic fuels for industrial applications and export. These efforts are essential for decarbonizing various sectors and enhancing the versatility of hydrogen in its energy landscape.

Notably, Saudi Arabia has formed partnerships with Germany and countries in Asia such as Japan and South Korea to facilitate hydrogen exports and collaborate on hydrogen technology development. Europe and Asia are targeted as key markets for Saudi hydrogen exports (Schoonover et al., 2024). Despite these advancements, Saudi Arabia faces challenges in scaling up green hydrogen production, especially regarding infrastructure and renewable energy deployment. The reliance on blue hydrogen in the short term poses a challenge for achieving full decarbonization. High production costs for green hydrogen and the need for rapid infrastructure development are additional hurdles. The summary of the hydrogen policy is given in Table 10.

[33] https://www.vision2030.gov.sa/en/explore/projects/saudi-green-initiative
[34] https://www.csis.org/analysis/saudi-arabias-hydrogen-industrial-strategy
[35] https://isa-ghic.org/countries/saudi-arabia

Table 10: Saudi Arabia's Hydrogen Policy

Policy Element	Details
Policy Focus	Green and blue hydrogen; major global exporter by 2030
Production Target	2.9 GW hydrogen capacity; 2.9 million tonnes/year by 2030, 4 million tonnes/year by 2035
Financial Incentives	Subsidies, government-backed investments, major projects like NEOM and Saudi Aramco's initiatives
Infrastructure	Port facilities, shipping infrastructure, domestic pipelines for hydrogen distribution
Power-to-X (PtX) Technologies	Focus on ammonia and synthetic fuels for industrial and export purposes
Key Institution(s) /Government Agencies	Ministry of Energy, Saudi Aramco, Public Investment Fund (PIF)
International Collaboration	Partnerships with Germany, Japan, and South Korea for export and technology development
Key Challenges	Scaling up green hydrogen production, infrastructure and renewable energy deployment

Morocco

Morocco's hydrogen policy, embedded in the National Hydrogen Strategy established in 2021, is driven by the Ministry of Energy and the Moroccan Agency for Sustainable Energy (MASEN). The strategy focuses on green hydrogen production, leveraging the country's abundant solar and wind energy resources to position Morocco as a major green hydrogen producer and exporter, particularly targeting European markets [36].

The country's key targets and goals is to achieve a 1.5 GW hydrogen production capacity and integrate solar energy to meet its 52% renewable energy mix target. The country aspires to secure 10% of the global hydrogen export market and reach a $52 billion hydrogen economy by 2030. (Ourya et al., 2023)

With the aspect of Financial Incentives and Support, Morocco provides financial support for green hydrogen projects through investment incentives, subsidies, and R&D funding. The country benefits from investments by international organizations such as the World Bank and the European Investment Bank (EIB). Public-private partnerships are also a key part of Morocco's approach to scaling up hydrogen production and infrastructure.[37]

Furthermore, the country is investing in hydrogen storage technologies, including compressed hydrogen and ammonia, due to its suitability for long-distance transport. Infrastructure development is focused on industrial clusters and export zones, with a particular emphasis on the Ouarzazate solar complex as a hydrogen production hub. Similarly, Morocco has a huge investment in PtX technologies to produce ammonia and synthetic fuels, which play a critical role in decarbonizing industries and supporting export capabilities. (Koshikwinja et al., 2025)

Morocco collaborates extensively with European countries, particularly Germany, to advance green hydrogen production and establish export channels. The country is a strategic partner in the

[36] https://www.masen.ma/en/green-hydrogen-moroccan-offer
[37] https://fsdafrica.org/wp-content/uploads/2023/05/Morocco-Green-Fund-08.05.23.pdf

European Union's green hydrogen import plans, solidifying its role as a key supplier. The development of port facilities and export infrastructure is ongoing, aimed at shipping ammonia and other hydrogen carriers to Europe. Morocco is also piloting hydrogen pipelines for domestic distribution and working to implement national safety standards for hydrogen production and transport, ensuring compliance with international export regulations.[38]

Nevertheless, Morocco faces challenges such as the high cost of green hydrogen production, the lack of large-scale infrastructure, and the significant investment needed to expand renewable energy capabilities. The summary of the hydrogen policy is given in Table 11.

Table 11: Morocco's Hydrogen Policy

Policy Element	Details
Policy Focus	Green hydrogen production leveraging solar and wind resources
Production Target	1.5 GW production capacity; $52 billion hydrogen economy by 2030
Financial Incentives	Investment support, subsidies, R&D funding, public Private partnerships
Infrastructure	Port facilities, hydrogen storage (compressed hydrogen, ammonia), pilot pipelines
PtX Technologies	Focus on ammonia and synthetic fuels for industry decarbonization
Key Institution(s) /Government Agencies	Ministry of Energy, Moroccan Agency for Sustainable Energy (MASEN)
International Collaboration	Strong partnerships with Europe (notably Germany) for green hydrogen exports
Key Challenges	High cost of green hydrogen production, Lack of large Scale infrastructure, High investment to expand renewable energy capabilities

South Africa (SA)

South Africa's hydrogen strategy is encompassed in various strategic plans, including the Integrated Resource Plan (IRP), the National Climate Change Adaptation Strategy, and the Green Hydrogen Industrial Development Plan. These strategies aim to diversify the energy mix, integrate hydrogen into the national grid, and promote industrial applications, with a target to produce 15 GW of hydrogen and build 1,200 hydrogen refueling stations by 2040.[39]

The country aims for a $15 billion hydrogen economy by 2030 to support its economic and energy diversification objectives. SA provides tax break, subsidies, and investment supports aimed at scaling up hydrogen infrastructure, including hydrogen refueling stations, hydrogen transportation corridors, and domestic hydrogen distribution systems. [40]

[38] https://www.reuters.com/sustainability/climate-energy/germany-morocco-agree-alliance-support-green-hydrogen-production-exports-2024-06-28/
[39] https://www.dst.gov.za/images/South_African_Hydrogen_Society_RoadmapV1.pdf
[40] https://www.csis.org/analysis/south-africas-hydrogen-strategy

The Department of Mineral Resources and Energy, the Department of Science and Innovation, the South African National Energy Development Institute (SANEDI), and the Council for Scientific and Industrial Research (CSIR) are key bodies responsible for overseeing hydrogen policies and strategies. South Africa collaborates with various international partners to develop its hydrogen strategy and foster technology exchange, although these collaborations are not yet as extensive or well-established as those of other countries. [41]

Though the development of national safety standards and protocols is essential to ensure safe production and handling practices**,** its current policies lack comprehensive regulations for hydrogen production and transport and also faces significant challenges, including the lack of clear regulations for hydrogen production, limited investment incentives, and insufficient public awareness. High technology costs, limited supply chain capabilities, public acceptance issues, and brain drain also pose barriers to the full implementation of hydrogen strategies. (Alfasfos et al., 2024)

The summary of the hydrogen policy is given in Table 12.

Table 12: South Africa's Hydrogen Policy

Policy Element	Details
Policy Focus	Green hydrogen production and energy mix diversification
Production Target	15 GW hydrogen production capacity by 2040
Financial Incentives	Tax breaks, subsidies, investment support
Infrastructure	Hydrogen hubs, underground storage, hydrogen refueling stations
PtX Technologies	
Key Institution(s) /Government Agencies	Department of Mineral Resources and Energy, Department of Science and Innovation, South African National Energy Development Institute (SANEDI), Council for Scientific and Industrial Research (CSIR)
International Collaboration	The Just Transition Energy Plan (JETP)42 (signed in 2021) allows SA to partner with countries such as Germany, UK, US and the EU decarbonisation collaboration, including clean hydrogen
Key Challenges	Lack of clear regulations, high technology costs, limited public awareness, supply chain issues, brain drain

Comparative Analysis of Hydrogen Policies across the countries

Table 13 summarizes the key elements of each selected country's hydrogen strategy[43]. It presents a clear analysis of how each country leverages its unique resources and addresses challenges in scaling up its hydrogen economy. Table 14, on the other hand, compares the strength and effectiveness of the policies, highlighting best practices, and offering valuable insights for countries like Nigeria to formulate comprehensive hydrogen policies.

[41] https://publications.rifs-potsdam.de/rest/items/item_6003193_1/component/file_6003194/content
[42] Just Energy Transition Partnership with South Africa
[43] https://d.docs.live.net/5d9498e31f548128/Desktop/Global%20Hydrogen%20Policy.xlsx

Table 13: Comparison of Key Elements of Hydrogen Strategies across countries

Country	Policy Focus	Production Targets	Financial Incentives	Key Challenges
Germany	Green/low-carbon hydrogen; decarbonization; Export of hydrogen technologies; import of hydrogen	10 GW by 2030	12 billion investments, grants, subsidies	High production costs, scaling infrastructure
United States	Green and blue hydrogen; broad industry adoption	Varied, ambitious production supported by IIJA and IRA	Tax credits, grants under IIJA and IRA	Regulatory inconsistencies, scaling and cost challenges
Australia	Green hydrogen; leveraging solar and wind resources	2 GW by 2030	CEFC and ARENA funding, state-level support	High production costs, limited domestic market
South Korea	Green and blue hydrogen; hydrogen society by 2040	15 GW by 2040	Subsidies and tax credits for production and infrastructure	High costs, infrastructure scaling, blue hydrogen reliance
Japan	Blue transitioning to green hydrogen; hydrogen-based society by 2050	Not specified in GW but with 2050 long-term goals	Subsidies for hydrogen production, FCV support	Scaling green hydrogen, import reliance, energy security
UAE	Green and blue hydrogen; global market leader	2.9 GW by 2030, 4 million tons per year by 2035	Investment funds, tax breaks, subsidies	High costs, blue hydrogen reliance, infrastructure development
Chile	Green hydrogen; export to Europe and Asia	2 GW by 2030	Grants, subsidies, international funding (e.g., EIB)	High production costs, logistical export challenges
Morocco	Green hydrogen; leveraging renewable resources for export	1.5 GW by 2030	Investment support, subsidies, R&D funding	High costs, infrastructure investment, large-scale deployment
South Africa	Green hydrogen; energy diversification	15 GW by 2040	Tax breaks, subsidies, investment support	Regulatory gaps, public awareness, technology costs

Table 14: Strength/ Effectiveness of Hydrogen Policies in Selected Countries

Country	Strengths	Effectiveness
Germany	**Comprehensive** focus on clean hydrogen; significant financial commitment (€9 billion investment); advanced infrastructure development, including hydrogen pipelines and storage solutions; strong international collaborations for green hydrogen imports.	**High** due to its alignment with decarbonization goals and robust support for technology and infrastructure.
United Arab Emirates (UAE)	**Balanced** focus on green and blue hydrogen; significant investments through state-backed projects; development of port infrastructure for exports; strategic partnerships with Europe and Asia.	**High**, leveraging existing energy resources and making rapid advancements in green hydrogen to meet global market demand.
United States	**Dual approach** with green and blue hydrogen, backed by major financial support through IIJA and IRA; broad incentives for R&D and infrastructure; existing energy network integration.	**High**, due to significant investment and a broad, adaptable approach to hydrogen development across industries.
Japan	**Long-term vision** transitioning from blue to green hydrogen; strong focus on fuel cell technology and PtX applications; established international partnerships, especially with Australia and Saudi Arabia.	**Moderate to high**, as the policy supports advanced technology integration and international collaboration, though limited by reliance on imports for energy security.
Chile	**Strong** focus on green hydrogen leveraging solar and wind resources; partnerships with Europe for export potential; targeted infrastructure investments for ammonia transport.	**Moderate**, with potential for high effectiveness if infrastructure and financial investments scale up.

Countries with Strong Potential	
Country	**Strength**
Morocco	Demonstrates a focused approach on green hydrogen production with international partnerships, particularly with Germany, but needs more infrastructure development and investment to realize full potential.
South Korea	Effective in building a “hydrogen society” with a mix of green and blue hydrogen, strong emphasis on fuel cell vehicles, and solid infrastructure plans. Needs to overcome scaling issues.

Summary/ Insight

To effectively compare the strategies for policy effectiveness across countries, it's important to evaluate a few key dimensions: alignment with national goals, scalability, financial commitment, infrastructure development, and international collaboration.

Policy Focus and Alignment with National Goals

Germany has a clear focus on green hydrogen, aligning with its stringent climate goals and commitment to full decarbonization by 2045[44]. This strategy is highly effective in aligning with Germany’s renewable energy expansion. On the other hand, United States balances green and blue hydrogen, leveraging natural gas while developing green hydrogen capabilities. This dual approach provides flexibility but may dilute the focus on complete decarbonization. Japan and South Korea prioritize fuel cell technology and aim to integrate hydrogen into transportation and industrial sectors. Their strategies focus on building a hydrogen society, which aligns well with their advanced industrial frameworks. UAE and Saudi Arabia capitalize on existing fossil fuel infrastructure for blue hydrogen while expanding renewable capacity. This approach allows them to maintain energy leadership but may slow the transition to fully green hydrogen. Chile and Morocco aim to leverage vast solar and wind resources for green hydrogen production, positioning themselves as leading exporters to Europe. Their strategies align with their national renewable energy goals but face scalability issues. South Africa emphasizes green hydrogen for energy diversification; however, regulatory and infrastructural limitations affect the policy's effectiveness.

Scalability and Infrastructure Development

Germany, UAE, and Saudi Arabia have made substantial progress in infrastructure, such as hydrogen pipelines, port facilities, and refueling stations, indicating a scalable approach. The U.S. benefits from existing energy infrastructure but faces regulatory inconsistencies that hinder nationwide scaling. Chile and Morocco have initiated pilot projects and port facility developments but require significant investment for scaling. South Africa has outlined plans for hydrogen hubs and refueling infrastructure but still lacks large-scale execution.

[44] Climate Change Act - climate neutrality by 2045

Financial Commitment and Investment Support

Germany leads with significant financial incentives, including a €12 billion investment aimed at boosting green hydrogen R&D and production. The U.S. provides a range of financial support through federal and state-level incentives such as the IIJA and IRA[45], promoting both green and blue hydrogen. Australia relies on funding through bodies like CEFC and ARENA to promote green hydrogen projects. South Korea and Japan offer subsidies and tax credits to support hydrogen production and fuel cell development. Saudi Arabia invest heavily in joint ventures like NEOM and large-scale production projects. Chile and Morocco benefit from international funding and public-private partnerships, but they face challenges in sustaining large-scale investment. South Africa offers limited financial incentives, including tax breaks and subsidies but lack comprehensive financial backing compared to other countries.

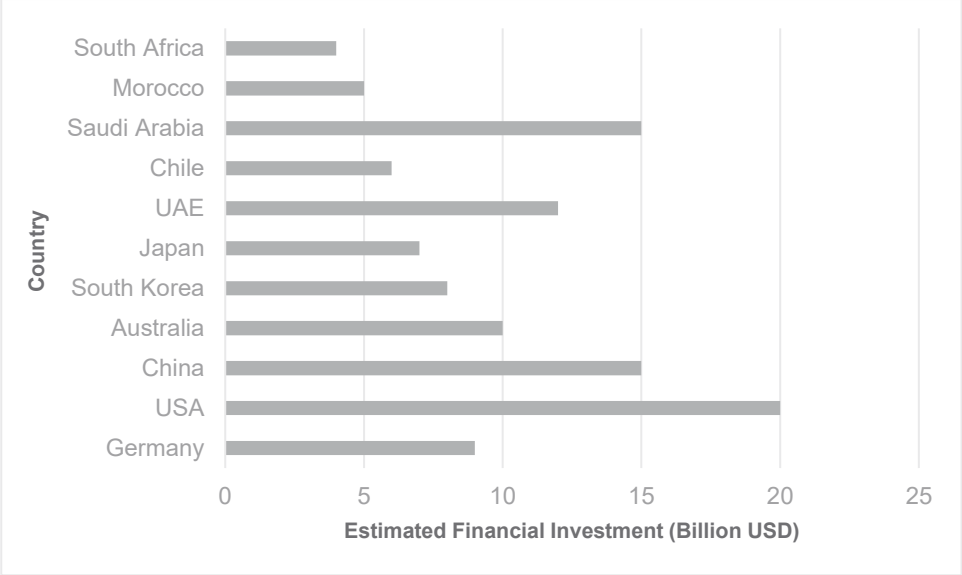


Figure 6: Financial Investments and Incentives in Hydrogen Strategies by Country

International Collaboration and Export/Import Strategies

Germany, Japan, and UAE have strong international partnerships, enhancing their effectiveness in technology exchange and export capacity while Chile and Morocco are strategically collaborating with European countries to establish export/import routes, which strengthens their global positioning. South Africa has started building partnerships, but they are not as extensive or deeply integrated as those in leading countries like Germany or UAE.

Challenges and Barriers

Germany faces high production costs but compensates with technological innovation and a clear policy framework while United States encounters regulatory inconsistencies at the state and federal levels, impacting policy coherence. The UAE and Saudi Arabia face the challenge of transitioning fully to green hydrogen, with environmental concerns related to blue hydrogen production. Chile and

[45] In January 2025, the Federal Government paused funds disbursement for some programs under this laws, especially programs that discourage fossil fuel development or boost electric vehicles. White House says order pausing IRA disbursements only applies to some programs | Reuters

Morocco must overcome high production costs and logistical challenges for long-distance exports. South Africa needs to address regulatory gaps, public awareness, and technology costs for greater policy effectiveness.

In summary, countries like Germany, UAE, Japan, and Chile are leading with robust infrastructure, financial incentives, and international partnerships. South Africa and Morocco show potential but need significant policy and infrastructure development. Germany, UAE, and United States stand out for their comprehensive and well-funded hydrogen policies. They have demonstrated clear strategic goals, substantial financial backing, infrastructure development, and international collaboration, which contribute to their high potential for policy success. Japan, Chile, and Morocco also show strong policies but face specific challenges like reliance on imports and scaling production. Countries like South Africa and Morocco are showing promise with ambitious strategies and renewable resource advantages but require significant advancements in regulatory frameworks, infrastructure, and investment to rank among the best in policy effectiveness.

07. Lessons for Nigeria

This section outlines the key insights derived from the comparative analysis of global hydrogen policies and the ECOWAS Green Hydrogen Policy and Strategy Framework (*a summary of the ECOWAS Hydrogen Policy, see appendix 1*) providing a foundation for Nigeria to formulate a strategic hydrogen policy that aligns with its unique resource base, economic priorities, and sustainability commitments. By examining best practices, challenges, and policy structures from countries such as Germany, the United States, Japan, and emerging hydrogen leaders like Chile and Morocco, Nigeria can position itself effectively in the global hydrogen market. Additionally, as a member of the African Union (AU), Nigeria stands to benefit significantly from the AU Green Hydrogen Strategy by aligning its national policies with the continental strategy, Similarly, lessons from the ECOWAS framework emphasize regional collaboration, harmonized regulations, and capacity-building as key drivers for a competitive hydrogen economy. The lessons drawn emphasize balancing domestic energy needs with the potential for international partnerships and exports, ensuring that policy development supports both environmental goals and economic growth.

Key Policy Insights

Table 15 highlights essential policy elements that can be adapted to develop a robust hydrogen strategy for Nigeria. These insights could serve as a guide for Nigeria in creating a balanced approach that leverages its abundant natural and renewable resources while addressing infrastructure development, industrial applications, and market integration.

Table 15: Key policy insights and implication for Nigeria

Identified Area	Insight	Implication for Nigeria
Resource Utilization	The type of available resources heavily influences hydrogen strategies. Germany, with limited renewables, focuses on imports, while countries like Chile, Morocco and ECOWAS countries leverage their abundant solar and wind resources for export-oriented green hydrogen.	Nigeria has vast solar, wind, and natural gas resources. A hybrid policy could promote both green and blue hydrogen, capitalizing on its renewable potential and existing natural gas infrastructure.
Infrastructure and Industrial Applications	Countries like Germany, South Korea, and Japan have aligned their hydrogen strategies with domestic industrial	Implementing hydrogen to decarbonize industries (e.g., petrochemicals, heavy transport, and power generation) could create

	decarbonization needs. ECOWAS emphasizes regional collaboration for infrastructure development and integrated industrial hubs.	a resilient domestic market and stimulate economic growth. Establishing hydrogen hubs near industrial zones can stimulate economic growth and ensure supply efficiency.
Export-Oriented Policies	Export-focused strategies, as seen in Chile, Australia, and Morocco, allow these nations to harness their renewable resources to serve hydrogen demand in Europe and Asia. ECOWAS already promotes regional export integration.	Nigeria's strategic location and access to Europe make it an ideal candidate for hydrogen export, particularly blue hydrogen. Partnerships with European countries could be formed to position Nigeria as a reliable hydrogen supplier.
Governmental and Private Collaboration	The U.S. and Australia's advancements stem from robust public-private partnerships, while ECOWAS advocates similar models to de-risk investment and accelerate project implementation.	Establishing partnerships between the government and private sector can accelerate infrastructure development, attract investment, and foster a skilled workforce in hydrogen technology.
Technology Transfer and International Cooperation	International cooperation, as demonstrated by Japan, the UAE, and Germany, plays a crucial role in securing investments, gaining expertise, and facilitating technology transfer. ECOWAS highlights partnerships with Germany, IRENA, and others for capacity building.	Nigeria can accelerate its path to a sustainable hydrogen economy by collaborating with hydrogen leaders like Germany (green hydrogen and industrial applications), Japan (fuel cell technology), and South Korea (hydrogen infrastructure). This would help Nigeria acquire advanced expertise in hydrogen production and use. Partnerships with the U.S. (CCUS and electrolysis) and Australia (scaling green hydrogen) offer insights into technology and export strategies, while the UAE provides models for blue hydrogen and export logistics.
Policy and Regulatory Frameworks	Robust policies and clear regulations are foundational to the success of hydrogen strategies. South Korea's Hydrogen Economy Roadmap and Germany's National Hydrogen Strategy are prime examples.	Nigeria should prioritize developing a comprehensive regulatory framework with incentives and safety standards that stimulate production and consumption across different sectors.

Hydrogen policy implementation	Countries like Germany, UAE and Japan show the importance of aligning hydrogen strategies across government bodies for cohesive energy and industrial policies. This enables Coordinated action, Public-Private Partnerships and International Collaborations to share investment risks and accelerate infrastructure and technology development, which can be a model for Nigeria.	Nigeria can involve the following ministries and agencies: Federal Ministry of Budget and Planning (to assure policy coherence and strategic alignment with the country's economic goals and sustainable energy transition goals), Energy Commission of Nigeria (ECN), Federal Ministry of Power to oversees energy integration and grid stability, Federal Ministry of Petroleum Resources (Gas), NNPC to focus on blue hydrogen and CCUS, Ministry of Environment to ensure environmental standards for hydrogen production, Federal Ministry of Industry, Trade, and Investment to promote industrial decarbonization and hydrogen exports, Federal Ministry of Science, Technology, and Innovation to coordinate R&D and technology development, National Renewable Energy Agency to drive green hydrogen projects from renewables and Nigerian Ports Authority to develop hydrogen export infrastructure.

Formulating Nigeria's Hydrogen Policy Based on Available Resources

Based on insights from hydrogen policies in the aforementioned countries, Nigeria's hydrogen policy can incorporate the following recommendations and best practices to achieve a resilient, competitive, and sustainable hydrogen economy. Table 16 summarises the recommendations and best practices.

1. **Resource-Based Hydrogen Production Strategy**
   - Nigeria could emulate Saudi Arabia and the UAE by utilizing its natural gas reserves for blue hydrogen production while capturing CO_2 emissions through CCUS. This will provide a quick entry into the market while green hydrogen infrastructure is developed, using Nigeria's vast solar and wind potential, especially in northern and coastal regions.
   - Policy Framework for Dual Pathways: Develop a phased approach that starts with blue hydrogen as a transitional solution and scales up green hydrogen production as renewable energy capacity and CCUS technology mature. This approach provides flexibility for the policy to evolve as renewable infrastructure and CCUS technology mature.

2. **Industrial Decarbonization and Domestic Applications**
   - Inspired by Germany's policy on industrial decarbonization, Nigeria could focus on integrating hydrogen into heavy industries, such as petrochemicals, steel, and cement production, to

reduce emissions and reliance on imported fuels. Launch pilot projects to showcase hydrogen's effectiveness in these sectors.

- Power Generation and Grid Stability: Blue hydrogen can provide a stable energy supply in the short term, while green hydrogen can support renewable energy integration, addressing grid stability and intermittency challenges.

3. **Hydrogen Export Potential and Strategic Partnerships**
   - Like Chile and Morocco, Nigeria should leverage its strategic location to establish itself as a green hydrogen exporter, targeting markets in Europe and North America. Forming partnerships with hydrogen-importing regions, such as the European Union, can enhance Nigeria's competitiveness.
   - Infrastructure Investment: Policies should support the development of liquefaction plants, pipelines, and port facilities for efficient hydrogen export. Collaborations with private and international investors will be crucial for advancing these capabilities.

4. **Invest in Hydrogen Storage, Distribution, and Refueling Infrastructure**
   - Drawing inspiration from Japan and South Korea, Nigeria could further explore the possibility to adopt hydrogen fuel cell vehicles (FCVs) and invest in refueling infrastructure, focusing on heavy-duty long-haul vehicles.[46]
   - Storage Solutions: Nigeria should prioritize investments in hydrogen storage technologies to secure a consistent supply for both domestic use and export, following Germany's successful models.

5. **Policy and Regulatory Frameworks to Drive Innovation**
   - Develop comprehensive production, storage, and safety standards similar to Germany's regulatory approach, ensuring quality and environmental responsibility. This includes setting hydrogen purity levels, emissions thresholds, as well as health and safety guidelines.
   - Incentives for R&D: Like the U.S. and Germany, Nigeria should establish funding mechanisms for R&D in electrolysis and CCUS. This can be driven by local universities and research institutions to foster innovation and improve cost efficiency.
   - Nigeria can adopt ECOWAS's phased model, focusing on legislative readiness and pilot projects in the short term, scaling up infrastructure and production in the medium term, and achieving global competitiveness in the long term.

6. **Public-Private Partnerships and International Collaboration**
   - Emulate the U.S. and Australia by leveraging public-private partnerships to share investment risks and accelerate infrastructure development. Policies should offer tax incentives, subsidies, and favorable loan terms to attract private sector investment.
   - Global Engagement: Nigeria should actively participate in international hydrogen forums and collaborate with countries like Germany, Japan, and South Korea to facilitate technology transfer and secure market access.
   - ECOWAS's approach to harmonized regulations and cross-border infrastructure highlights the importance of regional integration for efficient hydrogen production and export. Nigeria should align its strategy with ECOWAS goals to tap into shared opportunities, including export markets and capacity-building initiatives.

[46] In the transport sector, the use of H2/PtX only makes sense in individual cases, if electrification (by battery) is not possible, given that electric vehicles are far more energy-efficient than fuel cell vehicles.

- By integrating the AU's strategic objectives into its national framework, Nigeria can play a pivotal role in advancing the continent's green hydrogen agenda and reaping the associated economic and environmental benefits.

7. **Workforce Development and Education**
   - Like Germany, Nigeria should invest in STEM education and hydrogen-specific vocational training programs. Collaborate with local universities and training institutes to establish hydrogen-focused curricula and support workforce readiness.
   - R&D Institutions: Create dedicated R&D centers for hydrogen technology to drive innovation and provide technical expertise, as seen in South Korea.
   - Drawing from ECOWAS's Green Hydrogen Development Unit, Nigeria could establish a centralized hydrogen authority to coordinate policy implementation, monitor progress, and ensure regional alignment.

Table 16: Recommendations and Best Practices for Nigeria

Recommendations	Best Practices
Leverage Natural Gas for Short-Term Blue Hydrogen Production: Implement CCUS technologies and foster government-private sector partnerships to fund and develop projects.	Implement CCUS technology, as demonstrated by the UAE and Saudi Arabia, to reduce emissions. Encourage government, private sector, and international partnerships to fund CCUS projects.
Develop Green Hydrogen Infrastructure in Renewable-Rich Regions: Encourage investment in solar and wind energy infrastructure with subsidies and international partnerships.	Learn from Australia and Chile by providing incentives and subsidies for renewable energy projects. Partner with international investors and technology providers to accelerate deployment.
Prioritize Industrial Applications: Offer incentives for industries adopting hydrogen to decarbonize operations and launch pilot projects to showcase hydrogen's benefits.	Like Germany, offer tax breaks or subsidies for industries adopting hydrogen. Follow Japan and South Korea's approach of piloting industrial hydrogen applications.
Position as a Green Hydrogen Exporter: Establish partnerships with potential importers and develop export infrastructure. **Build Storage and Distribution Infrastructure:** Support these projects through public-private investments and grants.	Secure agreements with European partners and collaborate on technology transfer for hydrogen storage and transport, as seen in Morocco. Support hydrogen infrastructure through public private partnerships, following the models of Germany and the U.S. Create refueling infrastructure in key industrial zones.
Establish Comprehensive Policy Frameworks: Define production, safety, and environmental standards to attract investment.	Set stringent production standards, as practiced in Germany, to maintain hydrogen quality and safety. Establish a regulatory body to oversee compliance.
	Use PPPs to share investment risks, as demonstrated by Australia and the U.S.

Encourage Public-Private Partnerships and International Collaboration: Incentivize investments and participate in global alliances.	Participate in international hydrogen alliances for technology transfer.
Create Financial Incentives and Funding Mechanisms: Provide tax credits, subsidies, and grants for hydrogen projects	Follow the U.S. and South Korea's example of providing early-stage tax credits and low-interest loans.
Policy implementation	Establish or assign the overseeing of hydrogen development to government bodies like ministries and agencies as seen in countries like Germany, UAE and Japan.
Build a Skilled Workforce through Education and Training Programs: Develop hydrogen technology programs in partnership with educational institutions.	Germany's investment in STEM education can serve as a model. Partner with universities to create specialized hydrogen curricula.
Invest in R&D: Fund research for cost-efficient electrolysis, storage, and CCUS to ensure continuous innovation.	Emulate Germany and Japan's commitment to R&D funding, particularly for advancements in electrolysis and hydrogen storage. Collaborate with global leaders for technology adaptation.

Recommendations for Nigeria's Hydrogen, PtX Standards and Value Chain Regulation

Production standards	Storage and Transport Standards	Distribution and Handling Standards	Conversion Standards	Institutional Framework for Nigeria
Adopt Renewable-Based Electrolysis: Mandate the use of renewable energy sources (e.g., solar, wind, hydro) for green hydrogen production, supported by incentives for projects that meet specific sustainability criteria.	**Storage Regulations**: Develop comprehensive safety standards for hydrogen storage technologies, including compressed hydrogen, liquid hydrogen, and underground storage in salt caverns.	**Distribution Network Standards**: Develop standards for hydrogen distribution networks, including refueling stations and hydrogen hubs in urban and industrial areas.	**PtX Guidelines**: Create regulations for PtX applications, such as producing synthetic fuels, ammonia, and methanol, to facilitate their adoption in industrial processes.	**Lead Government Body**: Establish a dedicated national body, such as the Nigerian Hydrogen and Renewable Energy Commission (NHREC), to coordinate hydrogen policy development and implementation.
Set Efficiency Benchmarks: Establish minimum efficiency standards for electrolysis systems (e.g.,	**Transport Infrastructure**: Implement guidelines for hydrogen blending with natural gas in existing pipelines	**Handling Procedures**: Introduce training programs for personnel involved in handling hydrogen, focusing	**Sectoral Standards**: Implement sector-specific standards for the use of hydrogen in heavy transport, chemical	**Inter-Ministerial Coordination**: Foster collaboration between the Ministry of Gas/Petroleum,

achieving a conversion efficiency of at least 70-80%).	and develop regulations for constructing dedicated hydrogen pipelines.	on safe practices and emergency response measures.	production, and power generation, ensuring efficient conversion and minimal energy loss.	Ministry of Science, Technology and Innovation, Ministry of Power, Ministry of Environment, and Ministry of Industry to streamline hydrogen-related policies and initiatives.
Certification System: Implement a certification scheme for green hydrogen to validate production methods and ensure they meet sustainability criteria.	**Safety Protocols**: Establish rigorous safety protocols to manage the high reactivity and storage pressures of hydrogen, drawing from best practices used in countries like Japan and Germany.	**Leak Detection**: Require the use of advanced leak detection systems throughout the distribution network to minimize risk and enhance safety.	**Pilot Programs**: Support pilot projects that explore PtX applications in sectors like agriculture (ammonia-based fertilizers) and transport (synthetic fuels for heavy vehicles).	**PPPs**: Create platforms for partnerships between government agencies, private companies, and international stakeholders to pool resources, share expertise, and drive innovation.
Emissions Monitoring: Enforce strict monitoring of emissions during hydrogen production to ensure compliance with environmental regulations.	**Inspection and Maintenance**: Mandate periodic inspections and maintenance of storage and transport facilities to prevent leaks and ensure safety.	**Transportation Codes**: Establish transportation regulations that cover both domestic and export hydrogen transport by road, rail, and sea, with protocols for different hydrogen states (gaseous, liquid, or as derivatives).	**Emissions Control**: Ensure that PtX applications are compliant with emissions targets to promote sustainable growth.	**Advisory Board**: Form a Hydrogen Advisory Board consisting of experts from academia, industry, and international agencies to provide strategic guidance on policy and technical standards. Regional Offices: Set up regional offices to oversee the implementation of hydrogen projects and regulatory adherence at local levels, ensuring nationwide coverage.

Recommended Institutional Framework for Nigeria's Hydrogen Development

By involving these key ministries, Nigeria can create a coordinated hydrogen policy that leverages its resources and promotes industrial and energy transformation.

Ministry/Agency	Role in Hydrogen Strategy
Budget and National planning	Coordinate cross-ministerial efforts, oversee national strategy alignment, with the country's economic goals and sustainable energy transition goals.
Federal Ministry of Innovation, Science and Technology	Conduct R&D on all energy sources and carriers, incl. hydrogen, methanol, etc. integrate hydrogen into education and training curricula for skills development.
Energy Commission of Nigeria (ECN)	Planning and coordination of the hydrogen national policy
Ministry of Petroleum Resources - Gas (MPR)	Facilitate blue hydrogen development using Nigeria's natural gas resources and oversee CCUS projects to reduce carbon emissions.
Federal Ministry of Power (MoP)	Oversee hydrogen integration into the energy grid, ensure energy security, and guide hydrogen's role in stabilizing renewables.
Ministry of Environment (MoE)	Establish environmental standards for hydrogen production (especially for blue hydrogen) and ensure alignment with sustainability goals.
Ministry of Steel Development (MoD)	Support hydrogen-based decarbonization in the steel industry and encourage hydrogen adoption in steel manufacturing processes.
Ministry of Industry, Trade, and Investment (MoITI)	Drive hydrogen use in industrial applications, support decarbonization, and promote export opportunities.
Ministry of Agriculture and Food Security (MoA)	Explore hydrogen applications in agriculture, including using hydrogen-derived fertilizers and fuels for sustainable farming practices.
Ministry of Finance (MoF)	Provide financial incentives, tax breaks, and subsidies to support hydrogen projects and investments in hydrogen infrastructure.
Ministry of Transport (MoT)	Develop and implement hydrogen refueling infrastructure for transportation, including hydrogen fuel cell vehicles and freight transport.

Ministry of Aviation (MoA)	Promote hydrogen fuel use in aviation, support hydrogen-powered aircraft research, and plan for airport hydrogen refueling infrastructure.
Ministry of Budget and Economic Planning (MoBEP)	Allocate funding, plan budgetary resources, and prioritize hydrogen initiatives in line with national economic goals.
Ministry of Water Resources (MoWR)	Ensure sustainable water resource management for green hydrogen production, including water allocation for electrolysis processes.
Ministry of Marine and Blue Economy (MoMBL)	Support hydrogen as a marine fuel, develop port infrastructure for hydrogen exports, and ensure compliance with blue economy standards.
National Renewable Energy Agency	Promote green hydrogen development using renewable resources and facilitate projects that support hydrogen production.
Nigerian Ports Authority (NPA)	Develop export infrastructure, including port facilities, to ensure Nigeria's ports are equipped for hydrogen exports.
Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA)	Regulatory
Nigerian Upstream Petroleum Regulatory Commission (NUPRC)	Regulatory
The National Council for Climate Change (NCCC)	Impact assessment/ regulatory

Recommended Partnership for Nigeria's Hydrogen Development

Collaborating with countries that are leaders in hydrogen technology can help Nigeria build local expertise and develop a sustainable hydrogen economy. Table 16 highlights recommended potential global partnership for Nigeria

Country	Why Partner?	Benefits for Nigeria
Germany	Pioneer in green hydrogen production, with a focus on renewables, industrial applications, and advanced research.	Expertise in green hydrogen production, PtX technologies for synthetic fuels/ammonia, potential export partnerships.
Japan	Extensive experience with fuel cell technology and integrating hydrogen into transportation and power generation.	Insights into hydrogen-based transportation, support for developing hydrogen refueling infrastructure and industrial applications.

South Korea	Well-developed hydrogen economy roadmap, focusing on fuel cells, transportation, and industrial uses.	Technology transfer for hydrogen storage, fuel cells, and distribution infrastructure, aiding Nigeria's hydrogen network.
United States	Significant investments in green and blue hydrogen, with strong public-private partnerships and large-scale R&D.	Financial and technical support, especially in CCUS for blue hydrogen and electrolysis, along with strategies for private investment.
Australia	Major player in green hydrogen aiming to become a leading exporter, especially to Asia.	Insights into scaling green hydrogen with renewables, export infrastructure development, and hydrogen trading agreements.
United Arab Emirates (UAE)	Advancing both green and blue hydrogen, with investments in hydrogen production and export infrastructure.	Expertise in large-scale hydrogen logistics, including liquefaction and port infrastructure; support for blue hydrogen projects.

Potential Export Markets

Among the countries highlighted in Table 16, the potential export markets are in Europe and North America. In Europe, Germany, Netherlands, and other EU nations are looking to diversify energy sources and meet climate targets. Hence, Europe has a strong demand for green hydrogen as part of its decarbonization goals and offers well-established hydrogen import infrastructure and funding for clean energy imports. Similarly, in North America, the U.S. and Canada are ramping up their hydrogen use for industrial decarbonization and energy security. They also seek to diversify their import sources for green hydrogen.

Key International Partners and Collaboration Areas

Germany, Japan and UAE are recommended as the key international partners. Germany's ambitious hydrogen import goals and advanced green hydrogen technologies align well with Nigeria's renewable energy potential, making Germany a prime partner. Hence, Nigeria can collaborate in green hydrogen production and export partnerships, technology transfer in PtX applications, and infrastructure development. Also, Japan's extensive work in fuel cell technology and plans for hydrogen imports offer Nigeria a pathway to export green hydrogen and leverage Japanese advancements in transportation infrastructure. The area of collaboration should be in fuel cell technology for transportation, hydrogen storage and refueling infrastructure, and industrial hydrogen applications. For United Arab Emirates (UAE), collaboration can be in blue hydrogen production and export logistics, including port and liquefaction infrastructure, and expertise in leveraging fossil fuels for hydrogen production as the UAE's experience in blue hydrogen aligns with Nigeria's natural gas resources, providing a valuable partnership for blue hydrogen production and export infrastructure development.

Recommendation on Timeline and Roadmap for Nigeria's Hydrogen Development

Phase 1: Foundation and Planning (1-2 Years)

1. Establish a Coordinated Institutional Framework:
    - Use an existing agency such as the ECN (perhaps with modified name) to oversee policy development, inter-ministerial coordination, and private sector engagement.
2. Draft Regulatory and Safety Standards:
    - Develop initial standards for hydrogen production, transport, and safety. Begin with blue hydrogen using natural gas and CCUS while laying the groundwork for green hydrogen.
3. Introduce Investment Incentives:
    - Implement tax breaks, subsidies, and grants to attract private investment in pilot projects and hydrogen infrastructure.

Phase 2: Infrastructure Development and Pilot Programs (3-5 Years)

1. Launch Pilot Hydrogen Hubs and Infrastructure:
    - Establish hydrogen hubs in regions with high renewable potential and industrial demand. Construct initial storage and transport infrastructure, including pilot pipelines and refueling stations for transportation.
2. Begin Industrial Decarbonization Projects:
    - Initiate pilot projects for hydrogen use in heavy industries (e.g., petrochemicals, steel) to demonstrate feasibility and benefits.
3. Expand Partnerships:
    - Formalize partnerships with international hydrogen leaders to access technology and investment. Begin pilot exports with small-scale shipments of blue hydrogen.

Phase 3: Scaling Up and Market Integration (6-10 Years)

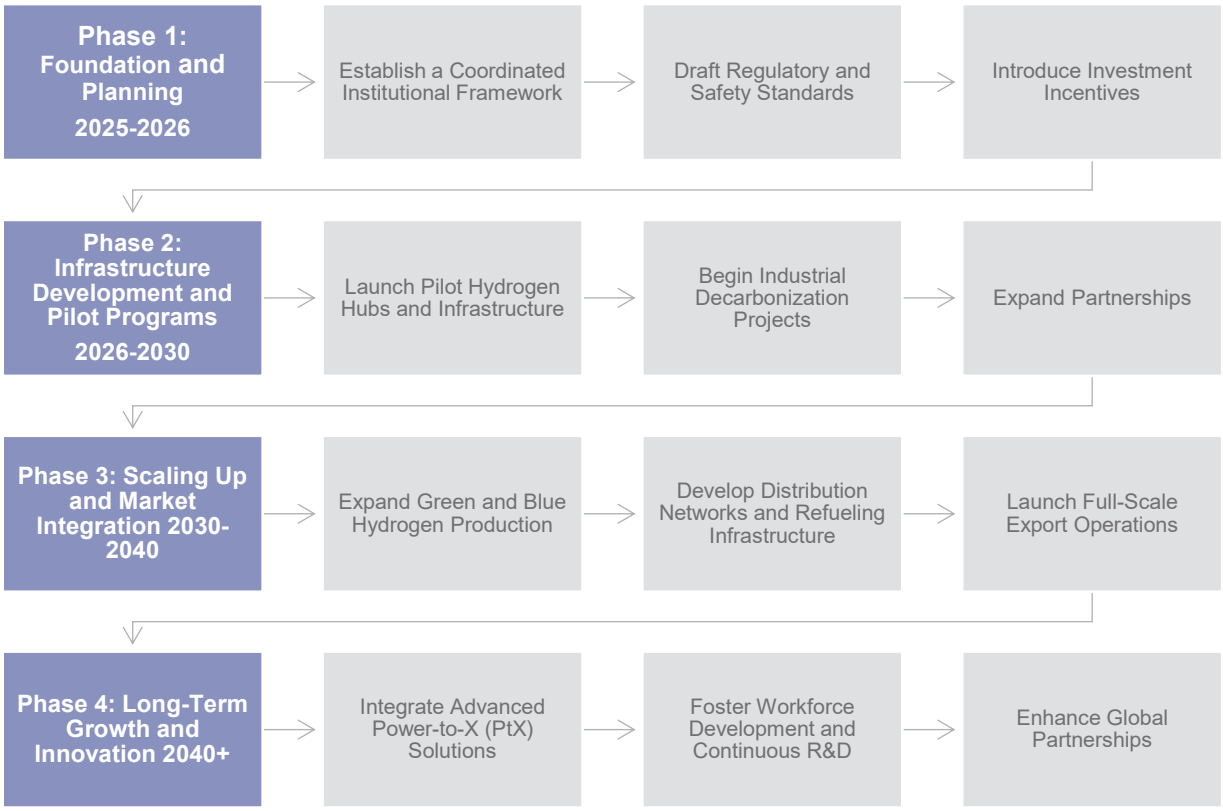
1. Expand Green and Blue Hydrogen Production:
    - Scale hydrogen production capacity to meet domestic and initial export demands. Start large-scale solar and wind projects to fuel green hydrogen.
2. Develop Distribution Networks and Refueling Infrastructure:
    - Build dedicated hydrogen pipelines in key industrial corridors and expand refueling stations to support FCVs and public transport.
3. Launch Full-Scale Export Operations:
    - Complete necessary export infrastructure (e.g., liquefaction plants and port facilities) to begin regular hydrogen exports to international markets.

Phase 4: Long-Term Growth and Innovation (10+ Years)

1. Integrate Advanced Power-to-X (PtX) Solutions:
    - Focus on PtX applications to produce synthetic fuels and ammonia for export and industrial use.
2. Foster Workforce Development and Continuous R&D:

- Expand educational programs and establish R&D centers dedicated to hydrogen and renewable energy technology.

3. Enhance Global Partnerships:
    - Strengthen international collaborations to stay competitive and advance hydrogen innovation.



08. Conclusion

In formulating a robust hydrogen policy, Nigeria stands at a pivotal moment to leverage global insights and tailor them to its unique strengths and development goals. By examining the hydrogen strategies of countries like Germany, the United States, Japan, and Saudi Arabia, Nigeria can see how policies can drive industrial decarbonization, energy security, and economic growth when aligned with regional resources and strategic objectives.

Nigeria's vast landscapes and abundant natural resources offer a strong foundation for renewable energy, from solar potential in the north to wind resources along coastal regions and biomass from agriculture. These diverse resources support a hybrid hydrogen approach: in the short term, blue hydrogen from Nigeria's natural gas, coupled with carbon capture, can meet immediate energy needs, while investments in solar and wind-powered green hydrogen will position Nigeria for long-term sustainability and export opportunities to markets like Europe and North America.

Success in this sector will require fostering public-private partnerships, creating clear regulatory frameworks, and investing in workforce training and R&D. Strategic international partnerships can bring the expertise and capital needed to scale sustainable hydrogen production. By harnessing its natural resources, Nigeria can lead in Africa's clean energy transition, creating a resilient, low-carbon future that drives economic growth, modernizes industries, and positions the country as a global energy innovator.

09. Appendix

APPENDIX 1

ECOWAS Green Hydrogen Policy and Strategy Framework

The ECOWAS[47] Green Hydrogen Policy and Strategy Framework aims to position the ECOWAS region as a competitive producer and supplier of green hydrogen, leveraging the region's renewable energy potential to drive socio-economic growth, sustainability, and global competitiveness. It emphasizes green hydrogen as a transformative energy source for decarbonizing industries, transportation, agriculture, and power systems. By doing so, it integrates with ECOWAS's broader energy policy and Vision 2050[48]. Below is a summary of the key components and strategies detailed in the policy:

Key Features

1. **Strategic Vision and Objectives**:

The policy vision targets achieving a green hydrogen production of 0.5 million tons per year by 2030 and 10 million tons by 2050. It seeks to harness regional renewable energy resources, foster investment, and build an enabling regulatory and institutional framework to support this development. The objectives are categorized into two:

a. **Short-Term (2023–2030):**

- Develop an enabling legislative framework and capacity-building initiatives.
- Undertake demonstration projects to stimulate investment.
- Establish strategic partnerships for technology transfer and financing.

b. **Long-Term (2031–2050):**

- Scale up to global competitiveness in green hydrogen production.
- Integrate green hydrogen into regional energy systems for industrial and economic development.

2. **Resource and Infrastructure Potential**: The policy highlights the region's solar, wind, and hydropower potential as critical for green hydrogen production while emphasizing the need for investments in electrolyzer capacity and infrastructure development, including hydrogen storage and export logistics.

3. **Phased Development**:
   a. **Phase 1 (2023-2025)**: Develop enabling environments, conduct feasibility studies, and launch demonstration projects.

[47] The **Economic Community of West African States** (**ECOWAS**) is a regional political and economic union of fifteen countries of West Africa.

[48] ecowas_green_hydrogen_policy_21112023.pdf, Global Hydrogen Review 2023 – Analysis - IEA

b. **Phase 2 (2025-2030)**: Build scalable hydrogen production clusters, develop infrastructure, and attract investment.
c. **Phase 3 (2030-2050)**: Scale to commercial production, establish export markets, and achieve integration into global hydrogen value chains.

4. **Targets and Investments**: The framework sets specific short-term targets for hydrogen clusters and production projects by 2026 and requires $3-5 billion in investments by 2030, with annual revenue projections of $1.25 billion.

5. **Institutional Framework**: Establish the ECOWAS Green Hydrogen Development Unit (EGHDU) to oversee policy implementation, coordination, and monitoring; and collaborate with member states to harmonize regulations and ensure policy alignment.

6. **International Collaboration**: Foster partnerships with global players like Germany, leveraging technical expertise and funding for initiatives like H2Atlas.

The framework adopts a phased approach for implementation, prioritizing regulatory harmonization, capacity-building, infrastructure development, and R&D. Additionally, it promotes international collaboration for financing and market development, while emphasizing local socio-economic benefits, including job creation. A summary of the ECOWAS framework is presented in the table below.

Category	Key Details
Vision	ECOWAS to become a competitive global supplier of green hydrogen, leveraging renewable energy potential for regional and international markets.
Targets	0.5 million tons/year by 2030; 10 million tons/year by 2050.
Phases	Phase 1: Pilot projects; Phase 2: Scaling production; Phase 3: Full commercialization.
Resource Base	Abundant solar, wind, and hydropower resources distributed across ECOWAS countries.
Challenges	Infrastructure gaps, high production costs, water resource limitations, and limited local expertise.
Funding Needs	$3-5 billion by 2030 for electrolyzers, production hubs, and infrastructure.
Institutional Framework	Creation of EGHDU and alignment with national policies for coordinated green hydrogen development.
Export Strategy	Prioritize partnerships with Europe and North America for hydrogen export markets.
Technology and R&D Focus	Electrolysis, CCUS, and renewable energy integration.
Regional Collaboration	Develop regional frameworks for hydrogen production, distribution, and export, with ECOWAS members sharing benefits.

APPENDIX 2

Africa Union (AU) Green Hydrogen Policy and Strategy Framework

The African Union (AU) Green Hydrogen Strategy and Action Plan was approved by African Ministers of Transport and Energy during the 3rd Extraordinary Ministerial Meeting of the AU's Specialized Technical Committee on Transport and Energy (STC-T&E) in December 2024[49]

This strategic initiative aims to position Africa as a global leader in green hydrogen by leveraging the continent's abundant renewable energy resources, access to key minerals, established trade relationships, and proximity to export markets[50]

Key Objectives of the AU Green Hydrogen Strategy

1. **Energy Security and Decarbonization:** Green hydrogen, produced using renewable energy sources such as solar and wind, is seen as a key solution for improving energy security, advancing decarbonization, and driving economic diversification across Africa.
2. **Economic Diversification and Job Creation:** By tapping into green hydrogen, African nations aim to diversify their energy mix while promoting industrialization, creating job opportunities, and generating revenue streams.
3. **Global Leadership in Green Hydrogen:** The strategy seeks to establish Africa as a key player in the global green hydrogen market, capitalizing on its renewable energy potential and strategic geographic location.

Strategic Actions:

- **Development of Domestic and Export Markets**: The strategy emphasizes a phased approach, focusing on the development of both domestic and export markets for green hydrogen.
- **Infrastructure and Policy Development:** It calls for the establishment of necessary infrastructure and supportive policies to facilitate the growth of the green hydrogen sector across the continent**.**

[49] African Union approves African Green Hydrogen Strategy and Action Plan - Green Building Africa
[50] African Ministers Approve Key Strategies for Africa's Energy Future - Africa-EU Energy Partnership

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