UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

A2D
Accelerate to Demonstrate Facility

MARKET ASSESSMENT ON CLEAN HYDROGEN INNOVATION IN DEVELOPING COUNTRIES

November 2024

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

A2D Accelerate to Demonstrate Facility

ACKNOWLEGMENT

This market assessment was conducted by Hinicio S.A. and under the overall guidance of Mr. Peter Warren, A2D Facility Manager, and Ms. Pankhuri Poddar, A2D Facility Clean Hydrogen Project Coordinator, within the Division of Climate Innovation and Montreal Protocol of the United Nations Industrial Development Organization (UNIDO). This effort was made possible through the support of the United Kingdom's Department for Energy Security and Net Zero (DESNZ).

UK Government

Authors from Hinicio: Ms. Paola Galeano, Ms. María José Riquelme, Ms. Francesca Cullacciati, Ms. Silvana Castañeda, Mr. Ignacio Kahler and Mr. Carlos Andrés López
Authors from PureResource: Mr. Sandeep Pahal and Ms. Ritika Yachna

The project team would like to thank the survey respondents and interviewed experts for their invaluable time and insights.

Hinicio puREsource partners

The UNIDO team would also like to express its gratitude to all those who through meetings, surveys and workshops contributed to this market assessment.

About UNIDO

UNIDO is a specialized agency of the United Nations with a unique mandate to promote, dynamize and accelerate industrial development. Our mandate is reflected in Sustainable Development Goal (SDG) 9: “Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation”, but UNIDO’s activities contribute to all the SDGs.

UNIDO’s vision is a world without poverty and hunger, where industry drives low-emission economies, improves living standards, and preserves the livable environment for present and future generations, leaving no one behind.

ABBREVIATIONS AND ACRONYMS

A2D	Accelerate-to-Demonstrate Facility
ADB	Asian Development Bank
CCUS	Carbon Capture, Utilisation, and Storage
DAC	Development Assistance Committee
DRI	Direct Reduced Iron
EBRD	European Bank for Reconstruction and Development
EIB	European Investment Bank
FCEV	Fuel Cell Electric Vehicle
FENOGE	Non-Conventional Energies and Efficient Energy Management Fund of Colombia
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	German Agency for International Cooperation
IDB	Inter-American Development Bank
IEA	International Energy Agency
IFC	International Finance Corporation
IIT	Indian Institutes of Technology
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IRESEN	Institute for Research in Solar Energy and New Energies of Morocco
JETP	Just Energy Transition Partnership
LOHC	Liquid Organic Hydrogen Carrier
MoU	Memorandum of Understanding
ODA	Official Development Assistance
PRL	Project Readiness Level
PV	Photovoltaic
R&D	Research and Development
SAF	Sustainable Aviation Fuel
SDG	Sustainable Development Goal
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolyser Cell
TRL	Technology Readiness Level
UK DESNZ	Department for Energy Security and Net Zero of the United Kingdom
UNIDO	United Nations Industrial Development Organization

CONTENTS

1

Introduction

Clean hydrogen technology innovation in developing countries faces unique challenges and opportunities that must be addressed within their specific contexts. The following report analyses the required ecosystems to boost the industry with an in depth analysis of 16 countries that are leading the way in Africa, Asia, Europe, and Latin America and the Caribbean. The A2D Facility seeks to address this gap by driving the commercialisation of clean hydrogen technologies and accelerating the adoption of innovative solutions.

1 INTRODUCTION

The global transition to clean hydrogen is increasingly recognised as a critical component in achieving decarbonisation goals and addressing climate change. Clean hydrogen, which is produced either from renewable sources or through steam methane reforming with carbon capture and storage (CCS), plays a critical role in this transformation. As the world seeks to reduce greenhouse gas (GHG) emissions and transition to sustainable energy systems, developing countries face unique challenges but also offer significant opportunities to deploy clean hydrogen technologies to transform their energy landscapes, expand sustainable industry practices, and contribute meaningfully to global climate action. Conversely, the establishment of robust innovation ecosystems is essential to accelerate the production and adoption of clean hydrogen. These ecosystems encompass a range of enabling policies and regulations, access to finance, skilled human resources, supportive research markets, renewable energy infrastructure, entrepreneurship, and networking assets.

To tackle these unique challenges and opportunities, in 2023, the UK Department for Energy Security and Net Zero (UK DESNZ) and the United Nations Industrial Development Organization (UNIDO) launched the A2D Facility. The A2D Facility is a large-scale, global programme focused on accelerating the commercialisation of innovative clean energy technologies in developing countries. It focuses on providing grant funding to support the implementation and operation of catalytic demonstration projects in the following initial thematic areas-of-focus: critical minerals, clean hydrogen, smart energy, and industrial decarbonisation. It addresses a significant gap in climate innovation funding for developing countries, focusing on the pilot demonstration phase of the climate innovation chain.

To support these goals, this market assessment provides a comprehensive overview of the clean hydrogen ecosystems in developing countries. It outlines the current state of technologies, projects, stakeholders, supporting initiatives, challenges, and opportunities, along with the delivery mechanisms shaping this emerging sector. The report also explores how the clean hydrogen industry can impact the achievement of Sustainable Development Goals (SDGs) and presents profiles of the most promising developing countries in terms of clean hydrogen innovation.

The research findings show that the majority of developing countries where clean hydrogen is being explored are in the initial stages of developing innovative clean hydrogen technologies. These efforts are either focused on Research and Development (R&D) or on adopting existing technologies imported from developed nations. Many projects rely on the adoption of these imported technologies because of significant challenges in testing and demonstrating new innovations in local environments. The main barriers include a shortage of skilled personnel, high costs, limited laboratory infrastructure, and insufficient access to necessary materials.

In this context, innovative clean hydrogen technologies for developing countries are defined as those that support the development, implementation, and operation of later-stage, on-the-ground pilot demonstration projects. These technologies create new value across the clean hydrogen value chain and employ solutions that are not yet widely adopted or implemented in that country's market, particularly those that can serve as influential examples.

The technologies considered in this market assessment include: (i) new or improved technological developments that have reached or are expected to reach Technology Readiness Level (TRL) 6-7; or (ii) the early adoption of existing innovative technologies (TRL 7-9) that have been tested in developed countries and are now being implemented in pilot or large-scale projects in specific developing countries. The progress of these projects is measured using Project Readiness Levels (PRLs), which indicate how quickly a project is advancing, regardless of the technological readiness.

This report provides a comprehensive analysis of how various elements and stakeholders within the clean hydrogen ecosystem—both within developing countries and globally—interact to drive innovation. The market assessment identified an illustrative list of projects and developing countries which boast the main characteristics of healthy ecosystems with the potential to boost clean hydrogen markets. It also identifies where and how the A2D Facility can best support the growth of the clean hydrogen sector in developing countries and contribute to global decarbonisation efforts. Based on the research conducted, promising projects shall incorporate a significant portion of the value chain in order to address the business case and not only the technological advancement. Also, they shall address local or site-specific conditions; system integration with the kind of renewable sources available (e.g., intermittent sources versus constant sources); end-use uptake and competitiveness; and seek levelised cost of hydrogen and derivatives.

In the following sections, we present the methodological approach used in this analysis and clarify the key concepts central to understanding the clean hydrogen landscape.

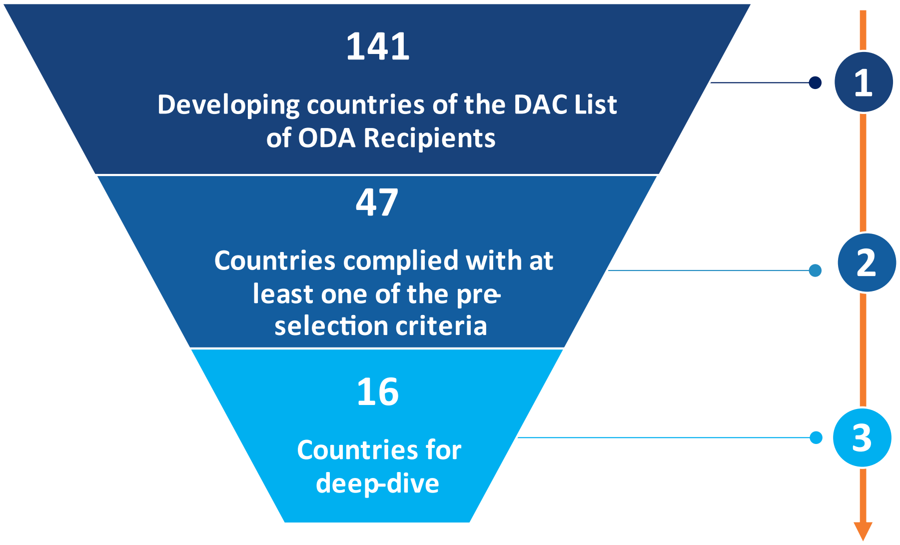
Methodological approach

The research methodology aimed to identify how the landscape of innovation is shaping in developing countries, the most advanced projects and the technologies they are employing, and the most competitive countries for clean hydrogen innovation. Beginning with a desk review of over 300 resources, the secondary data was supplemented with primary data collected through interviews, surveys, and workshops involving more than 100 international stakeholders, including developers, researchers, industry experts, government representatives, and international funding organisations working with or in developing countries.

Figure 1-1 shows the multi-method approach used to select the countries. The selection process applied three initial criteria: the presence of innovative hydrogen projects in advanced development stages, a national hydrogen strategy or roadmap, or the existence of at least one hydrogen association. These criteria demonstrated public or private sector interest in developing a clean hydrogen ecosystem and fostering technological innovation. As a result, 47 countries across Africa, Asia, Europe, Latin America, and the Caribbean were shortlisted.

From this shortlist, 16 countries were chosen for in-depth analysis through a step-by-step quantitative ranking method. This evaluation considered several factors: the presence of innovators and stakeholders, national initiatives, government or international funding, and technological research and projects at higher PRLs and TRLs. The outcome of this analysis was the identification of "deep-dive" countries, which are detailed in the final section of this report.

Figure 1-1: Funnel to pre-select 16 countries for in-depth study



Source: Hinicio (2024).

Market Assessment Structure

The market assessment is structured as follows:

1. Geographical Scope of Market Assessment: This section outlines the specific regions and developing countries that were the focus of the market assessment, providing details on the countries considered for analysis.

2. Technological Landscape in Developing Countries: This section explores the range of clean hydrogen technologies currently being developed and implemented across developing countries. It reviews advancements across the value chain, highlights ongoing projects, identifies barriers, and pinpoints gaps where further innovation is needed.

3. Innovators Driving Clean Hydrogen in Developing Countries: This section profiles the key innovators—including academic institutions, research bodies, and private sector companies—leading advancements in developing countries. It also examines the types of innovation being pursued, levels of technological readiness, and the challenges innovators face in scaling up.

4. Stakeholder Landscape in Developing Countries: The success of the clean hydrogen sector relies on the collaboration of various stakeholders. This section identifies and analyses the roles of key players such as government agencies, research institutions, industry leaders, funding bodies, and international partners. It emphasises the importance of collaboration in fostering a supportive ecosystem for clean hydrogen innovation.

5. Initiatives Supporting Clean Hydrogen in Developing Countries: A range of initiatives is driving clean hydrogen development across developing countries at national, regional, and international levels. This section categorises these initiatives into policies, programmes, hydrogen hubs, international partnerships, and financing programmes. It assesses their effectiveness in promoting clean hydrogen technologies and in fostering collaboration among stakeholders.

6. Delivery Mechanisms: Developing a robust clean hydrogen sector in developing countries requires effective delivery mechanisms. This section examines existing mechanisms, drawing lessons from the renewable energy sector, and discusses how these can be adapted to support the clean hydrogen industry. It also examines the financial, technological, and infrastructure requirements for scaling clean hydrogen projects.

7. Assessment of SDGs: Clean hydrogen has the potential to make significant contributions to achieving the SDGs. This section evaluates how clean hydrogen initiatives align with and advance specific SDGs, particularly Goal 1 (No Poverty), Goal 9 (Industry, Innovation, and Infrastructure), and Goal 13 (Climate Action). It also explores the socio-economic benefits that clean hydrogen could bring to developing countries.

8. Country Profiles: The final section presents detailed profiles of developing countries that are leading in clean hydrogen innovation. These profiles examine each country's innovation landscape, stakeholder engagement, current initiatives, and potential for future development. The profiled countries, which span across Africa, Asia, Europe, and Latin America and the Caribbean, have made notable progress in advancing clean hydrogen technologies. The countries included are Egypt, Kenya, Morocco, Namibia, South Africa, India, Indonesia, Malaysia, Viet Nam, Türkiye, Ukraine, Argentina, Brazil, Colombia, Costa Rica, and Mexico.

This comprehensive analysis provides stakeholders with valuable insights into the potential of developing countries in clean hydrogen innovation, opportunities for investment and collaboration, and strategies for overcoming challenges and barriers. As the global transition towards a greener future accelerates, developing countries will play an essential role in shaping the clean hydrogen economy worldwide.

2

Market Assessment Geographical Scope

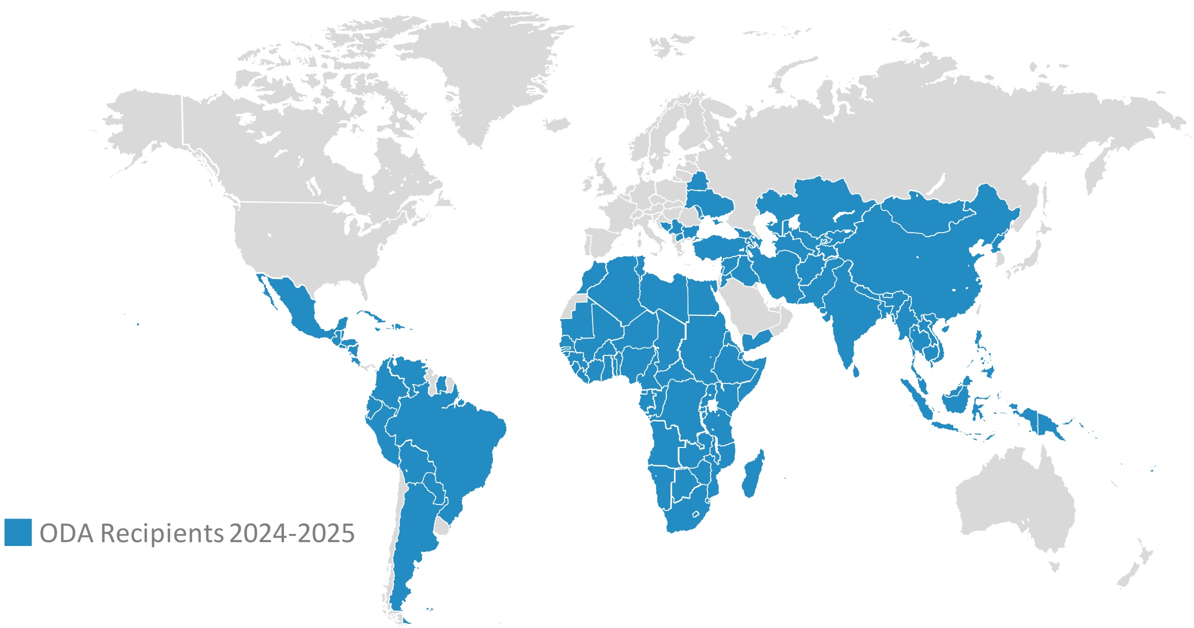
This market assessment taps into data from 141 developing countries identified by the OECD, unlocking powerful insights. This report uncovers key trends, strengths, and gaps shaping each region's future. The geographical scope provides valuable insights, particularly when concentrated on developing countries, where the challenges are both compelling and significant.

2 GEOGRAPHICAL SCOPE OF MARKET ASESSMENT

The geographical scope of this market assessment encompasses data from or related to one or more of the 141 developing countries identified in the Organization for Economic Co-operation and Development's (OECD) Development Assistance Committee (DAC) List of Official Development Assistance (ODA) Recipients for the years 2024 and 2025 (OECD, 2023).

The DAC list includes countries and territories eligible to receive ODA. These consist of all low- and middle-income countries, as defined by gross national income per capita according to the World Bank, excluding former G8 members, European Union (EU) member states, and countries with a confirmed date for EU accession. The list also includes all Least Developed Countries (LDCs) as defined by the United Nations (UN) (OECD, 2023).

Figure 2: Map of developing countries of the DAC List of ODA Recipients 2024-2025



Source: Hinicio (2024), based on the DAC List of ODA Recipients 2024-2025 (OECD, 2023)[1]

These countries were classified for different analyses in the following regions: Africa, Asia, Europe, and Latin America and the Caribbean (LAC).

[1] This map does not represent exact national boundaries. Due to scale limitations, it provides the most feasible approximation of geographical features.

3

Landscape of technologies in developing Countries

In developing countries, clean hydrogen technologies are still in the early stages, primarily focusing on the early adoption of existing solutions. However, significant progress is being made, with over 110 projects advancing to late-stage phases. Most of these projects are concentrated on hydrogen production and end-use applications, signaling promising developments in the sector.

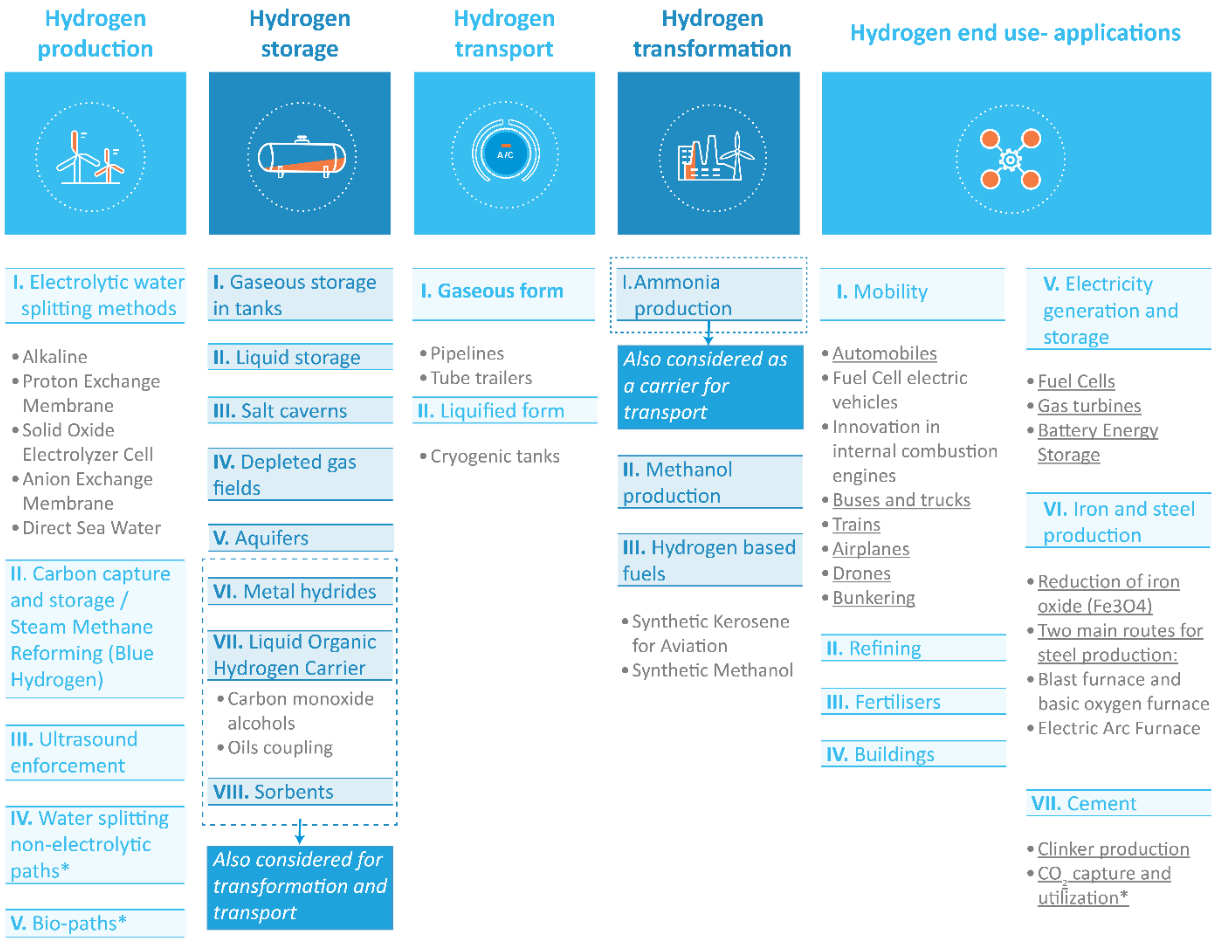
3 LANDSCAPE OF TECHNOLOGIES

KEY FINDINGS:

- **Hydrogen Projects**: 114 hydrogen projects (Leaving China aside) with TRLs 6–9 were identified across 35 developing countries. LAC and Asia lead in new technologies and early adoption.
- **Project Focus**: 41% of the projects focus on hydrogen production, followed by 23% on mobility. Electrolysis is favoured over Carbon Capture, Utilisation, and Storage (CCUS) in developing countries due to abundant renewable resources, though Asia leads in CCUS.
- **Underdeveloped Segments**: Storage, transport, and hydrogen carriers, excluding ammonia, remain underdeveloped across the value chain in developing countries, with 8 projects out of the 114 mapped.
- **Preferred Storage**: Geological storage is the most common method being explored for large hydrogen storage, as alternatives remain limited in these regions.
- **Location and Infrastructure**: Most projects are located near ports, reducing transport costs. Colombia and India are exploring hydrogen blending in gas pipelines.
- **Regional Breakdown**: LAC hosts 41 projects, while Africa has 28. In Africa, 36% of the projects are dedicated to hydrogen production, while over one-third of LAC's projects focus on this area. Africa and LAC possess geographical advantages that support hydrogen project development. Industrial demand in China and India drives hydrogen production in Asia. India has 17 of the 33 projects mapped in Asia (Leaving China aside), with half focused on mobility and a quarter on production.
- **Technology Trials**: Some companies from developing countries are conducting technology trials in developed nations, benefiting from superior infrastructure.
- **Funding**: Early-stage hydrogen projects are often financed by companies from high-income countries, targeting future hydrogen demand in favourable locations.

This section comprehensively reviews the current landscape of clean hydrogen-related technologies. This first subsection offers a general overview of the current clean hydrogen value chain and key findings of each segment in developing countries. This value chain includes production, storage, transport, transformation, and end-use Figure 3-1. After, the main trends by region—covering Asia, Africa, Europe and LAC [2] —are presented, highlighting the distribution of project development across different segments of the hydrogen value chain in these regions.

Figure 3-1: Technologies across the clean hydrogen value chain.



Source: Hinicio (2024)

[2] Oceania has not been considered in this analysis, since only Fiji is developing a clean hydrogen project.

In the figure above, each segment of the hydrogen value chain is accompanied by a list (in Roman numerals) of various technologies related to that segment, along with sub-categories or technology types (denoted by bullet points) that serve a common purpose. Technologies that are applicable to multiple categories within the hydrogen value chain are highlighted in blue boxes.

The clean hydrogen technology landscape includes a mix of mature technologies and those in the early stages of development across the clean hydrogen value chain. A technology is considered commercially mature when it achieves high TRLs, market acceptance, economic viability, regulatory compliance, scalability, and supporting infrastructure. Since many technologies still need to be commercially mature or widely tested in developing countries, this report defines a project as innovative when it develops or improves clean hydrogen-related technologies or applies mature or near-mature technologies as early adopters in these contexts. Such projects have the potential to create a catalytic impact on sectors such as industry, mobility, agriculture, buildings, or electricity.

This report focuses on technologies that support the development, implementation, and operation of later-stage, on-the-ground pilot demonstration projects in developing countries. These technologies aim to create new value across the clean hydrogen value chain and deploy clean hydrogen solutions that are not yet widely adopted or implemented in the local market. However, all TRLs and planning stages were examined to capture the challenges faced and identify where support is most needed, even though lower TRLs fall outside the scope of the A2D facility.

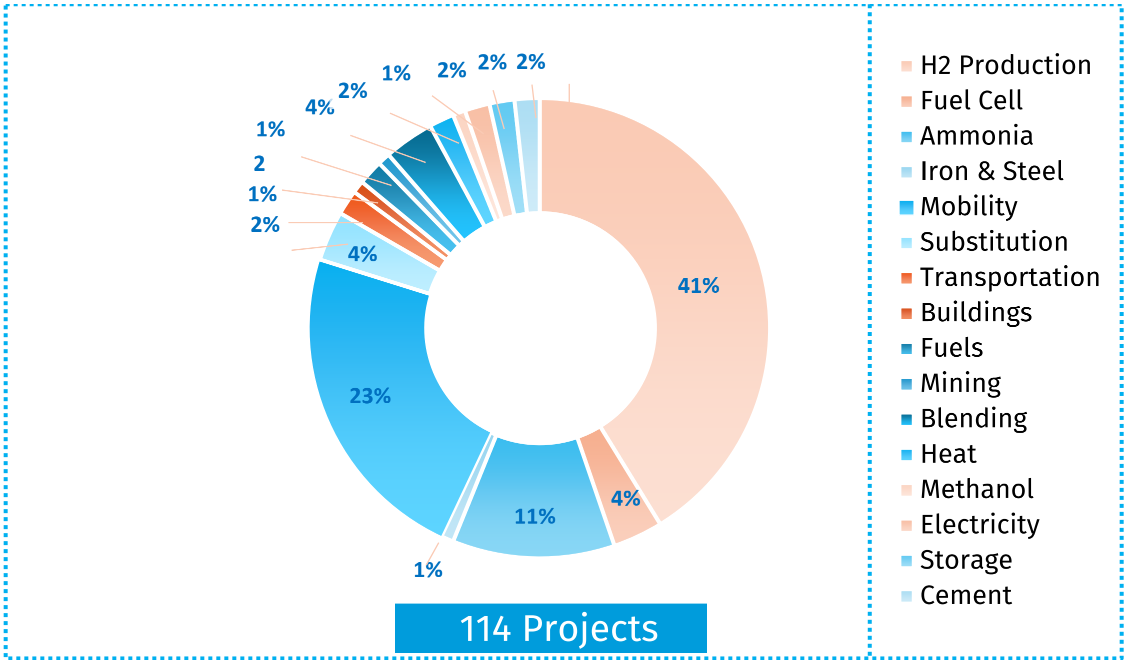
Global overview of clean hydrogen technology innovation in developing countries

More than 110 hydrogen projects with technologies in TRLs 6 to 9, in late-stage planning, were mapped across over 40 developing countries. These projects focus on either new technologies or early adoption, with LAC and Asia leading across the value chain. It is important to note that several other projects were identified in developing countries but were excluded from this analysis as they fall outside the scope of the A2D Facility. Many countries have signed Memorandums of Understanding (MoUs) with developers, but these projects have not progressed beyond pre-feasibility studies. In some cases, developers have suspended or cancelled their projects.

Most projects in developing countries focus on hydrogen production and end-use applications, with 73 of the 114 mapped projects (leaving China aside) targeting these areas. While hydrogen storage and distribution are also critical, they receive less attention, with only 4 out of 114 projects addressing these segments.

The distribution of project categories in developing countries is illustrated in the following figure. Please note that "H2 production" refers to net clean hydrogen production, and "electricity" refers to off-grid electricity production projects.

Figure 3-2: Share of focus categories for late-stage hydrogen-related projects in developing countries.[3]

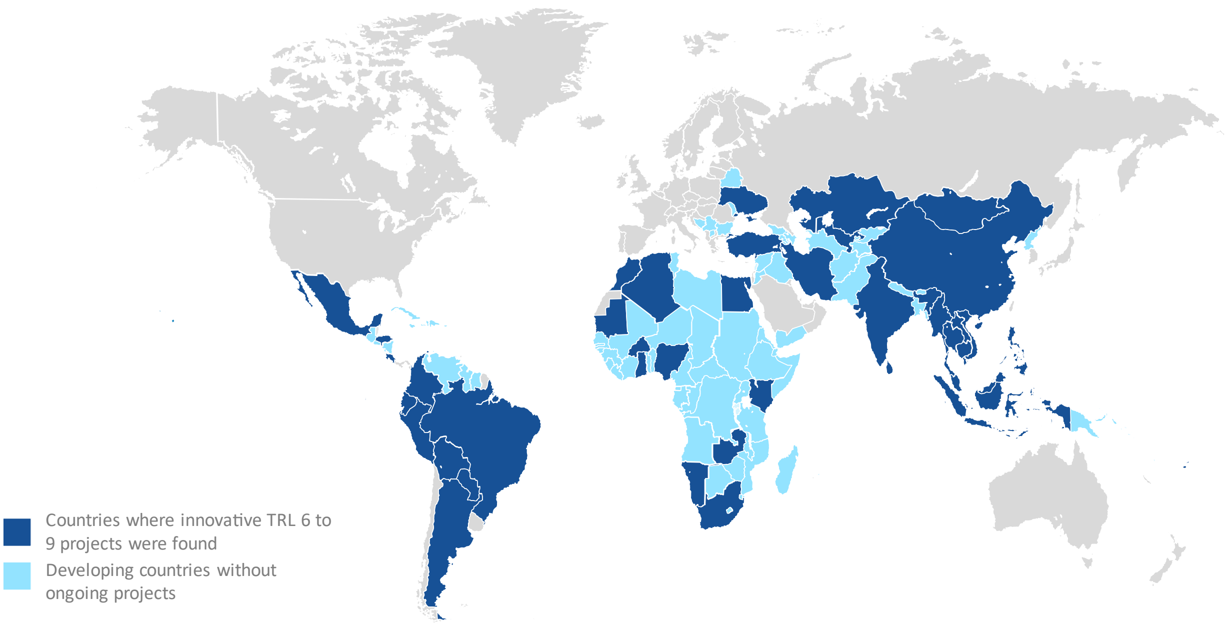


Source: Hinicio (2024)

Despite significant R&D efforts in developing countries, there remains a clear gap in scaling up clean hydrogen technologies. The map below illustrates the status of innovative hydrogen technologies and early adoption projects across these regions.

[3] Leaving China aside

Figure 3-3: Map of innovation and research developing countries

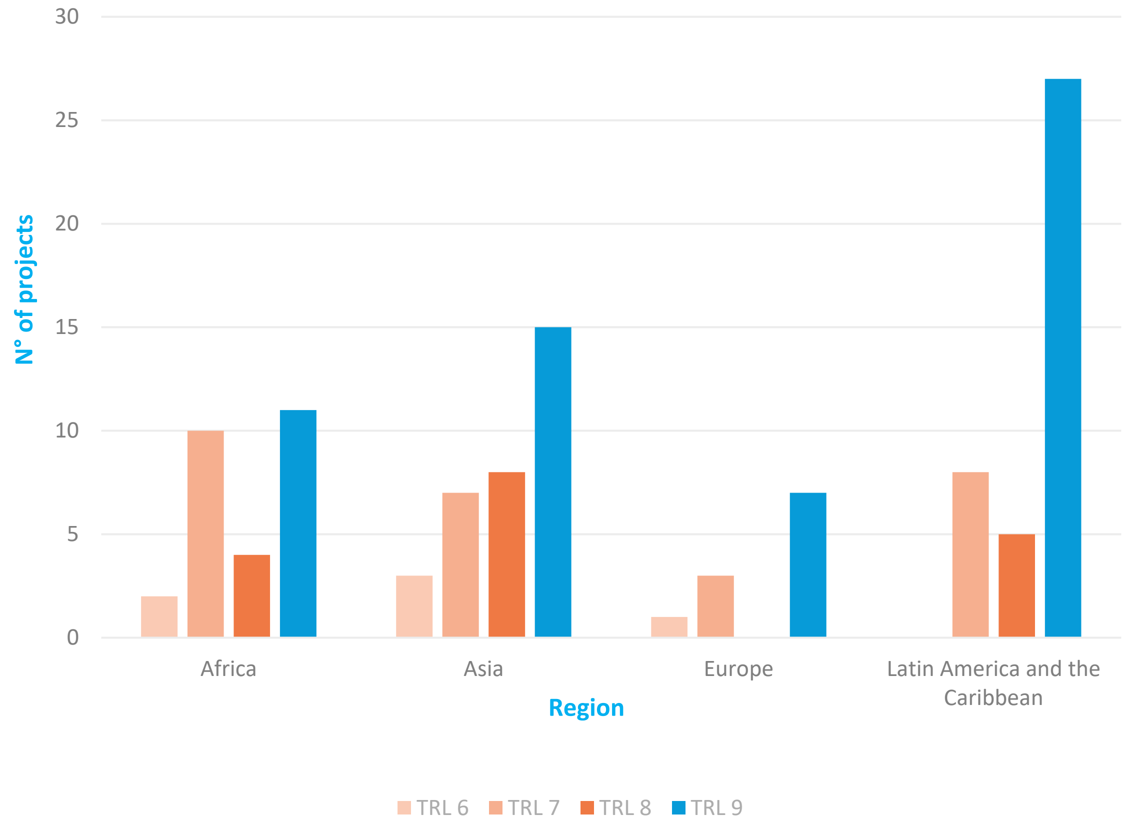


Source: Hinicio (2024)

Figure 3-4 below illustrates the projected maturity of technologies found among the mapped projects (focusing on both new technologies and early adoptions in advanced TRLs[4]), according to the International Energy Agency (IEA) categorisations of different hydrogen-related technologies based on the main technology implemented in the project[5].

[4] Advanced TRLs represent the transition from technology demonstration to commercialisation. This involves moving from prototype testing in relevant and operational environments (TRL 6-7), where many clean hydrogen technologies currently stand, to validating and proving fully developed systems in real-world commercial applications (TRL 8-9).
[5] Data base available at: https://www.ieahydrogen.org/trl-assessments/

Figure 3-4: Readiness level of the technologies under study per region (leaving China aside).



Source: Hinicio (2024)

The following subsections outline existing clean hydrogen technologies across various segments of the value chain, providing examples from developing countries and highlighting key findings for each segment.

Key findings

- Most projects in developing countries prioritise well-established electrolysis technologies, largely due to their renewable energy sources and the high costs associated with CCUS technologies. Additionally, the lack of oil and gas infrastructure in some developing countries makes CCUS less feasible, positioning electrolysis as a more viable option for hydrogen production.

- The Asian region is at the forefront of developing CCUS technologies for hydrogen production, with China, India, Indonesia, and Malaysia actively exploring these technologies within steam methane reforming (SMR) processes for low-carbon hydrogen and ammonia production. In contrast, no late-stage or conceptual CCUS projects have been identified in Latin America and the Caribbean[6], Africa, or Oceania.

- Hydrogen production projects in developing countries are primarily funded by companies from high-income countries, aiming to capitalise on the favourable geographical locations of these nations, in anticipation of the expected increase in hydrogen demand in the coming decades. Foreign companies from Germany, Japan, and Norway, for example, are found to be implementing their own technologies in developing countries to open, boost, and/or unlock the clean hydrogen economy across the globe and increase demand.

[6] Although certain countries are exploring CCUS technologies, they focus on oil refining rather than hydrogen production.

- Hydrogen-related manufacturing projects (Electrolysers, FCEV, etc.) weren't found across developing countries for future industrial-scale commercialisation purposes. Despite non presenting this type of activity, some countries as Brazil, México or India, presents considerable advantages in manufacturing processes. Brazil and are 2 Latin American countries with relevant manufacturing industries, especially Mexico since its proximity to the US markets, where actually foreigner companies intended to develop electrolysers manufacturing facilities (Nel ASA, 2016). While India, is pushing for local electrolyser manufacturing, among other clean hydrogen activities, with programmes as Strategic Interventions for Green Hydrogen Transition (SIGHT).

Clean hydrogen can be produced through water splitting by electrolysis or via SMR combined with CCUS technologies. Various electrolysis technologies are at different stages of development. Alkaline water electrolysis, one of the earliest methods, still requires improvements in both efficiency and cost reduction to become more competitive.

In contrast, newer methods such as Proton Exchange Membrane (PEM) electrolysis have already reached commercial viability. Emerging technologies such as Solid Oxide Electrolysis Cells (SOEC) offer the potential for higher energy efficiency and larger production capacities but are not yet mature enough for widespread adoption. Anion Exchange Membrane electrolysis, which combines features of alkaline and PEM technologies, is another promising approach, though it remains less advanced than its counterparts. Complementary technologies, such as CCUS, are also being developed to support clean hydrogen production, but they are still in the early stages of their development.

Pecém Green Hydrogen Hub — Fortescue

Country: Brazil	Capacity: 300.000 t/y of H_2
Status: EIA Approved	TRL: 9

The Facility, located in Port of Pecém, will produce 837 t/d of H_2 consuming 2.1 GW of renewable energy. The Hydrogen Hub to be developed in Pecém port will likely provide hydrogen, ammonia and other hydrogen-related products to European markets. The project is expected to commission in 2027 (H2business news, 2023).

Example of a relevant project in the field of hydrogen production.

Key Findings

- Alternative hydrogen storage systems in liquid form, in solution as a carrier (excluding those discussed in the conversion section of the report), or in metal hydrides have not yet been widely developed in developing countries. Additionally, there are no projects in the late stages of development that specify the use of any of these technologies.
- Geological storage systems, such as natural gas fields or salt caverns, as the one being explored in the Odessa Valley featured in the box below, are the primary storage solutions selected by hydrogen developers who have specified storage system for their projects. Storage for hydrogen and hydrogen-related energy are currently being developed in Türkiye, Mexico, India and Ukraine.

Hydrogen storage is being proposed as an alternative solution for electricity generation, particularly in industrial complexes or isolated regions. In recent years, various types of hydrogen storage have been developed, including liquid, gaseous, and solution-based systems. For gaseous storage, hydrogen can be stored in medium- to large-scale vessels within industrial complexes or in vast underground cavities. Salt caverns, depleted gas fields, and aquifers are viable options, depending on a country's geographical characteristics. However, advanced storage technologies—such as liquid organic hydrogen carriers (LOHCs), metal hydrides, and sorbents—have not yet been sufficiently developed or widely adopted in these regions. While promising, these technologies require further research and infrastructure development to become viable options in developing countries.

Odessa Valley

H2U

Country: Ukraine	Capacity: 3.6 t/y of H_2
Status: Feasibility study completed	TRL: 9

A renewable hydrogen production plant is planned with an initial electrolysis capacity of 100 MW, powered by 120 MW of solar and 80 MW of wind energy. The project aims to produce renewable electricity and "green" hydrogen for the domestic market and export to EU countries via pipelines through Romania, Hungary, Austria, and Germany, as well as export from the Black Sea to Rotterdam. The option of storing hydrogen in salt caverns has also been studied. Following the feasibility studies, with an estimated investment of 7–10 million EUR, the construction phase is expected to last 24 months, with phase 1 set to be commissioned in 2028 (Hydrogen Ukraine, 2024).

Example of a relevant project in the field of salt cavern storage.

Key findings

- Only a small number of the more than 110 projects have specified a transport method for their products or are even considering transport. This is because, in the analysed regions, production and end-use projects are mostly located near ports, where transport is not as significant a challenge. As a result, the transport segment is less developed compared to production and end-use. Most projects, especially those involving the production of pure hydrogen or its conversion into ammonia or fuels, are strategically positioned in coastal areas. The proximity to ports reduces the need for extensive transport solutions, making existing infrastructure, such as pipelines and tube trailers, sufficient for these projects.

- Although several new hydrogen pipelines have been announced worldwide, only a few in developing countries, such as Colombia and India, aim to distribute blended hydrogen directly into natural gas pipelines. In countries where natural gas is used for cooking and household appliances, testing must consider the effects of hydrogen in these stoves and appliances.

- Countries such as China and Morocco (in association with Nigeria), are developing long-range pure hydrogen transportation projects.

- Several significant hydrogen pipeline projects in Europe, involving developing countries, aim to advance the hydrogen economy and reduce carbon emissions. One such project is the SoutH2 Corridor, a 3,300 km network spanning Austria, Germany, and Italy, with connections to North Africa.

Hydrogen pipelines have been in operation since 1938, with an extensive network developed by major industrial gas suppliers. This infrastructure includes both pure hydrogen pipelines and systems that blend hydrogen with natural gas. Blending hydrogen with natural gas reduces the emission factor of the combusted gas by enhancing the calorific value of the combustion process. Hydrogen can also be transported in cryogenic tanks, where it is compressed to a liquid state at extremely low temperatures. However, maintaining the required temperature and pressure during transport is both complex and expensive.

Nigeria-Morocco Gas Pipeline

NNPC

ONHYM
OFFICE NATIONAL DES HYDROCARBURES ET DES MINES

Country: Nigeria-Morocco	Capacity: N/A
Status: Studies under development	TRL: <8

The project aims to develop the world's longest offshore hydrogen pipeline, approximately 5,600 km in length, connecting Nigeria with Morocco. This first-of-its-kind hydrogen transportation technology will enable Nigeria to link its hydrogen production projects to Moroccan ports, facilitating exports to markets across Europe (AGBI, 2024).

Example of a relevant project in the field of offshore hydrogen transportation.

Key findings

- Fertilisers are crucial in developing countries, where there is often a reliance on imported ammonia for fertiliser production. Access to locally produced fertilisers enhances food security in these regions. Clean ammonia production accounts for 11% of the 114 projects, most located in the LAC region.

- Chemicals and storage represent two significant project types, primarily focused on producing ammonia and e-fuels for clean fertilisers and future hydrogen-based mobility vehicles. Several late-stage ammonia projects are currently in development in Brazil, Bolivia, Ecuador, Mexico, Namibia, Paraguay, South

Africa, and Viet Nam. Additionally, the Ecuadorian government is developing a methanol project.

- Other compounds such as methanol, syngas and e-kerosene are being explored mostly in Argentina and South Africa. Brazil's Unigel aimed to produce e-fuels but abandoned the project due to lack of funding.

Before transportation, hydrogen can be converted into other products to increase its value or facilitate transport using existing infrastructure, rather than transporting hydrogen in its gaseous form, which presents technical and energy-related challenges. One common option is converting hydrogen into ammonia, a key component in fertilisers. Although processes such as the Haber-Bosch method are well established, using clean hydrogen in these processes helps decarbonise one of the world's most CO_2-intensive industries.

Additionally, hydrogen can be combined with captured carbon to produce synthetic fuels, such as methanol, methane, and sustainable aviation fuels. These net-zero fuels have the potential to replace traditional carbon-based fuels. Moreover, methanol production is already widely used in the chemical industry as a feedstock for plastics, solvents, and adhesives, as well as in the fuel industry.

HySHiFT sustainable aviation fuel (SAF) project

Country: South Africa	Capacity: 50 kt/d of synthetic Kerosene
Status: EPC Contracts	TRL: 7

The consortium plans to build a 200 MW electrolyser and 450 MW of renewable electricity to split water into hydrogen and oxygen. The clean hydrogen will be used in Sasol's existing Fischer-Tropsch facilities to produce 50 kt/d of Power-to-Liquid kerosene, which could fuel two flights between Germany and South Africa per day. The German Economic Affairs and Climate Action Ministry is providing €15 million for the first phase of the project, during which a 40 MW electrolyser will be constructed. Contractual negotiations are underway between the developers of the HySHiFT SAF project, and the intermediary company set up under Germany's H2Global scheme, known as Hintco, which enters long-term purchase contracts for clean hydrogen and derivatives such as ammonia, methanol, and SAF (Engineering news, 2024).

Example of a relevant project in the field of hydrogen-based fuels.

Hydrogen end-use applications

Key findings

- Clean hydrogen-based mobility projects are in operation across all continents, with public transport playing a key role in addressing urban mobility challenges in both large and small cities in developing countries. In the end-use segment of the value chain, fuel cell (FC) electric vehicles, FC trains, and FC buses account for 23% of the 114 projects mapped. Asian, European, and some African countries are developing FC trains given their well-established railway systems. In the LAC region, the focus is on private cars, followed by public transport with FC buses. Costa Rica, Colombia, and Türkiye have also deployed prototype refuelling stations for both large and small vehicles.

- End-use projects are also being tested in developed countries with advanced technology infrastructure. Examples include KARSAN, a Turkish company that developed hydrogen buses for its facilities in Germany, and Vale, a Brazilian company that supplies iron ore pellets for low-carbon steel production in Sweden.

- Developing countries are strategically positioning themselves to address sector-specific challenges, particularly in 'hard-to-abate' industries where hydrogen can have a significant impact. They are seeking to align hydrogen initiatives with regional strengths and industry needs. For example, countries with established oil and gas or chemical industries, coupled with strong solar or wind resources, capitalise on their expertise to develop clean ammonia projects and use hydrogen in their industries.

Hydrogen can be transformed into other molecules such as ammonia or LOHC carriers to facilitate its transport. Some of these carriers can also be used in end-use applications. Ammonia can carry hydrogen and be used directly as a fertiliser or to produce more complex fertilisers and molecules such as nitric acid or urea.

Technologies such as fuel cells, on-board hydrogen storage, hydrogen pumps, and refuelling infrastructure are prominent in this sector. Additionally, internal combustion engine technologies that burn hydrogen for propulsion have been revisited, demonstrating that hydrogen combustion has a role in transport.

Another significant application is in heavy industries such as cement and steel production. In steelmaking, hydrogen can be used as a reducing agent in the direct reduction iron (DRI) process, which produces only water vapour. Hydrogen can also be used in the Blast Furnace - Basic Oxygen Furnace process, partially reducing the use of coal. These applications are feasible due to hydrogen's reducing properties. Similarly, hydrogen can be used in the reduction of clinker during cement production.

The oil industry, particularly refineries, is a major producer and consumer of hydrogen. Hydrogen is used in various processes, such as removing impurities such as sulphur, nitrogen, and metals from crude oil fractions. It is also employed in hydrocracking, where larger, heavier hydrocarbon molecules are broken down into smaller, more valuable products such as gasoline, diesel, and jet fuel. In some oil-producing countries, decarbonisation can be achieved by replacing hydrogen produced from natural gas reforming with clean hydrogen. As in the fertiliser industry, the technologies involved require no major changes when switching to clean hydrogen.

Another important industry is power generation, where fossil fuels can be partially or fully replaced by clean hydrogen. Several manufacturers offer gas turbines capable of running on high hydrogen content fuels. However, the review of projects in developing countries revealed that few met the TRLs and stage of development required by the A2D facility.

Conversion of locomotives from diesel to hydrogen

Country: India	Capacity: 150 kt/y of H_2
Status: Commissioning	TRL: 6

Description:
The project involves 35 hydrogen trains and includes a 1 MW electrolyser from GreenH manufactured entirely in India, producing 420 kg of hydrogen daily. The refuelling infrastructure will feature 3,000 kg of hydrogen storage, compressors, and two dispensers with precoolers for fast refuelling. Field trials of the prototype are set to begin in 2024 on the Jind–Sonipat section of Northern Railway (EY, 2024).

Example of a relevant project in the field of rail mobility.

Regional Trends

This section explores regional trends, and how different regions are leveraging their geographical advantages and existing industries to implement clean hydrogen solutions. The trends observed across different countries reflect the competitiveness of their markets, particularly in those focusing on hydrogen production for export due to lower export prices and geographical advantages.

Figure 3.4 presents the number of projects currently under development and the intensity of hydrogen technology-related research across different regions (further details in Annexes 3 and 4). It is important to note that the PRL and TRL of applied technologies are not necessarily correlated. PRL 2 refers to projects that have passed the feasibility study stage, PRL 3 to those under construction or commissioning, and PRL 4 to projects already in operation, most of which have done so in recent years, with expansion phases planned.

Main trends per region

AFRICA

Main topics of projects per region

- H_2 Production
- Transport/ Mobility
- Chemicals

Intensity of research

Low Medium High

Projects 28

Leading Countries

- South Africa
- Namibia
- Morocco

ASIA

Main topics of projects per region

- H_2 Production
- Transport/ Mobility
- Blending

Intensity of research

Low Medium High

Projects 33

Leading Countries

- India
- Malaysia
- Vietnam

EUROPE

Main topics of projects per region

- H_2 Production
- Transport/ Mobility
- Storage

Intensity of research

Low Medium High

Projects 11

Leading Countries

- Ukraine
- Türkiye

LAC

Main topics of projects per region

- H_2 Production
- Transport/ Mobility
- Ammonia

Intensity of research

Low Medium High

Projects 41

Leading Countries

- Brazil
- Colombia
- Argentina

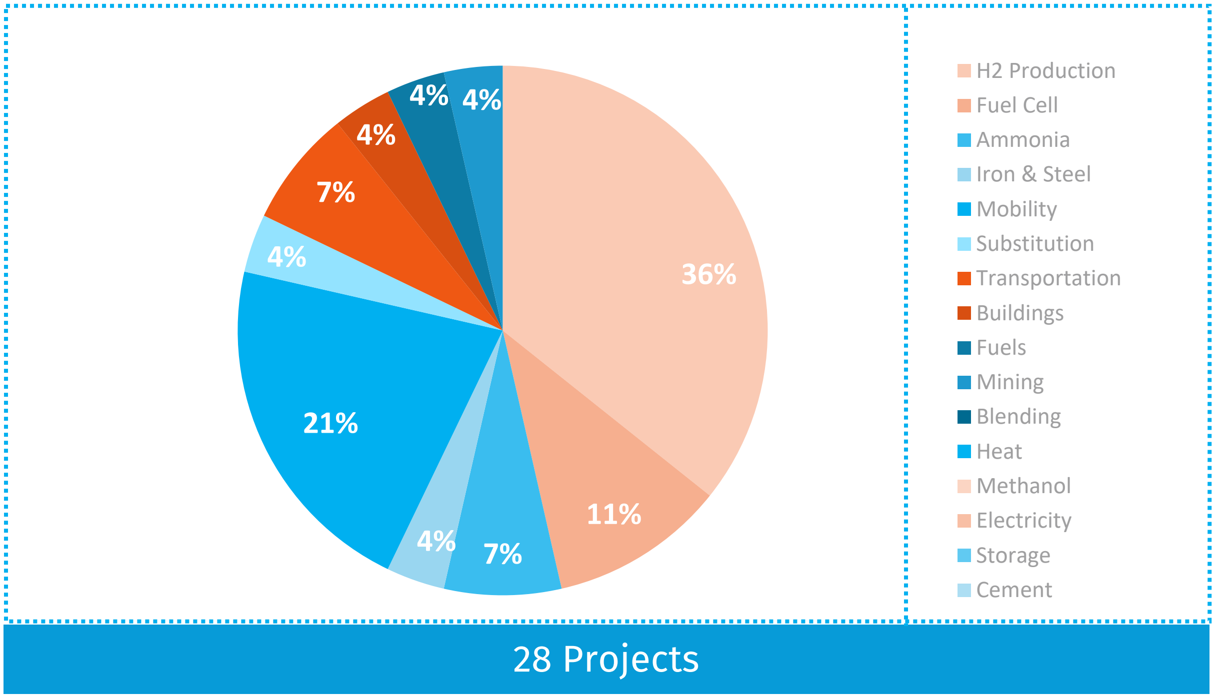
Source: Hinicio (2024)

Africa

In Africa, the development of hydrogen projects is concentrated in two key regions: the southern and northern regions of the continent. In the southern cone, countries such as Namibia and South Africa are attracting significant foreign investment to boost their hydrogen initiatives. In North Africa, Egypt, Mauritania, and Morocco are harnessing their vast solar resources for hydrogen production, with a clear focus on exporting to Europe, benefiting from their geographical proximity.

Figure 3-6 shows that Africa focuses on the production of hydrogen and sustainable mobility. Out of a total 28 projects, few were found in the segment of substitution, synthetic fuels production, applications for iron and steel industries. Also, fuel cell solutions for off-grid electricity production are aimed at communities with low access to electricity.

Figure 3-6: Africa landscape of project development by hydrogen value chain segment.



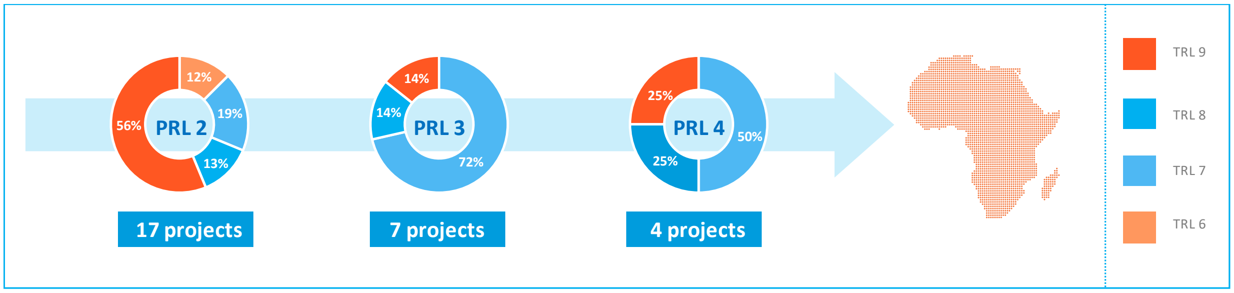
Source: Hinicio (2024)

Countries such as South Africa and Namibia are making notable progress in advancing their clean hydrogen industries. In contrast, neighboring nations face challenges such as high poverty rates, making clean hydrogen development a lower priority.

In sub-Saharan Africa, developers in countries such as Cameroon, Ghana, and Mauritania encounter significant barriers, including limited access to advanced technologies and financial resources. Additionally, short-term obstacles such as inadequate infrastructure for hydrogen exports and logistical issues in nations such as Namibia, Kenya, and Zimbabwe slow the deployment of clean hydrogen projects. These challenges are further intensified by political and economic instability.

In Northern Africa, efforts to operationalise clean mobility and hydrogen projects are ongoing. However, political instability, fluctuating economic conditions, and a continued reliance on fossil fuels pose risks to investment and project continuity.

Figure 3-7: Africa's hydrogen projects progress by TRL of the technologies.



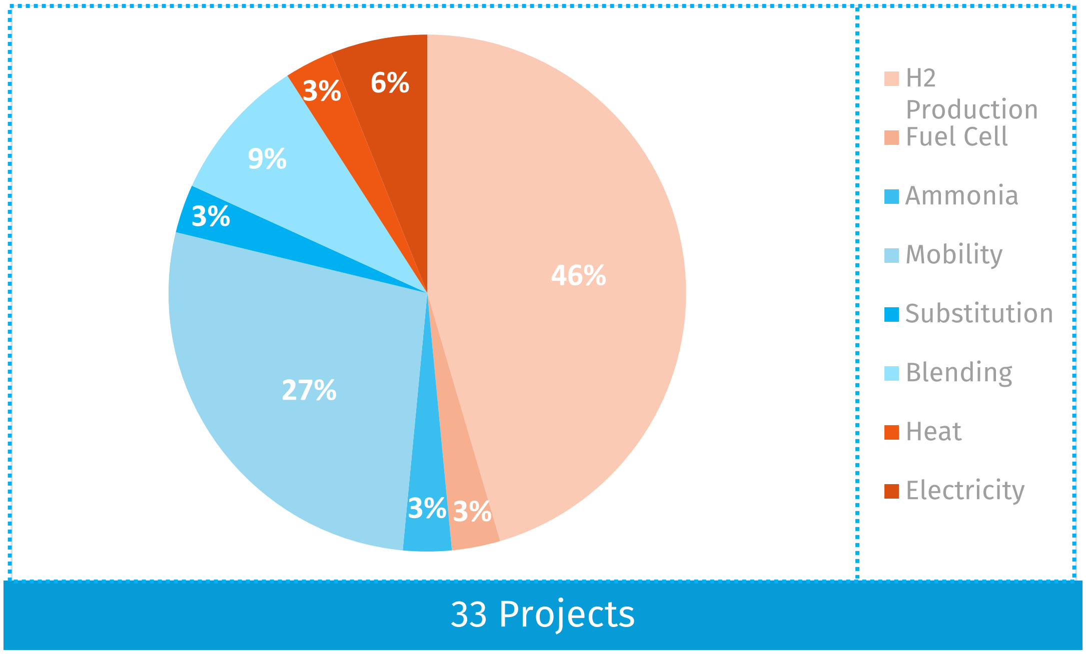
Source: Hinicio (2024)

As shown in the figure above, most projects are currently at PRL 2 or lower. Despite having lower TRL ratings, several TRL 7 and 8 projects are progressing toward operation, while conventional TRL 9 projects—focused mainly on hydrogen or ammonia production—remain in the planning phase.

Asia

In Asia, clean hydrogen production is particularly attractive due to the region's large industrial sector and the anticipated growth in domestic demand, as illustrated in Figure 3-8. Out of 33 projects (Leaving China aside), India leads with over 15 projects under development, including operational prototype plants and equipment. India leverages its vast natural resources, and growing energy needs to position itself as a leader in clean hydrogen production and use. Its innovation ecosystem benefits from a strong network of research centres, investments in education, and significant R&D funding. Malaysia and Indonesia also have late-stage projects, primarily focusing on clean hydrogen production through electrolysis in Malaysia. Meanwhile, Viet Nam is targeting end-use applications and ammonia production.

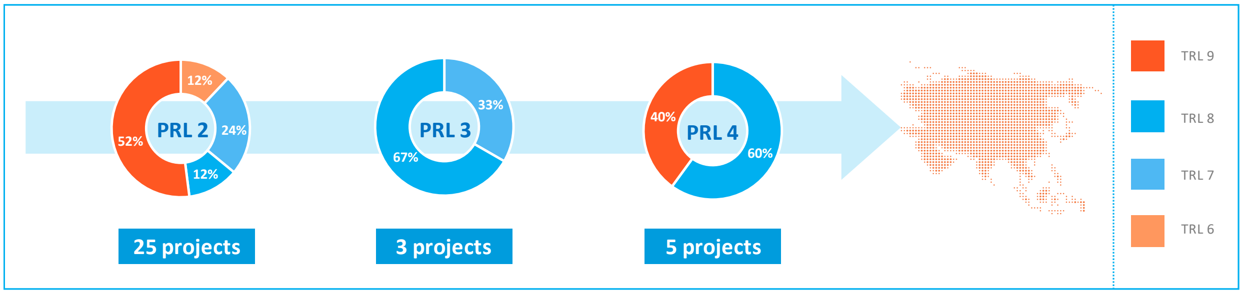
Figure 3-8: Asia Landscape of project development by hydrogen value chain segment category.



Source: Hinicio (2024)

Clean hydrogen projects may encounter risks related to regulatory diversity and varying levels of infrastructure development. In addition, there may be significant regional differences in access to technology and foreign or internal financial support according to surveyed and interviewed developers.

Figure 3-9: Asia's hydrogen projects progress by TRL of used technologies.



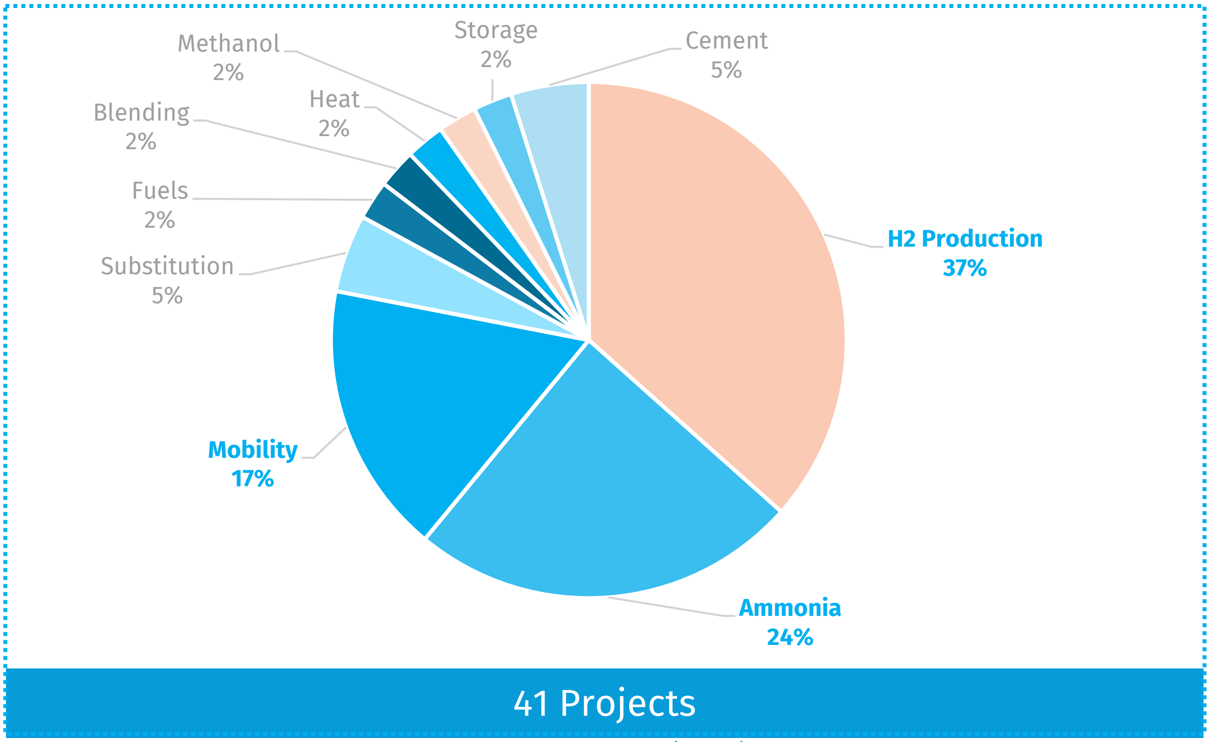
Source: Hinicio (2024)

Clean hydrogen production projects in Asia are currently in the late-stage planning phase, with several having progressed to the commissioning stage. These projects are now focused on achieving operational readiness, with plans for future expansions to increase capacity and meet growing demand.

Latin America and the Caribbean

Latin America and the Caribbean benefit from abundant solar and wind resources, which support the development of clean hydrogen projects and local clean ammonia production, with a total of 41 projects mapped. As the region is a net importer of fertilisers, local ammonia production is vital for enhancing food security. Additionally, the region faces significant pollution challenges due to large urban areas with dense populations and inefficient public transport, making clean hydrogen-based mobility a crucial solution for reducing emissions.

Figure 3-10: LAC Landscape of project development by hydrogen value chain segment category.



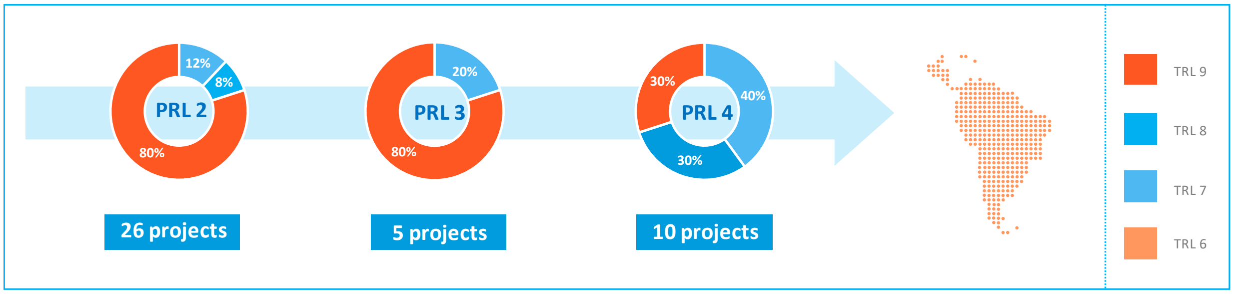
Source: Hinicio (2024)

In LAC, many countries are actively engaged in developing hydrogen projects. This growing interest in clean hydrogen is driving the region's energy transition and positioning it as a key player in the emerging global market. Countries such as

Brazil, Colombia, and Costa Rica are making significant progress, with several projects underway, supported by government incentives.

However, nations facing limited resources, financial constraints, and/or political challenges—such as Venezuela, Bolivia, most Central American countries (except Costa Rica and Panama), and many Caribbean nations—are less active. Internal issues make hydrogen development a secondary priority in these countries. Additionally, even in countries with active projects, the lack of regulatory frameworks and technical expertise presents challenges. Limitations in advanced infrastructure may also affect project implementation and long-term sustainability.

Figure 3-11: LAC's hydrogen projects progress by TRL of used technologies.



Source: Hinicio (2024)

As shown in Figure 3-10, most projects involve production of clean hydrogen or clean ammonia for export and local consumption. Demonstration mobility projects in TRL7 are rapidly reaching commissioning due to the small scale of the projects[7], operating with 1 to 3 vehicles. Consequently, they can achieve demonstrative phases much more quickly compared to projects involving large fleets of Fuel Cell Electric Vehicles (FCEVs).

Europe

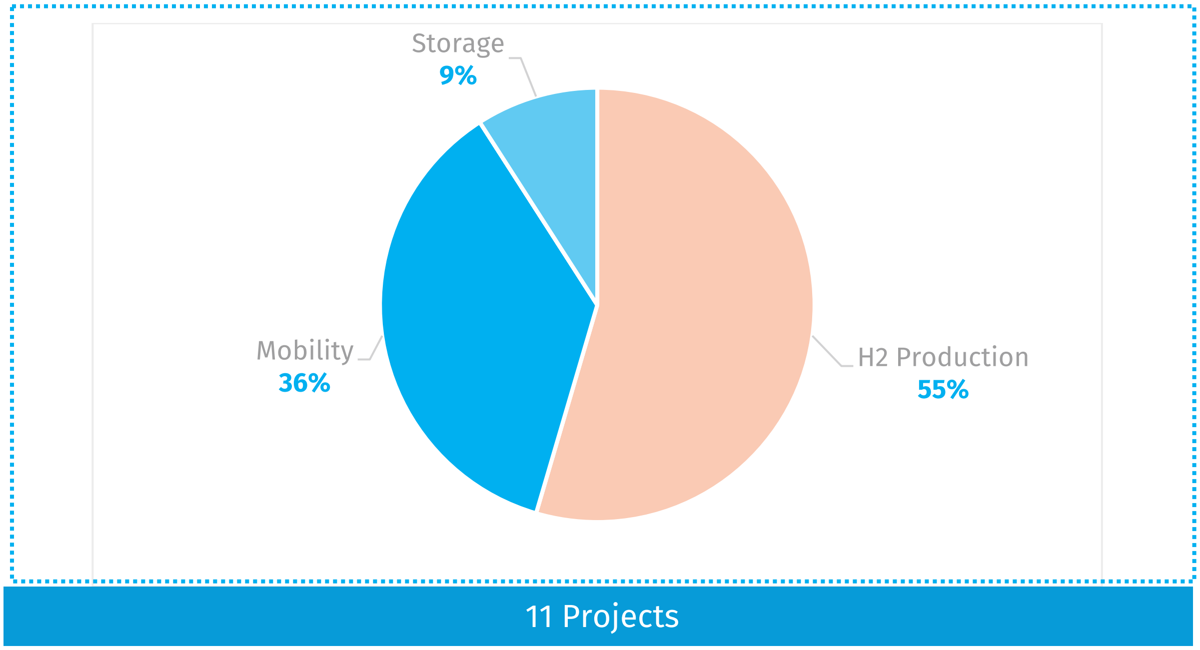
Ukraine and Türkiye are the only developing countries in Europe with projects that meet the criteria of the A2D initiative. Other European nations, such as Moldova, Bulgaria, and several Balkan countries, have not yet developed late-stage clean hydrogen projects. However, the region has actively participated in clean energy transition initiatives, such as the Balkan Hydrogen Cluster, which promotes green hydrogen as an alternative to hydrocarbon fuels.

[7] Projects that typically involve small fleets do not require substantial investments or carry significant risks.

Given its proximity to advanced and regulated markets in the EU, the region holds a competitive advantage in terms of transport costs, delivery times, and supply availability to other developing countries (3E News, 2023). A total of 11 projects were mapped in Ukraine and Türkiye, with 55% focused on clean hydrogen production, 36% on mobility, and 9% on storage. Of these, 10 are in PRL 2 and one in PRL 4. Among the PRL 2 projects, seven apply TRL 9 technologies, two use TRL 7, and one employs TRL 6.

Eastern Europe, however, still faces significant inequality and lacks a robust regulatory framework for clean hydrogen development. This situation is exacerbated by Russia's occupation of Ukraine. Similarly, Türkiye's proximity to conflict-prone countries in the Middle East complicates investment decisions for developers.

Figure 3-12: Europe's Landscape of project development by hydrogen value chain segment category.



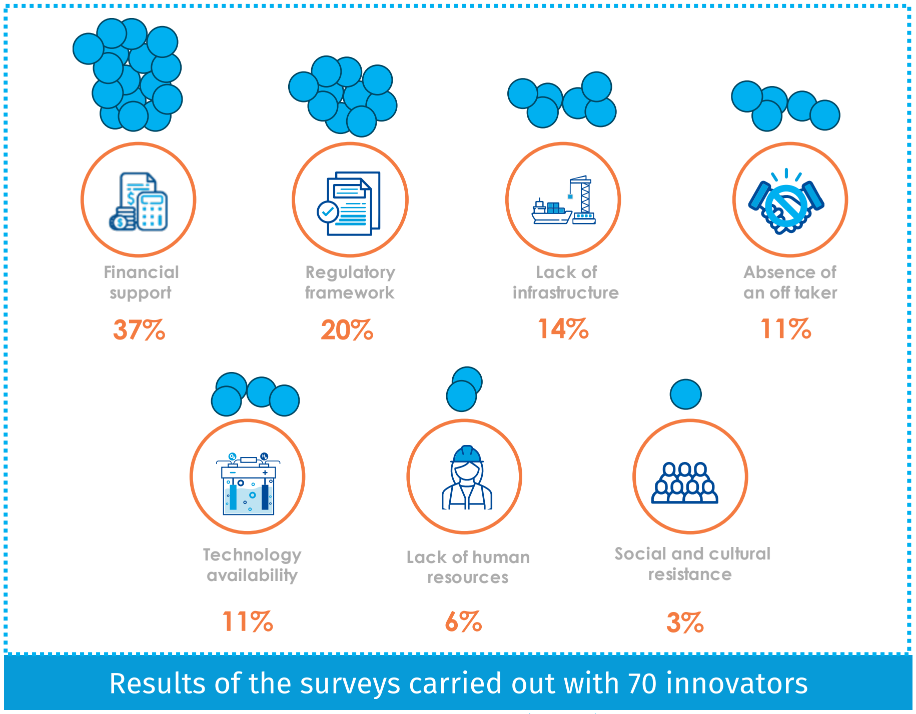
Source: Hinicio (2024)

Despite the differences between regions, technology innovation countries face similar developing challenges in addition to those encountered by all project developers worldwide.

Technical and financial challenges in developing countries

A comprehensive approach involving interviews, surveys, and workshops identified technical and financial challenges, gaps, and barriers. The survey of 70 innovators revealed a range of challenges, which are illustrated in the figure below.

Figure 3-13: Distribution of main challenges for hydrogen projects developers.



Source: Hinicio (2024)

Producing clean hydrogen presents significant challenges in both developed and developing countries. However, certain issues are particularly difficult to address in developing nations due to technical, regulatory, and financial constraints. Some of the primary challenges are:

- **Limited access to technology:** Developing countries often face challenges in accessing advanced technologies and innovations that are more readily available in developed nations. For example, access to electrolysers is limited, as European manufacturers tend to focus on domestic markets, while Chinese manufacturers, experiencing high demand, increasingly target the European market. Some developing countries are testing end-use applications with grey hydrogen, which hampers their ability to collect robust data for techno-economic assessments and secure necessary funding. Additionally, a lack of capital investment and the scarcity of renewable energy sources make clean hydrogen projects more difficult and costly to implement.

- These challenges are critical because hydrogen production technologies must evolve in tandem with other links in the value chain, particularly end-use applications. This parallel development ensures that as hydrogen production technologies mature and become more cost-effective, end-use applications will also be ready for widespread adoption.

- **Insufficient technology infrastructure, technical expertise and access to equipment and materials:** Developing countries face significant challenges due to a lack of essential equipment, materials, and trained personnel, which are critical not only for conducting research but also for testing and operating hydrogen facilities. These deficiencies hinder innovation and limit the ability to maintain and scale hydrogen infrastructure. International collaboration is crucial to bridging these gaps by providing access to resources and expertise.

- Some countries have made promising advances in hydrogen-related technologies, including the development of catalysts that do not rely on platinum-group metals (PGMs) and corrosion-resistant plates for alkaline environments or for high-temperature conditions, such as those encountered in SOECs. However, innovators in these countries often face difficulties in securing the funding required to acquire advanced equipment, much of which needs to be imported at significant cost.

- **Social and cultural resistance from local and indigenous communities:** Opposition from local and indigenous communities may arise due to concerns about environmental impacts, disruption of traditional lands, water scarcity, and exclusion from decision-making processes. Such resistance can hinder both the development of hydrogen projects and the adoption of hydrogen technologies. Additionally, large-scale hydrogen production presents broader social challenges, such as lengthy permitting processes and inadequate infrastructure, which can amplify community concerns. Continued reliance on fossil fuels may also undermine trust in clean energy projects, complicating efforts to gain local support.

- **Hydrogen distribution:** A key challenge during the planning stages of clean hydrogen projects is the lack of a clear strategy for transportation. Many projects do not adequately address how hydrogen will be moved from production sites to export terminals or consumption points. This gap in planning has only been effectively tackled by few projects. To ensure the success of hydrogen initiatives, it is essential to engage the public and develop the necessary infrastructure to support hydrogen transport.

- Despite these challenges, several projects have successfully incorporated hydrogen distribution solutions. For example, the Iracema Project and AES Brazil's initiative at the Port of Pecém includes maritime transport to Rotterdam. Similarly, in Ukraine, projects led by Hydrogen of Ukraine LLC (H2U) are exploring both gas pipelines for overland transport—connecting Ukraine to Germany via Romania, Hungary, and Austria—and maritime routes to Rotterdam. In Slovakia, a project is underway to transport hydrogen to a refinery through pipelines.

- **Regulatory and Policy Frameworks:** Inconsistent regulations, a lack of supportive policies, and insufficient R&D resources can hinder innovation and investment in hydrogen technologies. Many developing countries lack the robust regulatory and policy frameworks necessary to promote hydrogen innovation and attract investment.

- **Fossil fuels subsidies:** The provision of fossil fuel subsidies in many developing nations impedes the adoption of clean hydrogen, distorts markets, and creates fiscal burdens. In 2022, countries such as Malaysia and Viet Nam allocated fossil fuel subsidies amounting to 4% and 5% of their Gross Domestic Product (GDP), respectively. In Ukraine, subsidies reached as high as 13% of GDP. In the African region, many countries remain heavily dependent on fossil fuels and energy imports, with Morocco importing 90% of its energy needs.

- **Limited financial resources:** Innovation in developing countries is often constrained by limited financial resources, making it challenging to invest in the costly infrastructure and technologies required for research, R&D across the hydrogen value chain, from production to final use.

- The mobilisation of investments in clean hydrogen is further constrained by several key challenges, including high capital requirements, limited fiscal space, and insufficient public funding for green incentives. Additionally, the absence of a clear market for green hydrogen, combined with low levels of infrastructure and technology readiness in many developing countries, contributes to elevated production costs. Water scarcity and heavy reliance on energy imports also exacerbate the difficulties faced by numerous developing nations in advancing clean hydrogen projects.

Figure 3-14: Key financial barriers and risks hindering investments in Clean Hydrogen Industry

Key Barriers impacting Investments in Clean Hydrogen Technology in Developing Countries

Off-take/Market Risk

The absence of off-take agreements, uncertainty about market demand and supply absorption along with lack of critical infrastructure to facilitate market absorption creates ambiguity in the projection of revenue streams for investors.

Supply Barriers

Water availability and a low-cost, continuous electricity supply are essential for hydrogen production via electrolysis. Challenges in securing these resources result in high production costs and significant capital expenditure.

Macroeconomic Challenges

Limited fiscal space to offer green incentives hampers investor motivation. High debt-to-GDP ratios in some countries threatens debt sustainability, impacting economic feasibility of the projects. Market distortions arise from substantial fossil fuel subsidies.

Infrastructure Barriers

The early stage of infrastructure development in the clean hydrogen value chain introduces risks, delays, and necessitates high capital expenditures and production costs, creating uncertainties about economic feasibility of the project.

Regulatory Barriers

The lack of regulatory frameworks and standards for the clean hydrogen value chain leads to uncertainty for potential investors. Lengthy licensing processes and other formalities reduce efficiency and cause delays in project cycles.

Technological Barriers

Limited technological maturity for efficient production, storage, transmission and utilisation of clean hydrogen causes delays and high upfront costs, limiting the technical feasibility of projects. Shortage of skilled labor exacerbates these challenges.

Environmental and Social Barrierss

Establishing the clean hydrogen industry in ecologically sensitive regions requires strong regulations to ensure environmentally sustainable practices. Limited awareness among local communities impedes the wider adoption of clean hydrogen.

4

Landscape of innovators in developing Countries

Over 200 innovators are actively working on hydrogen-related technologies in developing countries. While universities and research institutes lead most of these projects, they're still mostly in the TRLs 3-5 range. In contrast, the industry is taking things further, hitting the more advanced TRLs 8-9, driving progress forward.

4 LANDSCAPE OF INNOVATORS IN DEVELOPING COUNTRIES

KEY FINDINGS

- **Innovators Identified**: Over 200 innovators were identified in developing countries, with 69 of them in China (27.6%) and 43 of them in India (17.4%), both countries leading the way, largely due to strong governmental support. 75 of these innovators are universities (33.9%), 29 are research institutions (13.4%), 20 pure-play clean hydrogen developers (8.9%), and 16 energy companies (8.0%).
- **Project Focus:** A significant number of projects focus on the early adoption and implementation of existing technologies. While technologies at TRLs 3-5 are being developed in educational centres, higher TRL technologies (6-9) are favoured by off-takers and energy companies for early adoption.
- **Hydrogen Production:** Given the renewable energy capacity and land availability in many developing countries, 105 of the 214 innovators (49.1%) focus on clean hydrogen production technologies and electrolyser manufacturing. By contrast, innovation in high-emission industries such as cement, iron, and steel accounts for less than 5%.
- **Mobility Focus:** Clean hydrogen for mobility is a common area of focus, particularly in road transport, including hydrogen fuel cell vehicles, buses, and trucks. Innovation in maritime and railway transportation is at an earlier stage, with projects identified only in China, Namibia, and India.
- **Start-ups:** Latin America has a notable presence of start-ups, reflecting the region's initiatives to support the entrepreneurial ecosystem, especially in clean energy.
- **Geographical Spread:** Despite the presence of innovators, they are found in only 42 of the 141 developing countries (29.7%). In regions such as Africa, where industrialisation is still in its early stages, clean hydrogen innovation remains limited as energy generation and electricity access take priority.
- **Off-Taker Involvement:** Off-takers are playing a key role in driving innovation as they seek to decarbonise their operations. They are increasingly engaging in clean hydrogen projects to meet their sustainability goals.
- **Key Risks:** The main risks identified by innovators are related to technology readiness and the Levelised Cost of Hydrogen (LCOH). Rising project costs are also a concern, leading some innovators to keep business plans private to avoid creating unrealistic expectations.
- **Collaboration:** Many innovators are forming partnerships to reduce project risks. Additionally, bridging the gap between academia and industry is critical to increasing innovation and attracting funding for R&D projects.

In the rapidly evolving clean hydrogen market, innovators are developing new technologies, enhancing existing ones, or leading in early adoption, which are crucial for advancing the sector in developing countries. This section explores the landscape of innovators in developing countries and is divided into two sub-sections:

1. **General landscape of clean hydrogen innovators in developing countries,** which provides regional insights and general trends.

2. **Profile of innovators,** which examines the different profiles of innovators shown in Table 4-1:

Table 4-1. Categories and sub-categories of Innovators

Research and Education	Energy Sector	Hydrogen Start-ups	Hydrogen Industry Players	Off-takers
Universities	Renewable energy companies	Start-ups	Pure-play clean hydrogen developers	Oil & gas companies
Research institutions	Electric power utilities and generators		Hydrogen technology equipment or component manufacturers	Automotive and transport companies
			Industrial gas companies	Chemical and fertiliser companies
				Other companies in hydrogen end-use applications

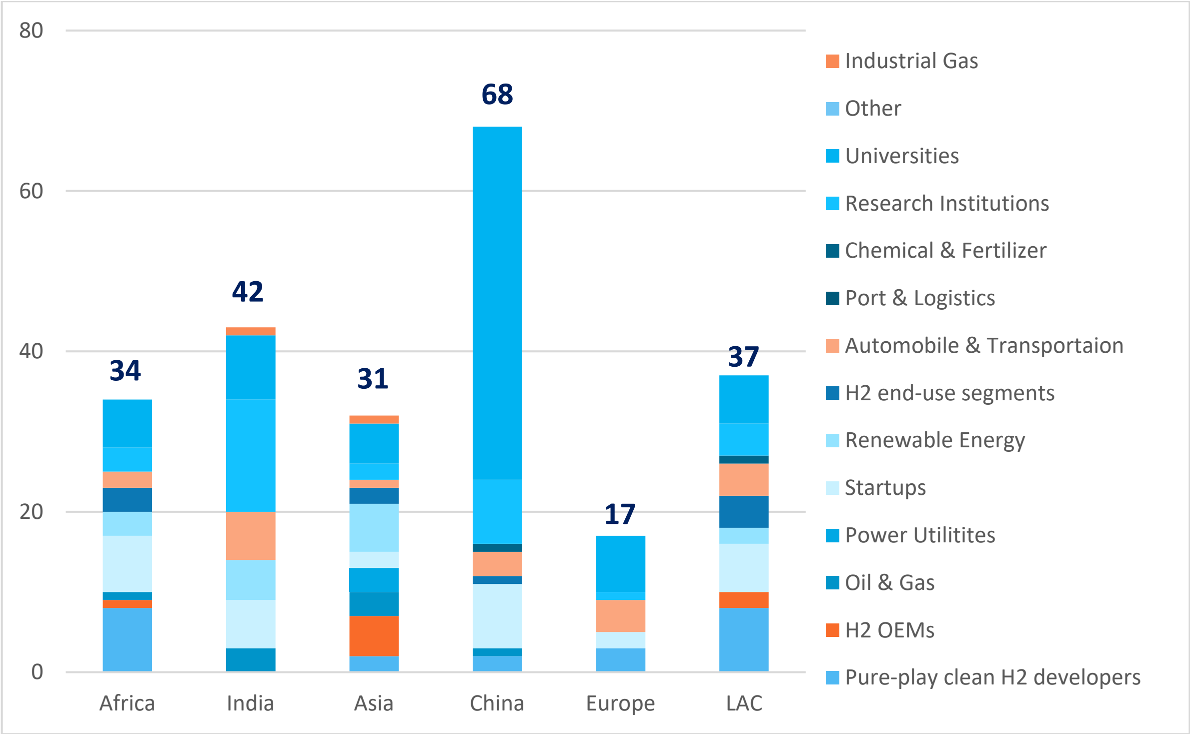
Source: Hinicio (2024).

General landscape of clean hydrogen innovators in developing countries

More than 200 innovators developing clean hydrogen projects were identified across different segments of the value chain. The number of innovators exceeds the number of projects because many involve multiple co-executors, as joint ventures between public, private, and academic entities are common. These collaborations, which often include both foreign and local companies, serve as a risk-sharing tool, given the high financial investment and innovative technologies involved. Such partnerships help distribute the financial burden, contribute specialised knowledge, and balance risks more effectively.

Of the 224 innovators, 75 of them belong to universities (33.9%), 29 to research institutes (13.4%), and private companies, including 20 pure-play clean hydrogen developers (8.9%). As illustrated in Figure 4-1, there is strong leadership in innovation from China, India, and other Asian countries, particularly among universities and research institutions, followed by Latin America and the Caribbean.

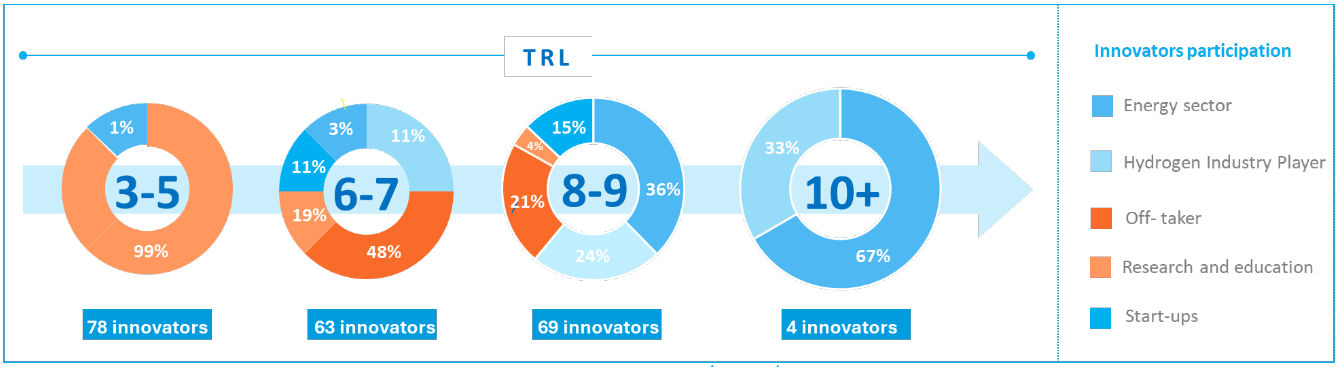
Figure 4-1: Innovators grouped by sub-category and Region.



Source: Hinicio (2024)

While educational institutions and universities typically present projects at lower TRL stages, mainly TRLs 4-5, industrial innovators often present projects at later TRLs, specifically 8-9, which are either in pilot demonstration phases or early implementation stages. These projects are innovative because they are adapting technology to local conditions. This progression is illustrated in Figure 4-2.

Figure 4-2: Distribution of the innovators according to the TRL of the projects



Source: Hinicio (2024).

77 of 78 (98.7%) of the projects in TRLs 3-5 are led by universities and research institutes, while 51 of 63 (81.0%) of the projects in TRLs 6-7 are led by the industrial sector. The early TRLs of projects led by research and education centres are primarily due to a lack of funding, laboratory infrastructure, and challenges related to diverse climate conditions for conducting demonstration projects in relevant environments. Additionally, limited knowledge, training, and human resources in clean hydrogen technologies can hinder the advancement of innovative solutions.

While several clean hydrogen technologies are technically feasible, the market is still in its early stages, making capacity building and enabling frameworks essential. There is significant potential to strengthen collaboration between academia and the private sector to advance these technologies. Programmes and initiatives, such as Morocco's Institute for Research in Solar Energy and New Energies (IRESEN), can play a crucial role in fostering these partnerships and driving innovation forward.

Box 4-1

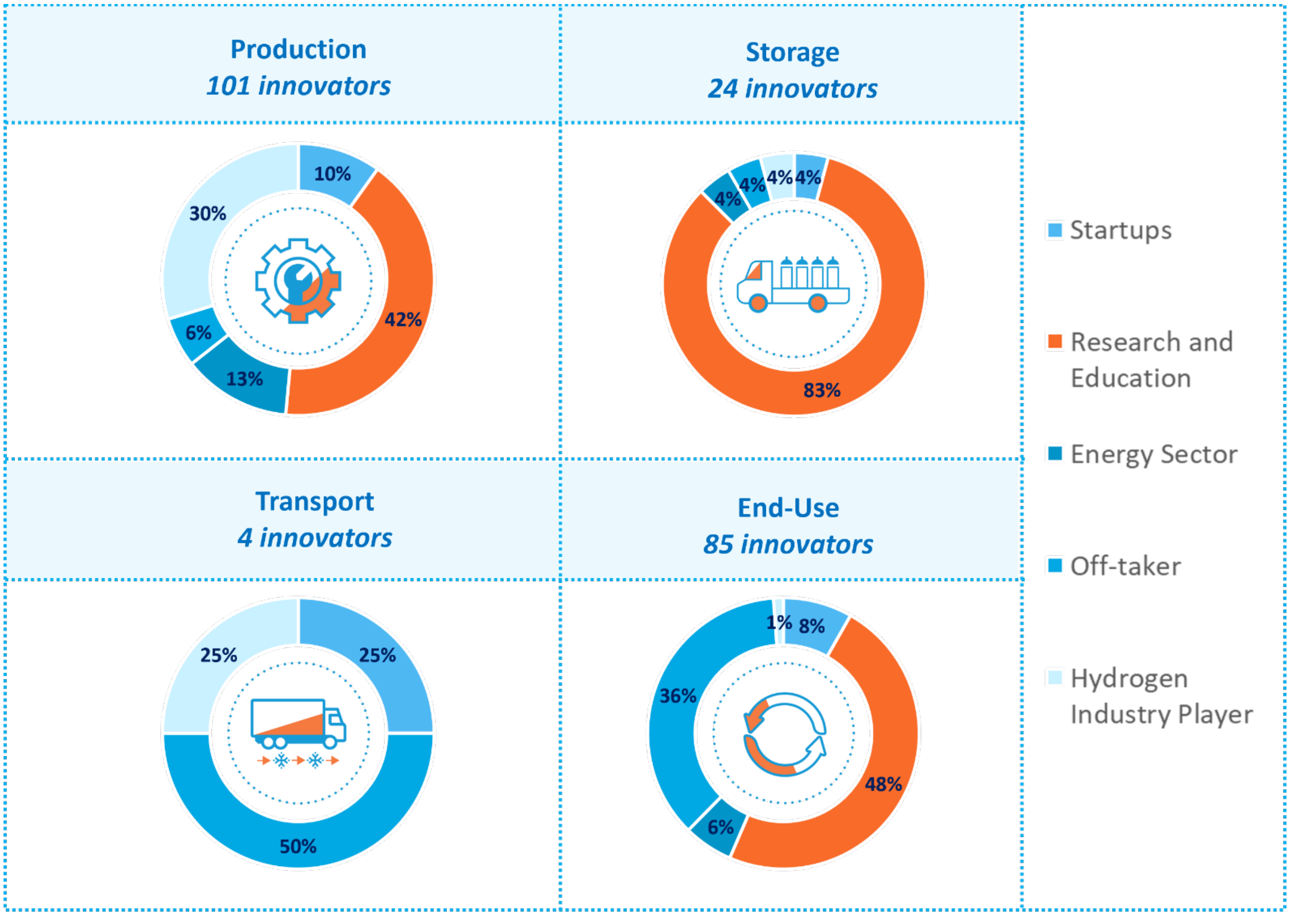
IRESEN

This government initiative supports the national energy strategy through a research centre for networking and research and innovation platforms in green technologies, to finance and assist collaborative applied research and innovation projects (IRESEN, 2024). The institute is also collaborating with the development of green hydrogen, with initiatives such as:

- Collaboration with European Bank for Reconstruction and Development (EBRD) to boost renewables, green hydrogen, and new technologies (EBRD, 2021).
- Establishing Morocco's first green hydrogen production system, in collaboration with Mohammed VI Polytechnic University (UM6P) (Morocco World News, 2022).
- Green hydrogen camp to promote green hydrogen in Morocco, with GIZ and the European Union funded Mediterranean Green Electrons and Molecules MED-GEM Network (MED-GEM, 2024).

Figure 4-3 and Figure 4-4 show that most innovation projects, 101 of 214 (47.2%), focus on clean hydrogen production, aligning with renewable energy companies' interest in next-generation technologies and clean hydrogen production.

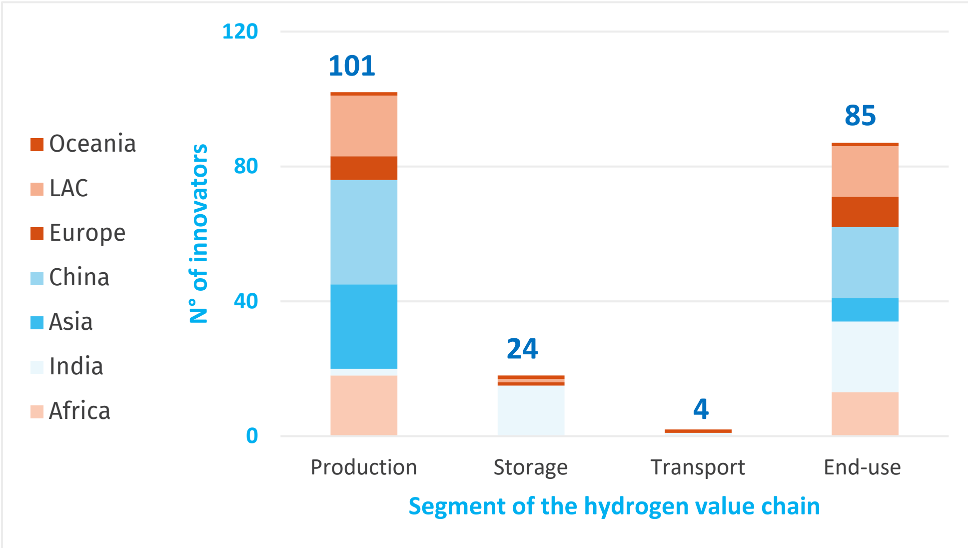
Figure 4-3: Nº of innovators by segment of the clean hydrogen value chain



Source: Hinicio (2024)

Over 80 innovators in developing countries are engaged in the development of clean hydrogen and derivatives end-use applications, with academic institutions and mobility companies spearheading these projects.

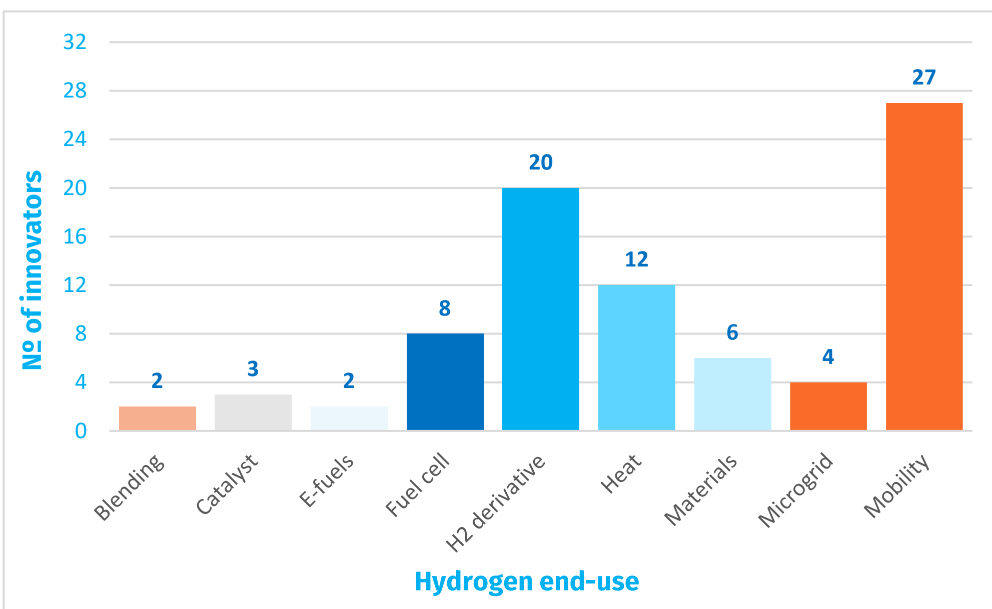
Figure 4-4: Number of innovators by region and segment of the clean hydrogen value chain.



Source: Hinicio (2024)

To better understand the technologies being developed for hydrogen end-uses, this category was divided into sub-categories, as shown in Figure 4-5.

Figure 4-5: Number of hydrogen end-use innovation projects by subcategory



Source: Hinicio (2024)

In the private sector, companies often drive innovation to meet internal demands, or client needs for improved or novel solutions. Their financial resources, market presence, and technical expertise enable them to support and scale innovative technologies effectively. However, in developing countries, the dynamics are different. Barriers to innovation can significantly impact all innovators, including established firms. Limited resources, infrastructure challenges, and regulatory hurdles constrain even well-established companies from fully advancing clean hydrogen technologies.

Profile of innovators

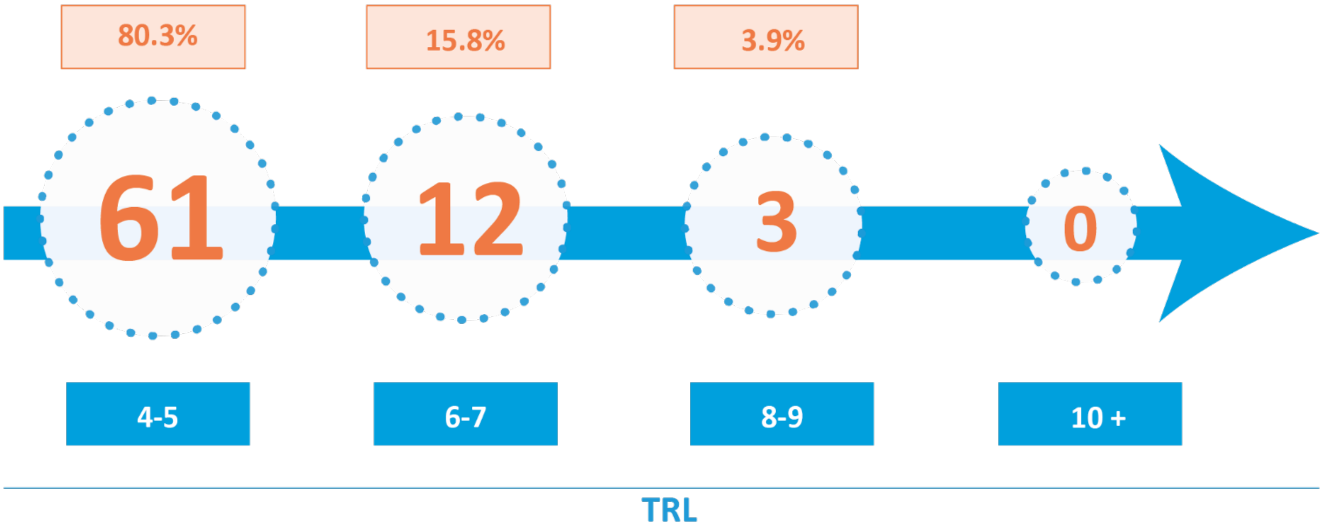
This section explores the various categories and sub-categories of innovators presented in Table 4-1, including the technologies they are working on, their current stages, and the drivers and barriers they face. The analysis covers projects in both early TRL stages and early adoption phases.

Research and Education

Both universities and research institutions focus on disruptive innovation, with an emphasis on new and innovative ideas that involve higher risks and greater uncertainty. They play a key role in providing laboratory infrastructure, conducting experimental analyses for proofs of concept, and offer expert professionals. Their efforts typically aim to patent and publish new processes and services.

Over 70 universities and 30 research institutions and educational centres across developing countries are working on innovative hydrogen solutions at TRLs 4-5, with more than 60 R&D projects. Projects at these stages were identified in countries across various regions, such as Argentina, Brazil, Mexico, Türkiye, and Iran.

Figure 4-6: N° of projects led by the universities and research institutions distributed by



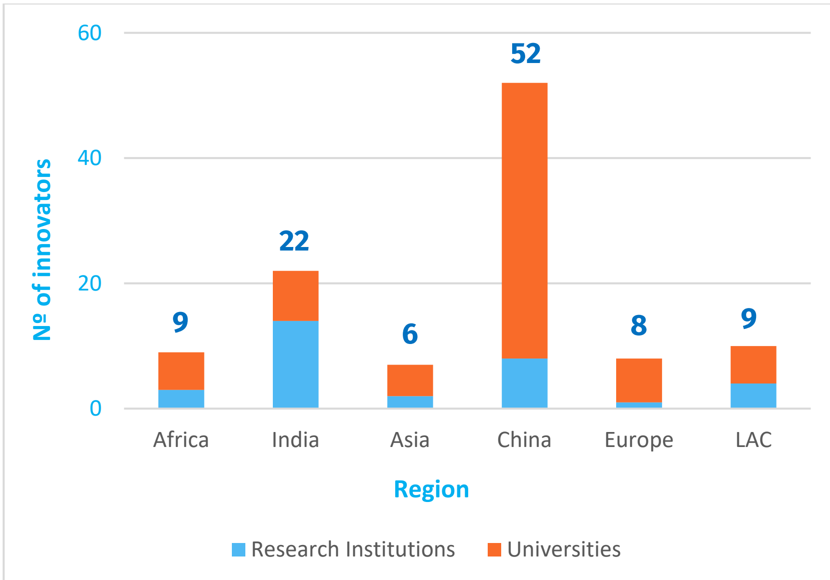
TRL

Source: Hinicio (2024).

However, of the 106 innovative projects which are being developed by these institutions, 51 of those are led by Chinese universities and research institutes (48.1%), followed by 16 led by Indian educational centres (15.1%), both of which focus on mainly on testing new materials and designing hydrogen systems. This demonstrates the strong support for innovation from the Chinese Government and the Indian Institutes of Technology (IIT[8]) respectively.

[8] A network of 23 engineering and technology institutions distributed across the country.

Figure 4-7: N° of universities and research institutes working on clean hydrogen innovation by region



Source: Hinicio (2024).

In some developing countries, the public sector supports innovation by launching calls for projects and establishing programmes open to academia. However, there appears to be a lack of coordination between educational institutions and industry to advance innovative projects collaboratively. Universities can also contribute research to innovative segments of clean hydrogen projects that are scaling up, such as the Daures project in Namibia, in which the University of Namibia is collaborating (Daures Green Hydrogen Village, 2024). Cooperation between public and private companies can also drive innovation, such as Y-TEC in Argentina (Y-TEC, 2024) (see Box 4-2).

Box 4-2

Y-TEC Argentina: Science, Technology, and R&D for the Energy Sector

- Y-TEC is an Argentinian company dedicated to R&D of new technologies for the energy industry. It is owned by the private energy company YPF and the Government Agency for the Promotion of Science and Technology CONICET.

- Y-TEC is developing a 1 MW alkaline electrolyser project to produce 200 Nm^3/h of clean hydrogen at 10 bar. The hydrogen will replace fossil fuels in Tenaris/Siderca's steel industry, financed by the Ministry of Science, Technology, and Innovation.

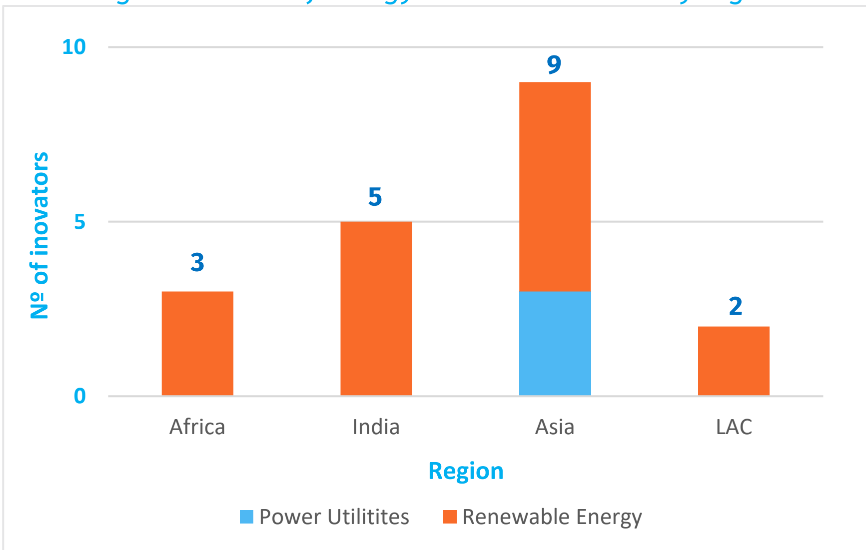
- This is an example of a partnership between a public R&D organisation, CONICET, and the private sector, YPF, to advance to a low-carbon emission ecosystem.

Energy Sector

The energy sector comprises renewable energy companies and electric power utilities and generators. Publicly owned electricity companies, such as state-owned electric utilities, have a strong presence in the energy sector in developing countries where electricity generation is still mostly conducted by them. These companies have announced clean hydrogen projects, such as Perusahaan Listrik Negara (PLN) in Indonesia, which is developing a clean hydrogen and ammonia project in North Sulawesi (Indonesia IHS , 2024).

However, it is renewable energy companies, many of which are foreign owned, that are driving innovation, not electric power utilities. These companies have already ventured into new technologies and gained valuable insights from addressing challenges such as intermittency and seasonality in renewable energy production.

Figure: 4-8: N° of Energy Sector innovators by region

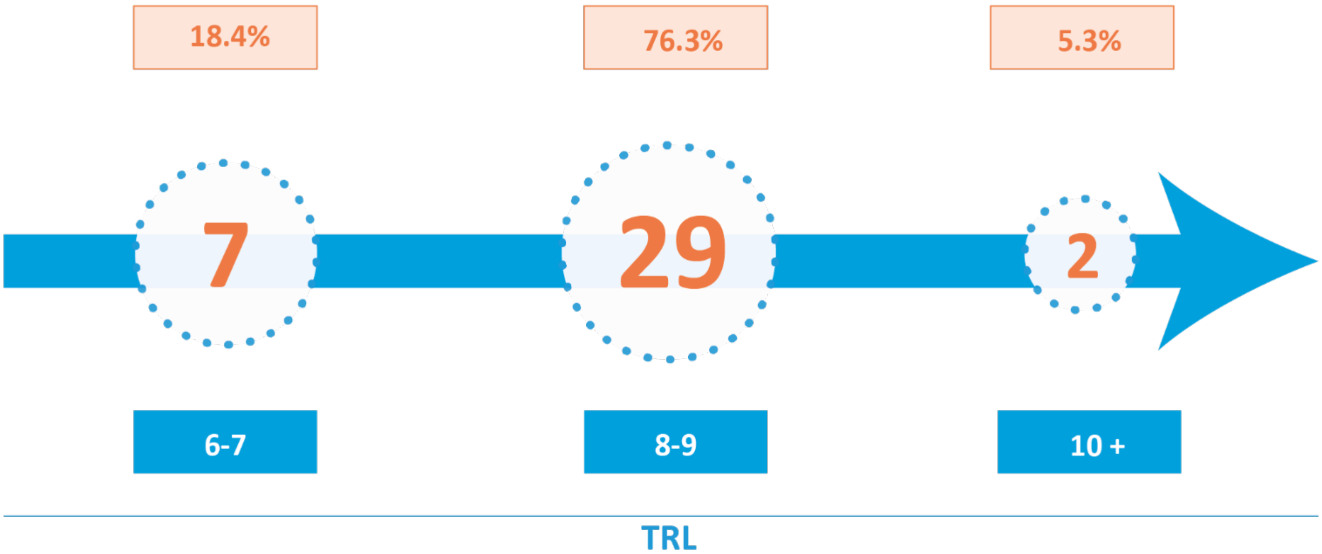


Source: Hinicio (2024)

Most of the innovators identified in the sector come from the Asian Region, particularly Indonesia, Malaysia, and India. Increased participation in other regions is expected, such as the Brazilian electric sector, following the Government's 2024 call to invest 1% of net operating revenue in clean hydrogen R&D. Ninety-five companies from the electric sector have already expressed interest (Ministry of Mines and Energy, 2024).

Innovative projects led by the energy sector are predominantly at TRLs 8-9, encompassing both early adoption initiatives and R&D in new technologies, most of which focus on clean hydrogen production.

Figure: 4-9: N° of projects led by the Energy Sector distributed by TRL



Source: Hinicio (2024)

However, significant challenges remain in renewable energy production, including the integration of various renewable sources, ecosystem-specific plant design, Original Equipment Manufacturer (OEM) optimisation, safety, stability, storage, and decarbonising the electricity grid. Companies such as Renewstable® by HDF are already working in different countries to tackle these issues (see Box 4-3).

Box 4-3

HDF Energy Renewstable® power plant

- One of the key challenges in renewable energy generation is grid instability caused by the intermittency of wind and solar technologies. HDF Energy is addressing this with its Renewstable® power plant, a multi-megawatt facility that integrates intermittent renewable energy sources with on-site energy storage in the form of clean hydrogen. This setup ensures continuous energy generation, providing 24/7 baseload power or peak shaving, while leveraging hydrogen to stabilise the grid. It also offers modular services that can adapt to the network's needs, preventing intermittency and enhancing grid resilience through island mode operation ((HDF Energy, 2024). This technology is being considered for projects in developing countries, including Namibia, Mexico, Indonesia, and the Philippines.

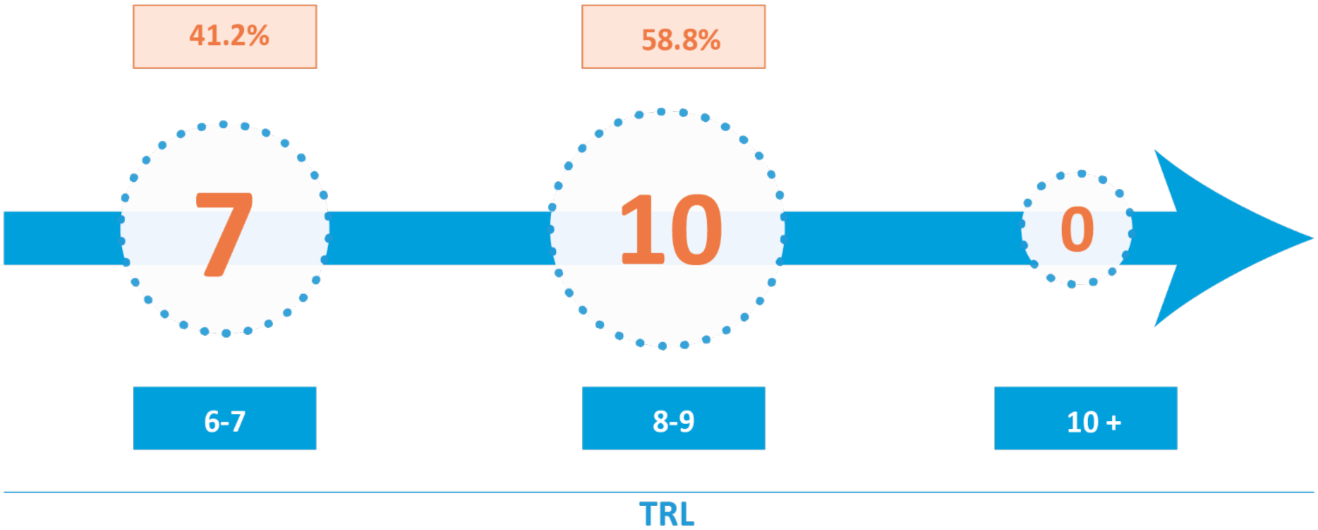
- Innovators entering the power sector, like HDF, will also need to secure power purchase agreements (PPAs) with off-takers, often state-owned utilities or governments, to raise funds and recover capital costs.

Hydrogen Start-ups

Hydrogen start-ups are early-stage companies focused on developing, producing, or advancing technologies and solutions related to clean hydrogen. Since start-ups typically emerge to solve specific problems and the clean hydrogen market is still relatively new, this type of innovator is only beginning to surface, advancing as challenges faced by project developers are identified. As a result, particularly in developing countries, the number of well-established hydrogen start-ups remains limited.

Most start-up-led projects are in TRLs 6-9, typically supported by private investment, which enables project scale-up.

Figure: 4-10: N° of projects identified led by hydrogen Start-ups distributed by TRL



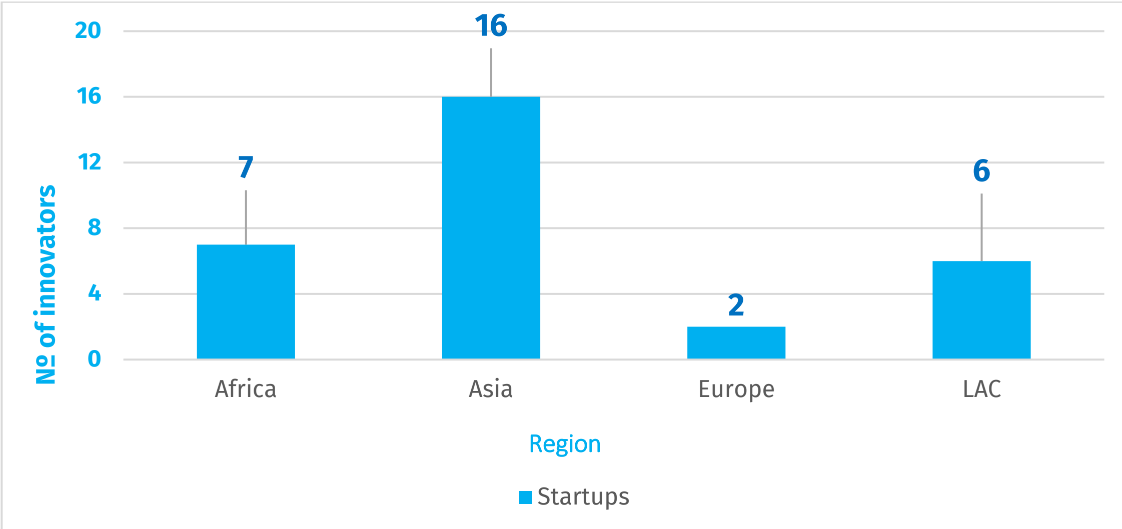
Source: Hinicio (2024).

Start-ups in the clean hydrogen sector and its derivatives face significantly higher risks, particularly in terms of technology readiness and access to financing. These challenges directly impact the number of start-ups emerging in developing countries and limit their growth potential. Unlike large-scale companies, which often have the financial stability to self-fund projects or secure external financing more easily, start-ups encounter far greater obstacles in securing the necessary resources to scale their innovations.

They typically need to explore alternative funding options due to limited financial resources. This challenge is exacerbated by the inherent risks of new technologies and markets, making it difficult for start-ups to attract investors, who are often reluctant to finance projects without clear, long-term commitments from off-takers.

Various start-ups have been identified in China and Latin America, focusing primarily on clean hydrogen production, clean ammonia projects, and mobility technologies. This growth may be driven by initiatives that support the entrepreneurial ecosystem, such as Start-up Mexico, Start-up Peru, and iNNpulsa Colombia. These programmes provide incubators, accelerators, co-working spaces, and training to help start-ups grow and connect with investors and industry experts. Additionally, national hydrogen associations have been established in several countries, including Argentina, Brazil, Peru, Colombia, and Costa Rica, linking different segments of the value chain and offering start-ups opportunities to connect with potential off-takers.

Figure: 4-11: N° of hydrogen start-up innovators distributed by region.



Source: Hinicio (2024).

Given the above constraints and challenges faced by start-ups, they tend to follow three different paths:

- **Failure Risks:** Financial constraints, lack of time-to-market, and the absence of off-take agreements are particularly challenging for clean hydrogen and its derivatives. While the product concept may be promising, the absence of market demand and consumers' reluctance in developing countries to pay premium prices create significant barriers. Additionally, new projects face inflation and rising borrowing costs, contributing to the failure of several start-ups.

- **Pathways to Growth:** Growth can be achieved by identifying the right market opportunities, implementing effective go-to-market strategies, and securing adequate financial support, as demonstrated by Hevolución in Colombia, a spin-off of OPEX (see Box 4-2).

- **Strategic Acquisitions:** Acquisition by a larger company with the financial capacity to overcome economic limitations is a key strategy. This approach provides access to a broader geographical market, expertise, and essential resources, particularly in emerging sectors such as clean hydrogen. For example, Hytron, a pioneering innovator in Brazil focused on integrated energy solutions, was acquired by the

German company The Neuman & Esser (NEA) Group (Hytron, 2020). This acquisition enabled Hytron to transition from a system manufacturer to a diversified full-solution provider ((Hydrocarbon Engineering, 2020).

Box 4-4

Hevolución, a Colombian start-up, raised over $4 million from local enterprises, allowing it to import equipment for clean hydrogen and ammonia production. Half of its ammonia output has already been secured by local off-takers in the refrigeration industry. With strong connections to Colombia's logistics sector, the project aims to address rising hydrogen demand by creating a sustainable mobility hub in collaboration with transport financiers and government agencies. A small hydroelectric power plant will supply stable energy under a 10-year PPA, while feasibility studies funded by the IDB aim to scale the project tenfold.

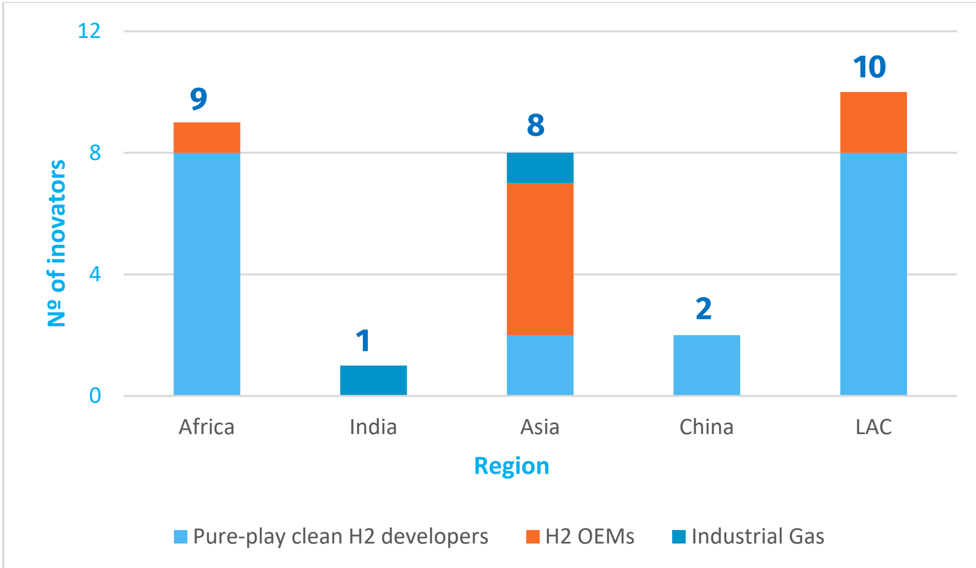
Hydrogen Industry Players

This category includes companies traditionally involved in the hydrogen and gases industry, as well as suppliers for hydrogen projects. Three key sub-categories focused on innovation in clean hydrogen were identified:

- **Industrial gas companies:** Companies that have historically worked with hydrogen and other industrial gases.
- **Pure-play clean hydrogen developers:** Companies exclusively focused on advancing technologies within the clean hydrogen value chain.
- **Hydrogen OEMs:** Companies developing innovative equipment for electrolysis, membranes, or carbon capture and storage, facilitating the integration of hydrogen technologies across various sectors.

Most innovators in this category are pure-play clean hydrogen developers, with a strong presence in Latin America. Countries such as Brazil and Argentina, along with their neighbours, show significant potential for clean hydrogen development, creating opportunities to establish a regional hub.

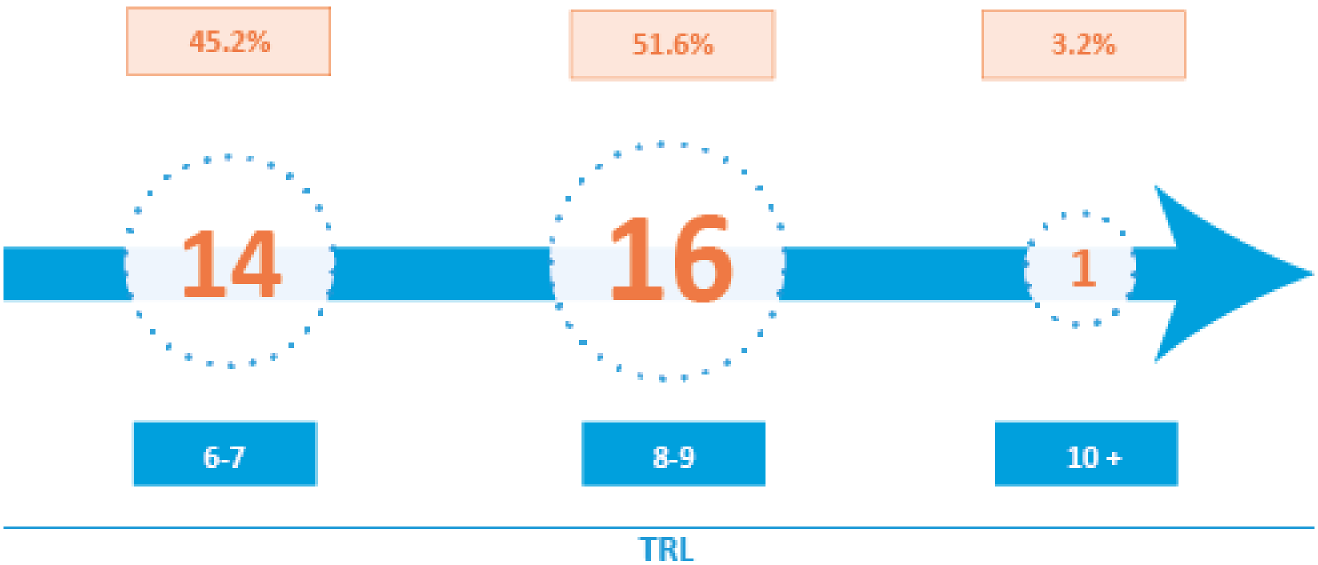
Figure: 4-12: N° of Hydrogen Industry Player innovators by region



Source: Hinicio (2024).

The innovative projects of hydrogen industry players are predominantly in TRLs 8-9 or in pilot demonstration phases, encompassing both the development of new technologies and early adoption projects. These companies are typically working with technologies that have already surpassed lower TRL stages and laboratory tests. They focus on optimising applications or implementing existing technologies in developing countries, which generally present lower risks.

Figure: 4-13: N° of projects led by Hydrogen Industry Players distributed by TRL.



Source: Hinicio (2024)

Off-take Innovators

Off-takers for clean hydrogen are the companies that use and purchase clean hydrogen for their operations. In some cases, they function solely as off-takers to decarbonise their operations, as discussed in Section 5 about stakeholders. However, they can also act as innovators when they engage in R&D, develop their own technologies, or participate directly in early adoption projects. This section analyses off-takers as innovators and divides them into four groups for a more detailed analysis:

- **Oil & gas companies** are increasingly exploring hydrogen as a low-carbon alternative to traditional fossil fuels, leveraging their expertise and existing infrastructure. These companies often have more resources than other innovators, and in many developing countries, state-owned enterprises play a significant role in steering national energy transition goals. For example, state-owned Ecopetrol in Colombia has developed a pilot project for hydrogen production at its Cartagena refinery, introduced a hydrogen bus, and is planning to build two clean hydrogen production plants, each with a capacity of 40 to 60 MW, for its two refineries (Ecopetrol, 2022). Similarly, state-owned Petrobras in Brazil is exploring options to replace fossil-based hydrogen used in its refineries with renewable hydrogen (Argus, 2023).

- **Automotive and transport companies,** including rail, air, and maritime sectors, focus on hydrogen mobility and hydrogen as a clean energy solution for fleets and operations, particularly where electrification is challenging (see Box 4-3).

Box 4-5

Ad Astra: Advancing Costa Rica's Hydrogen Transportation Ecosystem

Ad Astra Energy, a leading company in green hydrogen and e-mobility in Costa Rica, pioneered sustainable transport with the first carbon-free demonstration of a hydrogen electric bus and its associated infrastructure in Central America. The project, known as the "Costa Rica Hydrogen Transportation Ecosystem," has been producing green hydrogen for the Nyuti bus, as well as for four Toyota Mirai vehicles in touristic areas. The project has been primarily funded through private equity, with significant public seed funding at its inception. Ad Astra is also an implementing partner of the NAMA Facility in Costa Rica and plans to expand its operations through this partnership.

- **Chemical and Fertiliser Companies** are exploring hydrogen as a feedstock for chemicals such as ammonia and fertiliser manufacturing. For example, the global leader, National Moroccan Phosphate Company (OCP) and Fortescue Energy plan to develop green energy, hydrogen and ammonia in Morocco (Fortescue, 2024).

Box 4-6

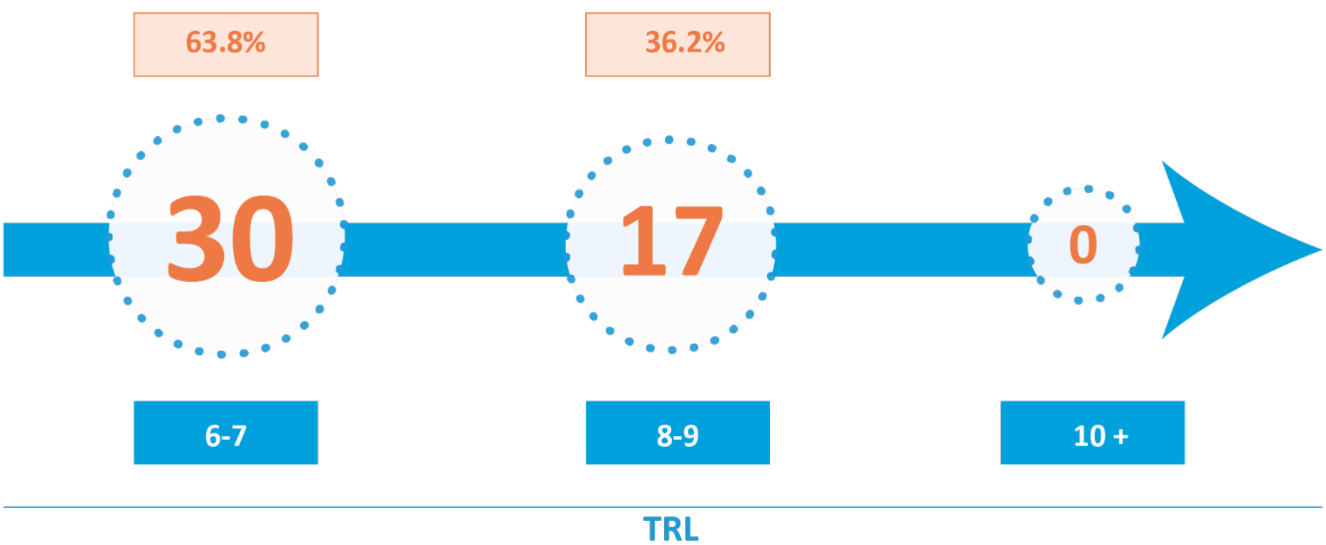
The OCP Group and its Sustainable Approach

OCP Group, one of the largest phosphate and fertiliser companies in the world, based in Morocco, aims to be carbon neutral by 2040. The company has announced plans to develop a hydrogen and renewable ammonia production facility in southern Morocco, along with a partnership with Fortescue Energy to advance green energy initiatives.

- **Other hydrogen end-use application industries,** such as cement, steel, and mining use hydrogen, and therefore are important off-takers. Under this category, Anglo American in South Africa has already launched a prototype of a hydrogen-powered mining truck (ESMAP, 2022), and Holcim plans to set up a trial of hydrogen injection in kilns at one or more of its cement plants in Mexico (Global Cement, 2023). This category also includes natural gas companies, which are involved in blending hydrogen with natural gas for heating and other applications. These companies can also act as off-takers. Hydrogen blending offers a pathway to gradually decarbonise natural gas networks.

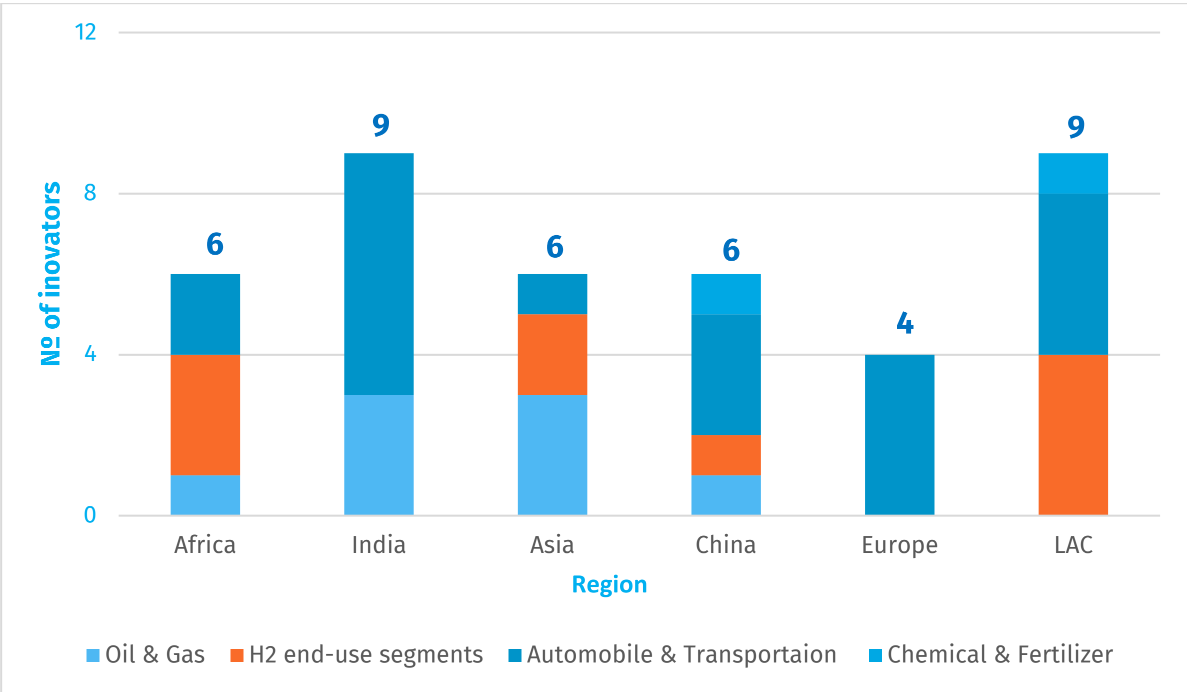
Off-takers' projects are in the later stages of development, primarily in TRLs 6-7, and in the testing phase at TRLs 8-9. This mostly reflects the implementation of already existing technologies in early adoption phases, aiming to apply to incorporate clean hydrogen into their existing industries.

Figure: 4-14: N° of projects led by Off-takers distributed by TRL



Most innovators in this category are in LAC, primarily focusing on technologies for mobility and chemical production, and in India, where those are active in the off-take segment, leveraging the country's established oil and gas industry while exploring hydrogen as a low-carbon alternative.

Figure: 4-15: N° of innovators in the Off-take sector by region



Source: Hinicio (2024)

5

Landscape of stakeholders in developing Countries

The development of a robust hydrogen market hinges on the collaborative efforts of all market segments, underscoring the need for government involvement from the outset. However, the role of off-takers cannot be overlooked, as they drive demand, facilitate funding for developers, and propel market growth.

5 LANDSCAPE OF STAKEHOLDERS IN DEVELOPING COUNTRIES

KEY FINDINGS

- **Innovation Ecosystem:** A coordinated effort from public, private, academic, and international stakeholders is crucial for a successful clean hydrogen ecosystem. Research institutions, universities, and off-takers play key roles beyond being innovators.
- **Government Entities:** Governments are essential for clean hydrogen development, creating regulatory frameworks that provide certainty for investors. Countries with active hydrogen projects tend to have governments heavily involved in promoting and financing the hydrogen market.
- **National Hydrogen Associations:** Only 28 of 141 developing countries (19.9%) have established national hydrogen associations, which play a critical role in advancing clean hydrogen initiatives by linking industrial sectors and governments.
- **Off-takers:** Off-take agreements are key for financial viability, ensuring demand and long-term project bankability. Many off-takers in developing countries will likely come from developed nations with binding regulations in place.
- **Industry Adoption:** The private and public sectors, particularly in energy, fuel, hydrogen production, infrastructure, and refining, are often early adopters of clean hydrogen technologies, driven by regulatory requirements and market incentives.
- **Ports and Logistics:** Ports and logistics companies are essential for developing the infrastructure needed to export clean hydrogen and derivatives, and for importing equipment and materials required for hydrogen projects, especially in import-reliant countries.
- **International Stakeholders:** International stakeholders provide funding, technical assistance, and act as market enablers by launching initiatives that support clean hydrogen project developers.
- **Global Companies:** International companies, both as investors and off-takers, are crucial for scaling up production and generating demand for clean hydrogen.

The stakeholders involved in advancing clean hydrogen in developing countries encompass a diverse range of entities, each contributing distinct expertise and resources.

In this section, we present stakeholders which contribute to the development of the clean hydrogen ecosystem[9]. These groups play essential roles in supporting the growth and adoption of clean hydrogen technologies, ensuring a comprehensive approach to its implementation. To better understand their roles in the deployment of clean hydrogen, stakeholders were grouped into different categories. The table below outlines these categories, and the types of stakeholders identified, followed by sections detailing the main roles of each stakeholder group.

Table 5-1. Categories and types of Stakeholders

Category	Types of stakeholders	Examples
Government Entities	Ministries	Ministry of Energy, Ministry of Transport, Ministry of Environment, Ministry of Science and Technology, etc.
	Other public institutions	Electricity Regulatory Agency of Brazil, National Science and Technology Development Agency (NSTDA) of Thailand
Research Institutions	Universities	Botswana University of Agriculture and Natural Resources, Ho Technical University
	Research institutes	National Energy Research Centre, National Institute of Electricity and Clean Energy
Hydrogen/Energy Associations	Hydrogen associations[10]	India Hydrogen Alliance (IH2A), Mexican Hydrogen Society, GH2 Namibia
	Energy associations	Armenian Energy Agency, Renewable Energy Association of Eswatini
Funding Institutions[11]	National Financial Institutions and Banks	Brazilian Development Bank, OCBC Bank in Malaysia
	International Finance Institutions	International Finance Corporation (IFC), Inter-American Development Bank (IDB) Invest, Development Bank of Southern Africa, EBRD

[9] Although innovators are also stakeholders, considering the scope of this report, they are studied in a separate category (Section 6) to provide a more detailed analysis.
[10] Regional associations, on the other hand, are analysed in the section on initiatives, as they serve as cooperation platforms between countries.
[11] Section 7 further elaborates on the funding instruments being utilised by financial institutions and other stakeholders to finance clean hydrogen projects in developing countries.

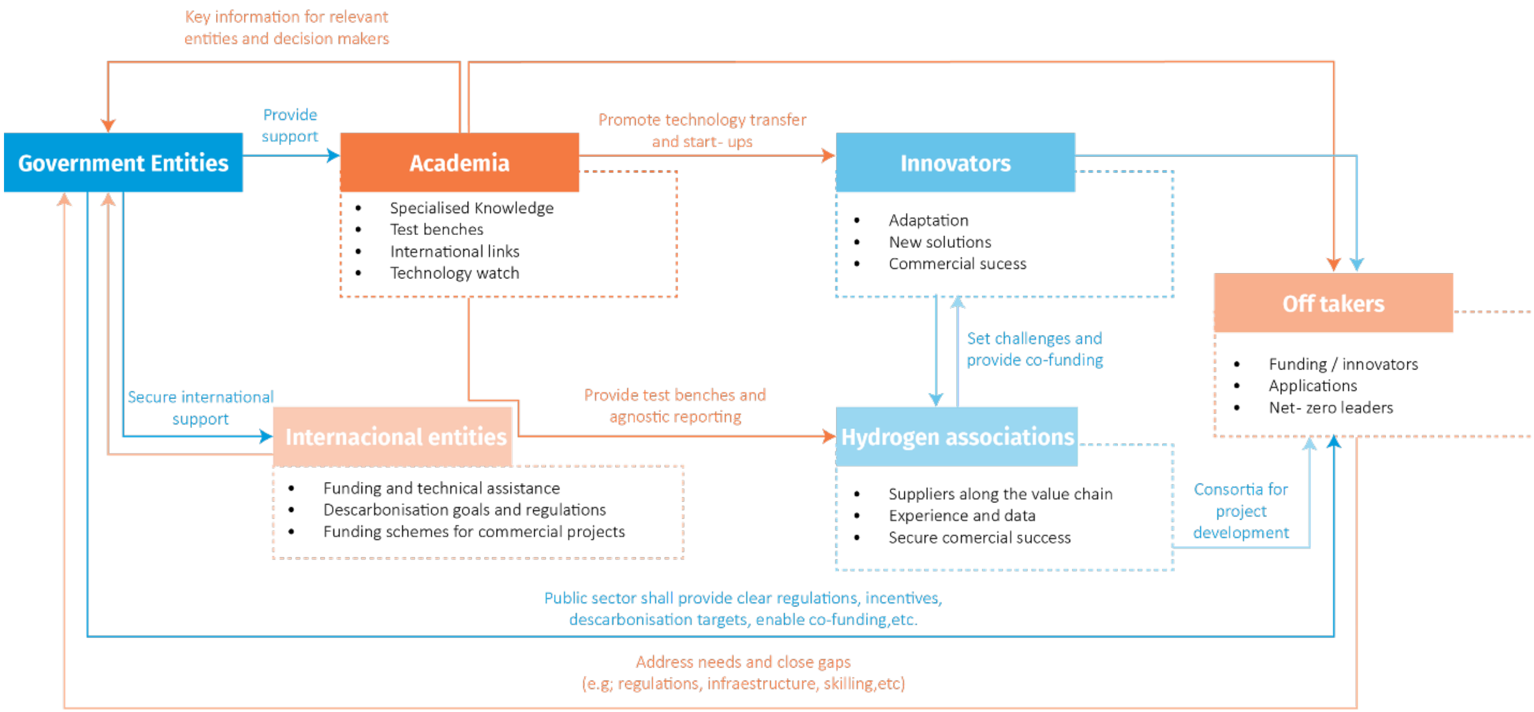
	Private Funding	Capital Ventures SG Malaysia, Social Alpha India, National Financial Institution of Mexico (NAFIN)
Off-takers[12]	Public sector companies	PT Petarmina Indonesia, National Moroccan Phosphate Company OCP
	Private sector companies	Deloitte, Anglo American, HDF Energy, ReNew Power India, Ad Astra Rocket Costa Rica, HyIron Namibia
International Stakeholders	Development Banks	World Bank – Energy Sector Management Assistance Program (ESMAP) Hydrogen for Development Partnership, IDB, African Development Bank (AfDB), Asian Development Bank (ADB)
	International Climate Funds	Green Climate Fund, Climate Investment Fund, Global Energy Efficiency and Renewable Energy Fund
	International Think Tanks	IEA, International Renewable Energy Agency (IRENA), International Association for Hydrogen Energy (IAHE)
	International Organisations	UNIDO, United Nations Environmental Program (UNEP)
	Donor governments / Development Agencies	UK DESNZ, Japan International Cooperation Agency (JICA), Federal Ministry for Economic Affairs and Climate Action of Germany, German Agency for International Cooperation (GIZ)

Source: Hinicio (2024).

The stakeholders considered are legal entities that contribute, either at the national, regional, or international level, through various initiatives to the development of innovation. The following figure shows the main stakeholders and their roles, which are involved in different stages of innovation, including market enablement and product off-take.

[12] Although off-takers were previously analysed in Section 6, not all of them are involved in the innovation landscape and may participate only on the demand side.

Figure 5-1: Role of key stakeholders involved at different stages of innovation.



Source: Hinicio (2024).

Government Entities

- Governments are key enablers of clean hydrogen development, as they are responsible for designing and enforcing the policies and regulatory framework necessary to advance the clean hydrogen economy. They are also key in administering R&D funds, stimulating demand, creating a viable market, and attracting investment. The absence of such a framework and enabling conditions in developing countries has been identified as a common barrier for innovators seeking to develop technology projects.

- Hydrogen regulatory sandboxes can promote innovation by allowing the government to test regulations while innovators advance their projects without fear of breaching the law.

- Financing mechanisms and strategies are, in many cases, regulated and managed by the government. Promoting and obtaining public and private funds and creating incentives (e.g. tax and import duties exemptions) is vital for capital-intensive pilot demonstration projects and scalability.

- The countries where the most activity in the development of hydrogen technologies and projects has been identified align with those where government entities are actively involved in promoting the development of the hydrogen market, allocating resources, and attracting financing and interest from international stakeholders.

Research Institutions

- Research institutions, technology centres, and universities, have reported technologies in lower stages of development, primarily at TRLs 4-5. The construction of hydrogen laboratories and the availability of materials and infrastructure in research facilities, accessible to multiple innovators, will enable innovation to expand. International cooperation is also key, since developed countries with high-quality educational centres can assist developing countries in advancing these efforts, such as the initiative of IRESEN and the International PtX Hub in Morocco (see Box 5-1) (International PtX Hub, 2024).

- Additionally, research centres and institutions can focus on improving efficiency, reducing costs, and addressing technical challenges associated with the implementation of "First-of-a-kind" technologies in these countries. This is very important when adapting technologies to local conditions.

- Finally, universities and other educational institutions play a vital role in training professionals and technicians for the development, operation and maintenance of clean hydrogen plants, including the supply of parts and equipment. This also drives job creation and the growth of new businesses.

Box 5-1

IRESEN and International PtX Hub's Power-to-Liquid pilot plant to increase market readiness and capacities in Morocco

- IRESEN, the Moroccan R&D agency, launched the Green H2 Applications Platform (GH2A) to provide an R&D and training platform open to both industry players and international academic teams.
- The platform will integrate a Power-to-Liquid pilot plant in collaboration with the International PtX Hub. The demonstration unit is designed to showcase the entire value chain and allow Moroccan and international scientists and engineers to gain hands-on experience with technologies such as Fischer-Tropsch synthesis, refining, and electrolysis.
- This initiative will disseminate practical knowledge about Power-to-X and create momentum for future industrial-scale projects.

Hydrogen Associations

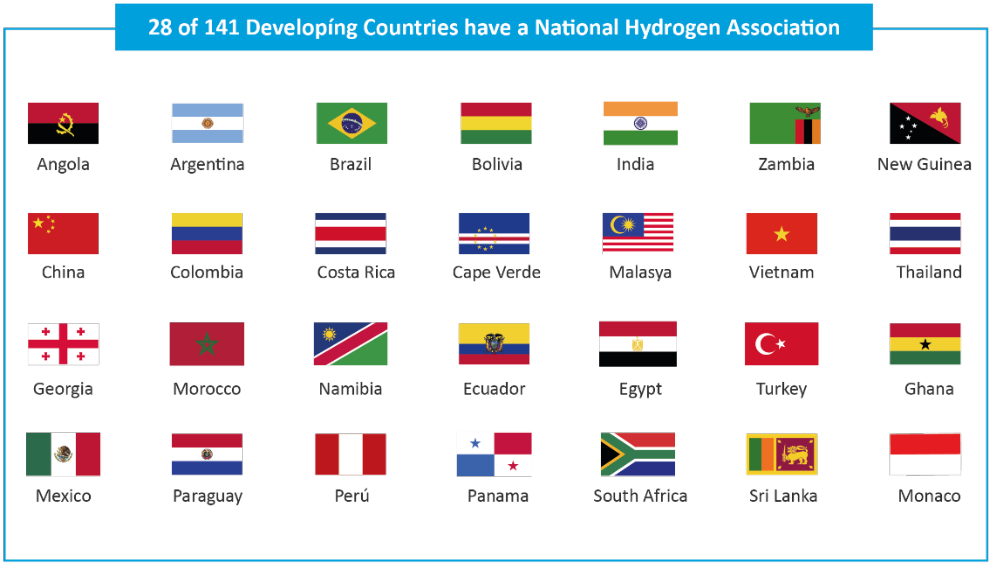
- Bringing the hydrogen community together is one of the primary roles of national hydrogen associations, which serve as platforms for cooperation and coordination. These industry associations enhance collaboration among relevant stakeholders in the hydrogen ecosystem and demonstrate the private sector's interest in advancing the clean hydrogen market.

- Building policy and regulatory frameworks can be supported by associations, which provide insights to policymakers and consolidate industry concerns, helping to shape the regulatory landscape and investment strategies according to stakeholders' needs.

- Conferences, events, and other knowledge-sharing platforms are typically hosted by such associations, which facilitate networking and address common challenges faced by actors involved in the clean hydrogen industry in developing countries.

- Associations unite companies in different sectors, bringing together the various components of the hydrogen value chain. Integrating each segment of the value chain can help identify synergies among different players, facilitate progress toward common goals, and prevent duplicated efforts.

- In countries without National Hydrogen Associations, renewable energy associations can contribute to decision-making processes for clean hydrogen, but it is usually not their main priority.



Funding Institutions

- Funding mechanisms and financial instruments for clean hydrogen projects are essential, given the significant capital required to develop this emerging market, such as the World Bank and KfW, which have announced mechanisms to finance clean hydrogen projects in developing countries.

- The promotion of delivery mechanisms for clean hydrogen, such as Venture Capital and R&D funds, is being supported both by foreign financing institutions and local governments in developing countries. For example, Singapore Capitale Ventures is supporting clean hydrogen development in Malaysia (Reccessary, 2024) and the R&D scheme under the National Green Hydrogen Mission by the Indian Government (Ministry of New and Renewable Energy, 2023). Cooperation agreements have also been established between funding institutions and private sector companies, such as the partnership between Hyphen Hydrogen Energy and the Development Bank of Southern Africa (DBSA) in Namibia.

- The development and refinement of concepts, leveraging networks, project preparation, and capacity building are additional areas where financing is needed to advance clean hydrogen innovation. Financial incentives remain necessary, for example, to mobilise resources for knowledge transfer among actors across the hydrogen value chain, to standardise medium-term rather than long-term off-take agreements, and to manage currency risks, especially in developing countries.

Due to the significant role funding institutions play in enabling innovation, they are specifically analysed in Section 7 on Delivery Mechanisms.

Off-takers: from industry players to consumers

- The role of industrial off-takers is critical to advance the clean hydrogen market as they grant financial viability and ensure demand. Securing off-take agreements demonstrates long-term bankability and allows project developers to mobilise capital required for bringing innovative projects off-the-ground. It is necessary to move beyond letters of intent and memorandums of understanding towards binding agreements to request funding.

- Industries from the private and public sectors are often the first to adopt and deploy clean hydrogen technologies. These industries typically lead as innovators, investors, or off-takers.

- Several consortiums and partnerships between national and international companies, from both the public and private sectors, are actively involved in emerging clean hydrogen projects by securing off-take agreements. In developing countries that may lack the capacity to scale up clean hydrogen technologies, foreign or state-owned companies often provide funding, technological expertise, and off-take agreements.

- In developing countries, potential local industrial off-takers and consumers usually lack the incentive to pay premium prices due to the absence of mandatory regulations. As a result, foreign off-take companies, which can afford these prices, play a crucial role. Securing off-take agreements for export is essential for advancing projects to further stages and eventually enabling production for local off-takers.

International Stakeholders

- Technical assistance, capacity-building programmes, and financing mechanisms are essential for the development of clean hydrogen technologies in developing countries. Therefore, international initiatives for clean hydrogen are crucial. Some of these initiatives are further discussed in Section 6.

- Knowledge sharing and collaboration among stakeholders, promoted by international development organisations, are crucial in the context of developing countries, especially given the common challenges these nations face in building knowledge.

- Specialised support programmes to help developing countries overcome identified barriers and encourage transition to clean hydrogen have been established by international organisations such as UNIDO, the IDB, and the World Bank. For example, the World Bank's Hydrogen for Development Partnership (H4D) offers capacity building, regulatory solutions, business models, and financing to facilitate the development of clean hydrogen in these nations. Also, the IDB and the Latin American Energy Organization (OLADE) are supporting the development of a certification scheme for the LAC Region, CertHiLAC, aiming to serve as a regional dialogue platform for those countries to certify clean hydrogen products and derivatives.

- Collaboration and coordination among international agencies are crucial for joining efforts and avoiding duplication of work, ensuring that initiatives do not overlap. Although several programmes have been identified, there is a lack of initiatives focusing exclusively on R&D. This may be one reason why most innovative projects in these countries are focused on early adoption rather than the development of new technologies.

6

Landscape of initiatives in developing Countries

Most initiatives are national or global. National efforts shape policies and regulations, while regional collaborations facilitate partnerships and knowledge exchange. International initiatives provide invaluable assistance and funding, but it is essential that they align with local requirements.

6 LANDSCAPE OF INITIATIVES IN DEVELOPING COUNTRIES

KEY FINDINGS

- **Initiatives Identified**: National, regional, and international initiatives were identified. National initiatives focus on policy and regulatory development, regional ones facilitate collaboration and knowledge sharing, while international efforts primarily provide technical assistance and funding. However, all face challenges in effectively promoting technology innovation. Only 37 of 141 (26.2%) of developing countries are involved in the international initiatives mapped. Brazil, China, India, Morocco, and South Africa are the main recipients of international cooperation.

- **National Hydrogen Strategies**: 28 of the 141 developing countries (19.9%) have published a national hydrogen strategy or roadmap. Additionally, only 20 (14.2%) mention supporting innovation and technological development, and 18 (12.7%) state they will establish R&D programmes or include a section focused on R&D, technology, and innovation.

- **Regulatory Frameworks**: Most developing countries still lack binding regulations for clean hydrogen use or R&D. Binding regulatory frameworks and incentives are essential to kickstart projects.

- **Hydrogen Hubs**: National hydrogen hubs are being planned in more than 15 developing countries, though China is the only country with a fully operational hub.

- **Regional Initiatives**: Regional initiatives offer platforms for knowledge sharing, best practices, and networking between industry stakeholders. They can be improved by pooling financial resources, reducing costs through shared investments, and accelerating technology transfer among participating countries.

- **International Initiatives**: Several international initiatives address similar challenges, such as regulations and standards. However, gaps remain in knowledge transfer, R&D programmes, technology innovation, market-oriented initiatives, and broader infrastructure needs in developing countries. Critical areas for innovation, such as laboratory resources, materials, education, and hydrogen security protocols, are often neglected.

- **Certification Schemes**: Few certification schemes for clean hydrogen exist in developing countries. China has implemented one, Brazil has made significant progress, and 12 countries in LAC are working on the regional certification scheme, CertHiLAC.

The initiatives supporting clean hydrogen in developing countries were grouped considering three different scopes: country, regional, and international initiatives, to have a broad comprehension of incentives that promote clean hydrogen at different levels.

National Initiatives

National policies, such as hydrogen strategies and roadmaps, highlight the public sector's interest and commitment to developing the clean hydrogen ecosystem. However, as of November 2024, only 27 of the 141 developing countries (19.1%) have published a national hydrogen strategy or roadmap. Of these, 20 countries (14.2%) mention support for innovation and R&D in clean hydrogen technologies. Furthermore, 18 countries (12.7%) include a programme or specific section focused on R&D, innovation, or technological development. Despite these efforts, many of these roadmaps have yet to translate into effective policies and laws that provide actual funding.

Figure 6-1: Number of countries by region which have already published a National Green Strategy or Roadmap.

Source: Hinicio (2024)

- Some countries have already established policies to support R&D, such as Brazil, where generation concessionaires and companies authorised to produce electricity independently are required to invest, annually, at least 1% (one percent) of their net operating revenue in research and development in the electricity sector, excluding, by exemption, companies that generate energy exclusively from wind, solar, biomass, small hydroelectric plants and qualified cogeneration installations[13]. This year is focused particularly on clean hydrogen technologies[14]. However, most project developers require incentives to keep advancing their projects to become profitable.

- In most developing countries, there is limited binding regulation for clean hydrogen use nor for hydrogen-based R&D, which is vital for stimulating demand.

- Regulatory sandboxes allow innovative technologies and processes related to clean hydrogen to be tested in controlled experimental environments. They gather valuable experience, identify potential issues, and help governments understand the necessary regulatory requirements, enabling new technologies to reach the market more quickly.

- Hydrogen hubs[15] are geographical areas that have clean energy sources and potential connective infrastructure. Ideally, hydrogen hubs encompass all segments of the hydrogen value chain: production, storage, distribution, and end-use. They also facilitate the adoption of new technologies, testing, and scaling-up, thanks to the enabling infrastructure. Several developing countries have advantageous conditions for hydrogen hubs, thanks to their renewable energy potential, extensive land areas, and in some cases, they are further supported by existing port infrastructure.

- Over 15 hubs have been announced in developing countries[16] such as Brazil, Namibia, Morocco, Türkiye, Thailand and Ukraine. However, the only fully operational hydrogen hub in a developing country is the Rugao Hydrogen Energy Town in China (Mission Innovation, 2024). A notable example is Ukraine which has announced two hydrogen hubs: Reni in the Odessa region and Zakarpattia. These hubs will focus on exporting to Europe and leveraging existing natural gas networks. The hydrogen hub in the Odessa region has received support from the UK (see Box 6-1).

[13] LAW No. 9,991 OF JULY 24, 2000 (Presidency of the Republic of Brazil).
[14] This information was gathered from the interviews carried out with national stakeholders.
[15] Different terms and definitions for the hydrogen valley concept have been developed. Examples include hydrogen hubs (United States of America, Australia), hydrogen clusters (China, Australia, parts of Europe) and hydrogen ecosystems (parts of Europe) (Clean Hydrogen JU, 2022). For this report, the term "hydrogen hub" is used.
[16] Specific hydrogen hubs for each country are presented in Section 10.

Box 6-1

Support from the UK to the Odessa Hydrogen Valley in Ukraine

- H2U is a green hydrogen development company headquartered in Kyiv, which is currently working on two hydrogen valleys in Ukraine which are Transcarpathia and Odessa Valley.
- In 2024, as part of the Innovate Ukraine competition funded by the British Foreign Ministry and conducted by the British Embassy in Kyiv, H2U was awarded resources to implement a project in the Odessa Region (H2U, 2024).
- This funding will support feasibility studies for hydrogen, solar, and wind power plants, the construction of pipelines for hydrogen transportation, and the geological assessment of underground storage in salt formations.
- This initiative exemplifies international cooperation in sustainable energy between developed regions and emerging markets.

Developing countries that mostly have introduced policy initiatives and regulatory frameworks to advance the clean hydrogen market include Brazil, India, Morocco, and Egypt. These countries have implemented various policy instruments, such as:

- **Brazil's** Government has finalised the rules for the Brazilian Hydrogen Certification Scheme (SBCH2), passing legislation that sets a GHG threshold of 7 kg CO_2eq/kg H_2 for low-carbon hydrogen (IEA, 2024).
- Law No. 14,990/2024 has established Brazil's Low-Carbon Hydrogen Development Program (PHBC), to allow for tax credits to be granted on the sale of low-carbon hydrogen between 2028 and 2032. (Mattos Filho, 2024).
- The president has signed into the country's new biofuels law, requiring airlines to reduce emissions on domestic flights by at least 1% in 2027 and rising to 10% by 2037 using SAF (Ishka Global, 2024).

- **India** launched a tender for hydrogen hubs in August 2024, with USD 24 million during 2025-2026 to set up at least two renewable hydrogen hubs (IEA, 2024).

- The country has announced policy of 5-15% renewable hydrogen quota for the refining sector starting from 2026-2027. The state-owned Indian Oil Corporation has set its own target of 50% by 2030 (IEA, 2024).
- The Green Hydrogen Standard for India specifies green hydrogen with an emission threshold of 2 kg CO_2 equivalent / kg H_2 (Ministry of New and Renewable Energy of India, 2023).

- India has launched an auction scheme, calls, and has allocated budget for electrolyser manufacturing, to demonstrate renewable hydrogen use in steel, trucks, buses, vehicles and shipping, bunkering and refuelling, to promote domestic technology development funding up to 80% of the total project cost, to demonstrate use in existing blast furnaces and 100% hydrogen in DRI furnaces.

- **Egypt's** Law No. 2 of 2024 went into effect in 2024 and outlines various incentives for green hydrogen production projects and their derivatives, including a green hydrogen cash incentive, a value added tax (VAT) exemption, and several other tax exemptions (Deloitte, 2024).
- Necessary machines, tools, devices, raw materials, and transport methods required to carry out the licensed activity for green hydrogen production projects and their derivatives (excluding passenger vehicles) are exempt from VAT. Moreover, exports from these projects will be subject to VAT at a rate of 0% (Deloitte, 2024)..
- The government provides several other tax exemptions, including an exemption from property tax on properties used in the projects, stamp tax, and documentation fees. Also included in the law are exemptions from taxes tied to contracts establishing companies and facilities, contracts for credit facilities and associated mortgages, and contracts for land registration necessary for setting up the projects. The projects are also exempt from customs duty on all imports needed for their establishment, apart from passenger cars (Deloitte, 2024).

- **Morocco's** government announced that it would allocate a million hectares of land (10,000 square kilometres) for renewable hydrogen projects, with an initial 3,000sq km on offer, subdivided into lots of between 100 and 300sq km (Hydrogen Insight, 2024).
- The new incentives also include exemptions from import duty and VAT, tax exemptions (AGBI, 2024).

Regional Initiatives

Regional initiatives provide platforms for sharing technical expertise and best practices. Moreover, they foster knowledge exchange and capacity building, allowing nations to collectively address regulatory, technical, and market challenges in clean hydrogen innovation. They can be further accelerated to pool of financial resources, reduce costs through shared investments, and accelerate technology transfer among participating countries.

Shared infrastructure initiatives can also enhance the different regions´ potential. Several potential regional hubs were identified to serve as connections between hydrogen consumers, producers, and exporters, leveraging shared infrastructure and renewable energy sources to reduce costs.

- **Within LAC,** countries in more advanced phases of becoming clean hydrogen exporters have the potential of sharing port and storage infrastructure and logistics to enhance their export potential. The potential hubs identified are Argentina, Brazil, Paraguay, and Uruguay; Central America and Mexico; Panama and Colombia; and Trinidad and Tobago (IDB, 2023).

- **Southeast Asian** countries as Indonesia, Viet Nam, and Malaysia are exploring collaborations to export clean hydrogen to nearby target markets such as Japan, South Korea, and Singapore, to ensure consistent off-take demand.

- **Africa** has the potential to develop regional hydrogen hubs in Southern countries such as Namibia and South Africa, both of which have already made significant advances in the hydrogen ecosystem. Furthermore, these countries can collaborate with neighbouring landlocked countries to leverage their potential.

- **North African countries,** such as Morocco and Egypt, can leverage their proximity to Europe and the Middle East to establish potential regional hydrogen hubs. Morocco, in collaboration with Mauritania, Argelia, Tunisia and Senegal, have the potential to develop the Northwestern Africa Hub that could export up to 7.5 Mt of clean H_2 (European Investment Bank, 2022).

There are a few regional alliances which are bringing countries together to advance towards a clean hydrogen economy. Such initiatives allow developing countries that have not developed roadmaps or policies and that are not part of international initiatives to connect and get involved in the clean hydrogen economy. Regional initiatives mapped are:

Latin America and the Caribbean

- **LAC Clean Hydrogen Action (LCHA)** is a regional association that includes hydrogen associations from six members, five of which are developing countries: Argentina, Peru, Colombia, Mexico, and Costa Rica (H2 Chile, 2023).

- **H2LAC** is a regional collaborative platform for knowledge sharing that promotes the development of green hydrogen and its derivatives across LAC. It brings together nearly 50 partners from 16 LAC countries (H2LAC, 2022).

- **CertHiLAC** is the regional certification scheme promoted by the IDB for the LAC region. It aims to foster regional integration, avoid duplication of efforts, and enhance competitiveness for LAC producers. Twelve countries are participating: Argentina, Chile, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Panama, Paraguay, the Dominican Republic, and Uruguay (IDB, 2023).

Africa

- **The Africa Green Hydrogen Alliance (AGHA)** was launched in 2021 and currently has seven members: Egypt, Kenya, Mauritania, Morocco, Namibia, South Africa, and Angola, all of which are developing Countries (Climate Champions, 2022).

- **The African Hydrogen Partnership (AHP)** is an African non-profit trade association dedicated to the development of green and natural hydrogen resources and related technologies in the Region, with more than thirty members of different African countries.

Asia

- **The Asia-Pacific Green Hydrogen Alliance (APAC)** aims to accelerate green hydrogen development in the Asia-Pacific region. Of the five members, only Indonesia is considered a developing country, while the others are Australia, Japan, Singapore, and South Korea (Green Hydrogen Organisation, n.d.).

Figure 6-2: Map of Regional hydrogen associations and their respective members from developing countries (in orange) and potential regional hubs (in grey).

Source: Hinicio (2024).

As can be seen throughout this section, there are not many regional initiatives in place as of today. In terms of policies and regulatory frameworks, no such initiatives were identified at the regional level. However, when analysing the region by individual countries, the LAC countries are the ones that have implemented the most policy instruments (each on its own), with Brazil, Colombia, and Costa Rica standing out. These three countries have established regulatory frameworks to promote investment in and the use of hydrogen and its derivatives within their respective territories. Examples include Brazil's laws, mentioned in the national initiatives section, Colombia's Climate Action Act (Baker McKenzie, 2022), and Costa Rica's Decree 44318 (Costa Rican Legal Information System, 2024).

International Initiatives

International cooperation is crucial for developing a clean hydrogen ecosystem that fosters innovation, especially since many developing countries lack the necessary resources and capabilities. International partnerships play a vital role in supporting the development of a clean hydrogen economy, acting as platforms for collaboration among stakeholders across different regions to accelerate the energy transition. Below are some of the leading international initiatives identified, along with their main objectives and participating countries[17].

[17] For each of the initiatives presented, developing countries are shown above the arrow, while developed countries are shown below it.

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

A2D Accelerate to Demonstrate Facility

BREAKTHROUGH AGENDA

Coordinates, prioritises, and enhances global cooperation on research and innovation to make clean technologies affordable and accessible in all regions by 2030.

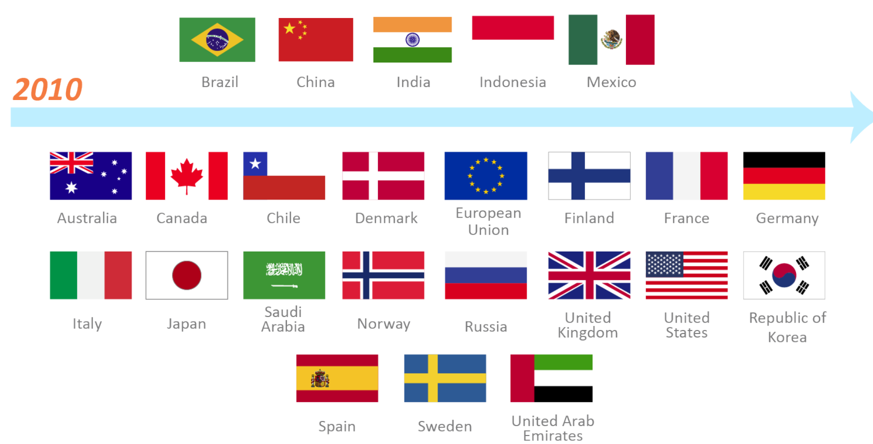
Hydrogen Breakthrough

Set Priority International Actions for 2024 to prioritise international efforts to advance specific priority international actions:

H1. Standards & Certification
H2. Demand Creation & Management
H3. Research & Innovation
H4. Finance & Investment
H5. Landscape Coordination

CLEAN ENERGY MINISTERIAL
Advancing Clean Energy Together

Global forum to promote policies, programmes and knowledge transfer.



Hydrogen Initiative (H2I)

Multi-government initiative aiming to advance policies, programmes and projects that accelerate the commercialisation and deployment of hydrogen fuels and technologies across all aspects of the economy.

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

A2D Accelerate to Demonstrate Facility

CLIMATE CLUB

The CC is an open, inclusive forum for cooperation on accelerating climate action and increasing ambition. One of its pillars is based on transforming industries

Argentina, Bangladesh, Colombia, Costa Rica, Egypt, Kazakhstan, Kenya, Morocco, Mozambiques, Peru, Thailand, Türkiye, Ukraine, Vanuatu, Indonesia

2023

Australia, Austria, Belgium, Canada, Chile, Denmark, European Union, Finland, Slovakia, Republic of Korea, Sweden, Uruguay, United Kingdom, United States, Germany, France, Poland, Spain, Luxembourg, Norway, Netherlands, New Zealand, Italy, Japan, Singapore, Ireland, Switzerland

G7 Hydrogen Action Pact

The Climate Club takes into account the Hydrogen Action Pact by G7 to ramp up low-carbon and renewable hydrogen and power-to-X production, trade, transport and use.

G20 BRASIL 2024
CONSTRUINDO UM MUNDO JUSTO E UM PLANETA SUSTENTÁVEL

The G20 intergovernmental forum is working to address major issues as climate change mitigation.

Argentina, Brazil, China, India, Indonesia, Mexico, South Africa, Türkiye

1999

Australia, Canada, European Union, France, Germany, Italy, Japan, Republic of Korea, Russia, Saudi Arabia, United Kingdom, United States

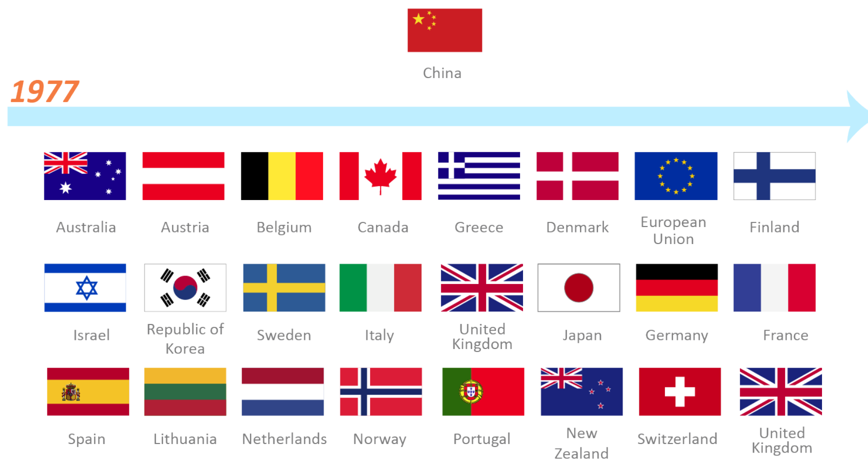
Clean hydrogen initiatives

G20 Summit 2023 was held in India, with important cooperation in the field of an accent on clean hydrogen.

The 2024 G20 Summit will be held in Brazil, after which members expect to deliver a roadmap with policy guidelines to accelerate market development for new sustainable fuels, including hydrogen and its derivatives, and sustainable fuels.

Hydrogen TCP

The Hydrogen Technology Collaboration Programme was established under the IEA to pursue collaborative hydrogen research and development and information exchange.



It is the premier global resource for technical expertise in hydrogen Research, Development, and Demonstration (RD&D). Divided in Tasks, each one addresses specific topics related to research in hydrogen technologies and applications, such as underground storage, energy storage, conversion, among others.

Hydrogen 4 Development Partnership

ESMAP's global platform to accelerate clean hydrogen deployment by fostering international cooperation needed to afford tailored-made solutions for low and middle-income countries.

Hydrogen for Development Partnership

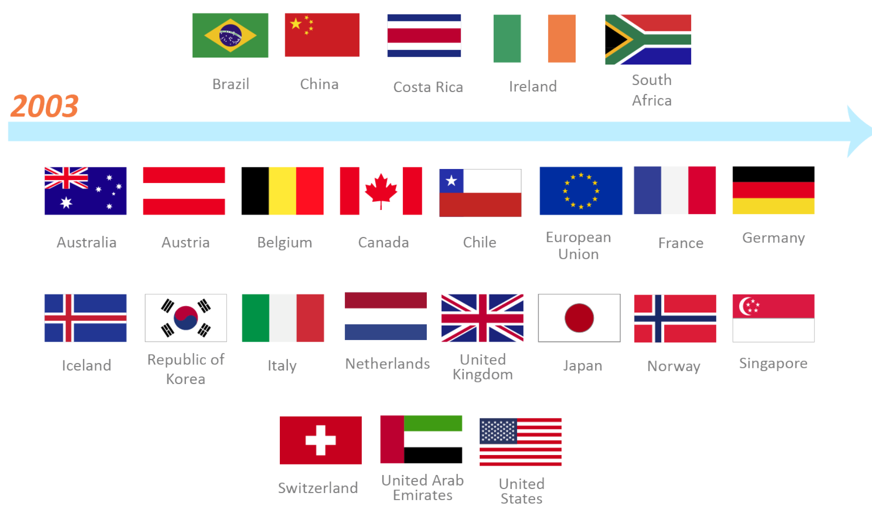
The Hydrogen for Development (H4D) has supported several countries that have included low-emissions hydrogen in the Long-Term Decarbonization Strategies with concessional finance and technical assistance. Developing countries which have already received support are Brazil, Colombia, Costa Rica, Mexico, Ukraine, Mauritania, Namibia, South Africa, Morocco, and India.

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
Progress by innovation

A2D Accelerate to Demonstrate Facility

IPHE

The IPHE is an international inter-governmental partnership whose objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using fuel cells and hydrogen technologies. The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) is an international inter-governmental partnership whose objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using fuel cells and hydrogen technologies.



H2-DEIA

In 2023, in collaboration with the Hydrogen Council, they launched H2-DEIA initiative to champion diversity, equity, inclusion and accessibility in the rapidly expanding global hydrogen economy, serving as a global platform for sharing best practices, and supporting workforce development to advance an inclusive and equitable hydrogen and fuel cell economy.

International PtX Hub

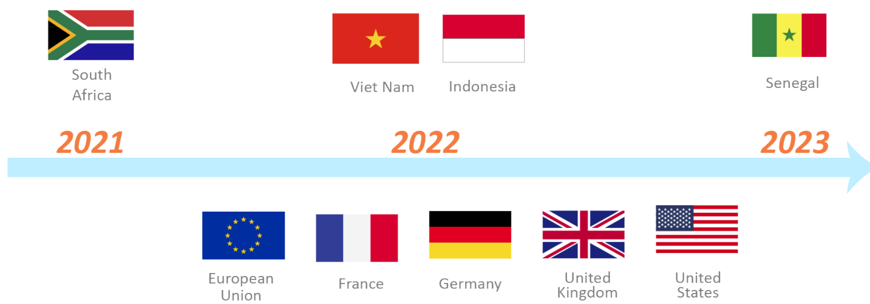
The PtX Hub is a centre of expertise and collaboration for innovative and sustainable green hydrogen and Power-to-X value chains. Has targeted in 13 developing countries.

Hydrogen Initiatives

The PtX Hub builds and fosters strong networks between industry, academia, administrations, and civil society with hubs in Africa, Asia, Europe, and Latin America. PtX offers policy and regulatory advice, capacity building, and cross-sectoral stakeholder dialogues.

JETP

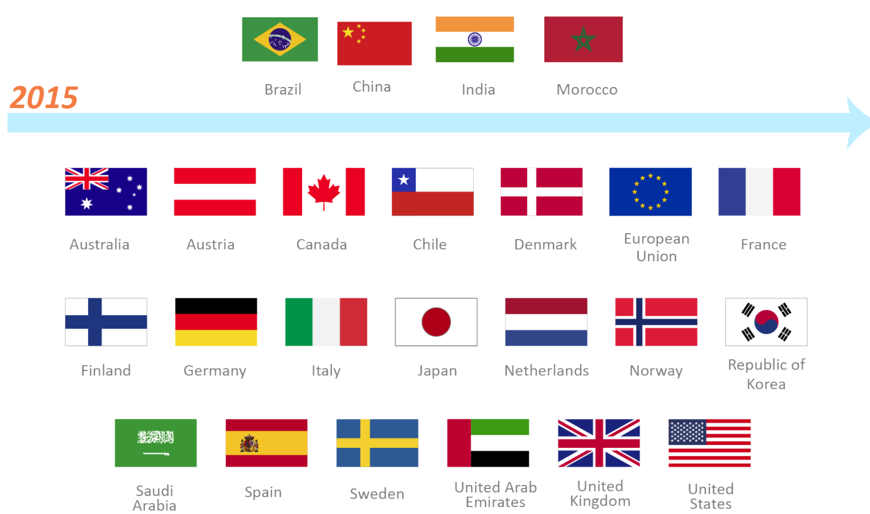
Just Energy Transition Partnerships (JETPs) are a new plurilateral structure for accelerating the phase-out of fossil fuels, and to develop new economic opportunities such as green hydrogen.



These intergovernmental partnerships coordinate financial resources and technical assistance from countries in the Global North to a recipient country to help it in this regard. To date, JETPs have targeted emerging economies that produce and consume coal on a large scale: South Africa, Indonesia, Viet Nam, and Senegal.

MISSION INNOVATION

Global initiative to accelerate public and private clean energy innovation to address climate change, make clean energy affordable to consumers, and create green jobs and commercial opportunities.



Focus on Renewable and Clean Hydrogen

This initiative catalyses action and investment in research, development and demonstration to make clean energy affordable, attractive and accessible for all. With different Innovation Challenges established, one of those focuses on Renewable and Clean Hydrogen, to accelerate the development of a global hydrogen market by identifying and overcoming key technological barriers.

Gaps and Overlaps in International Partnerships

Although multiple initiatives are supporting developing economies in creating a clean hydrogen ecosystem, gaps remain that need to be addressed.

These international initiatives support the creation of a global clean hydrogen ecosystem but overlap in their geographical scope, they are mostly focused on developed countries or in a few developing countries, as will be shown below in Figure 6-3. Tailored initiatives for developing countries, such as the International PtX Hub, market creators, and financial cooperation from developed to developing countries, are crucial for overcoming limitations related to investment resources, expertise, and technical know-how.

These absences can be analysed from two perspectives: how they provide support and to whom they provide support.

Topics to be addressed

Most initiatives and international cooperation for developing countries tend to concentrate on similar objectives, such as supporting prefeasibility studies, the development of regulatory frameworks, and technical and financial assistance; or are focused on global standards and recommendations that do not consider the challenges in developing countries. This overlap can lead to an overemphasis on certain challenges, while leaving other critical aspects unattended:

- **Technology innovation challenges** such as a lack of laboratories and materials, capacity and knowledge building, and hydrogen security protocols should be addressed.

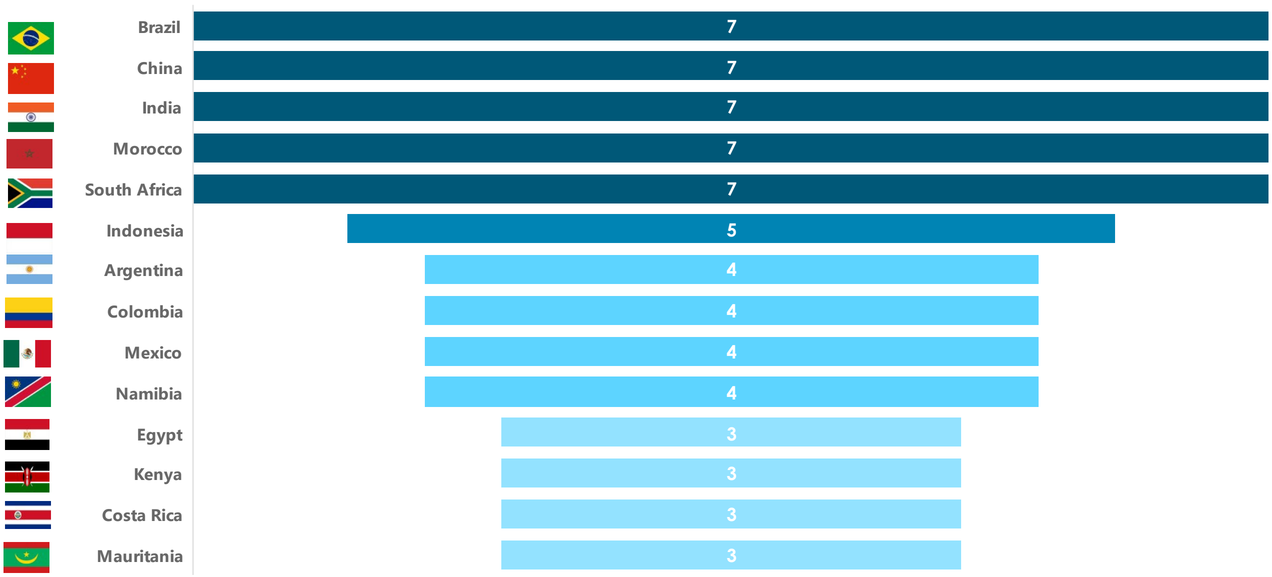
- **Most initiatives focus on hydrogen production and exploring end-use applications** but a broader analysis of the support for the required infrastructure to export and the unattended segments of the clean hydrogen value chain: transport and storage, are also required.

- **Coordination between the countries is not clear.** Initiatives that provide country-specific support to emerging markets can disseminate knowledge by not only sharing their findings but also facilitating cross-country technological exchanges. For example, South Africa, Indonesia, Viet Nam, and Senegal have received support from the Just Energy Transition Partnership, but there is limited coordination between them. Expanding collaborative thinking both within and among countries, promoting dialogue in the Global

South, and sharing regional perspectives are effective ways to minimise duplicated efforts and overlaps.

- **Only 26.2% of all developing countries were found to be members of the international initiatives mapped.** Brazil, China, India, Morocco, and South Africa receive most of the international cooperation, followed by Indonesia, Argentina, Colombia, Mexico, and Namibia. Although several initiatives focus on developing countries and emerging economies in the context of clean hydrogen, in practice, they often concentrate on a select group of nations.

Figure 6-3: Number of cross-regional clean hydrogen initiatives identified of which each developing country is a member[18]



Source: Hinicio (2024)

The majority of initiatives supporting clean hydrogen in developing countries are allocated to countries with the potential to progress in this area. However, it is crucial not to overlook those that could offer innovative solutions in the field of clean hydrogen with the right support. This approach ensures the optimal utilisation of resources while also fostering the development of clean hydrogen technologies in countries with untapped potential.

[18] Other developing countries identified as participating in only one of the international initiatives include Algeria, Angola, Azerbaijan, Bangladesh, Cambodia, Djibouti, Egypt, Ethiopia, Guinea-Bissau, Jordan, Kazakhstan, Kenya, Lithuania, Mozambique, Nigeria, Panama, Peru, Senegal, Serbia, Thailand, Ukraine, and Vanuatu.

7

Delivery mechanisms

To de-risk investments and enable the large-scale development of the clean hydrogen industry, it is essential to have robust and tailored financial instruments and delivery mechanisms that are context-specific and align with the potential of each country.

7 DELIVERY MECHANISMS

KEY FINDINGS

- **Delivery Mechanisms:** There is a lack of established delivery mechanisms specifically tailored to the clean hydrogen industry in developing countries.
- **National Hydrogen Strategies:** Several countries have introduced national hydrogen strategies to boost investment across the clean hydrogen value chain. For example, Morocco has implemented investor incentives, while Namibia has launched the SDG One Fund, aiming to mobilise $1 billion.
- **Government Incentives:** Governments are increasingly offering subsidies, tax exemptions, and concessions to attract private sector investments and support project developers. For instance, Colombia's Energy Transition Law (2021) provides fiscal incentives for "green" and "blue" hydrogen, and Brazil's Rehidro Law offers tax exemptions for low-carbon hydrogen production.
- **Role of DFIs and MDBs:** Development Finance Institutions and Multilateral Development Banks play a critical role in providing financial and technical assistance. In Africa, institutions like the European Investment Bank and KfW Development Bank have extended concessional finance, while in Latin America, the Inter-American Development Bank supports hydrogen roadmaps and clean mobility projects.
- **R&D and Research Infrastructure:** Research and development, along with innovation, are being advanced through the establishment of research labs, innovation hubs, and centres of excellence in developing countries. Government and private sector partnerships are supporting these efforts. Countries like India, Türkiye, and Morocco are promoting R&D for clean hydrogen production and storage technologies through dedicated strategies, while India's National Green Hydrogen Mission has allocated $48 million to foster partnerships between academia and industry.
- **Private Sector Involvement:** The private sector is increasingly partnering with universities and providing funding through Corporate Social Responsibility programmes to support clean hydrogen innovation. Although private sector involvement remains limited, state-owned enterprises in the oil and natural gas sectors are leading key projects. Additionally, clean hydrogen start-ups are emerging, such as India's Hygenco, which raised $25.4 million in private equity through the NEEV-II Fund.

This section provides a comprehensive overview of the existing delivery mechanisms and funding initiatives supporting clean hydrogen projects in developing countries.

The evaluation of the current funding landscape for clean hydrogen projects in developing countries focused on identifying and analysing key delivery mechanisms and funding initiatives across all regions. Insights from stakeholder interviews were incorporated to provide practical perspectives on the delivery mechanisms and confirm their relevance.

As mentioned in section 3, industry experts have pointed out several key challenges: inadequate infrastructure, limited market demand, low technological maturity, shortages of skilled labour, and constrained fiscal capacity. Furthermore, fossil fuel subsidies persist, leading to market distortions. Collectively, these factors contribute to financial risks, making it difficult to secure funding for clean hydrogen initiatives.

An analysis of delivery mechanisms and funding initiatives in 16 countries reveals that governments, development finance institutions, and multilateral development banks are playing pivotal roles in supporting the clean hydrogen sector through grants, concessional financing, technical assistance, and development loans[19].

A significant lack of transparency around funding structures for clean hydrogen projects in developing countries remains a challenge. However, publicly available information indicates that private sector involvement, though growing, is still relatively limited.

Governments are actively advancing the clean hydrogen industry through various policy measures. These efforts include subsidies, tax breaks, blending mandates to boost industrial demand, stronger legal frameworks for research and innovation, and the establishment of research institutes. Additionally, funding for research and development is being increased to stimulate innovation in the sector. State-Owned Enterprises are also forming partnerships with private players and local entities, taking a leading role in scaling key projects and providing financial backing in developing nations.

Delivery Mechanisms and Funding Initiatives by Regions[20]

Evaluation of funding landscape highlights that developing countries are actively advancing their clean hydrogen industries, supported by governments, international

[19] Details of funding institutions are presented in Annex 4.
[20] The identified delivery mechanisms and the funding initiatives are outlined in Annex 4 as well as respective country profiles.

funding, strategic partnerships, and technical assistance among other initiatives. The current focus is on capacity building, mitigating infrastructure and supply risks, and strengthening regulatory frameworks to support industrial decarbonisation while promoting economic growth. While countries in the LAC region lead in financing the adoption of clean technologies, nations in Asia and Africa are actively gaining momentum, driven by government initiatives and private sector collaborations as well as international support.

Africa

In Africa, Development Finance Institutions and other organisations play a crucial role in advancing the clean hydrogen sector. They provide concessional financing, grants, and loans to support infrastructure development, research, innovation, and workforce training. Key institutions such as KfW Development Bank, GIZ, the European Investment Bank, and the Government of Germany offer both technical and financial support across the continent. For instance, Namibia’s SDG One Fund aims to raise $1 billion for green hydrogen projects and related infrastructure (Climate Fund Managers, 2023).

In South Africa, KfW Development Bank, in partnership with the Council of Scientific and Industrial Research, Meridian Economics, and the South African Industrial Development Corporation, has provided more than $200 million in concessional financing on behalf of the German government. This funding supports the production, transportation, export, and storage of green hydrogen, as well as the transition of industries such as heavy industry, chemicals, and transport to hydrogen-based alternatives. In Egypt, SCATEC’s Green Hydrogen Project secured a 20-year off-take agreement through the first H2Global Auction (Scatec, 2024). Regional partners act as intermediaries, responsible for distributing funds to public and private recipients or serving as project implementers.

South Africa has also established Centres of Excellence to advance research and innovation in hydrogen technologies. One of these, HySA Catalysis, is a Centre of Competence hosted by the University of Cape Town and MINTEK, South Africa's national mineral research organisation. HySA focuses on developing early-stage technologies for hydrogen and fuel cells, from material development to prototype creation. Its commercial arm, HyPlat, specialises in fuel cell technology, delivering membrane electrode assemblies and platinum-based catalysts for low-temperature PEM fuel cells (H2.SA, GIZ, 2023).

Asia

India's National Green Hydrogen Mission is one of the standout initiatives in Asia, backed by a $2.4 billion government investment. This comprehensive strategy supports the growth of green hydrogen through subsidies for domestic electrolyser manufacturing, funding for pilot projects, R&D allocations, and workforce training to upskill workers (Ministry of New and Renewable Energy, 2023).

Leading Indian institutions such as IIT Madras and IIT Delhi are establishing research laboratories and innovation hubs focused on advancing green hydrogen technologies. Private companies such as Hyundai and Indus Towers have provided financial support to establish Hydrogen Innovation Hubs (Green H2 World , 2024). In addition, India has developed a national R&D roadmap for the hydrogen value chain and launched an R&D scheme to provide research grants under its National Green Hydrogen Mission (Ministry of New and Renewable Energy, 2023).

Malaysia and Indonesia are also actively supporting the development of hydrogen innovation ecosystems. Organisations such as GreenTech Malaysia and the Malaysian Hydrogen Fuel Cell Association (MyHFC) are promoting the adoption of green energy. Universities are contributing to research efforts, with centres such as the Institute of Fuel Cell at Universiti Kebangsaan Malaysia and the Centre of Hydrogen Energy at Universiti Teknologi Malaysia leading academic research. Collaborative efforts between industries and academia, often supported by Corporate Social Responsibility funding, are driving clean hydrogen innovation.

In India, IIT Delhi partnered with Kirloskar Oil Engines Limited (KOEL) and the Indian Oil R&D Centre (IOCL) to develop hydrogen technology for zero-emission electricity production in spark-ignition generators. This project was funded by the Ministry of New and Renewable Energy, KOEL, and IOCL (IIT Delhi, 2021). Meanwhile, the World Bank has extended a $3 billion concessional loan to support India's green hydrogen market (World Bank, 2024), and the European Investment Bank (EIB) has provided $1 billion for large-scale green hydrogen hubs across the country (European Investment Bank , 2022).

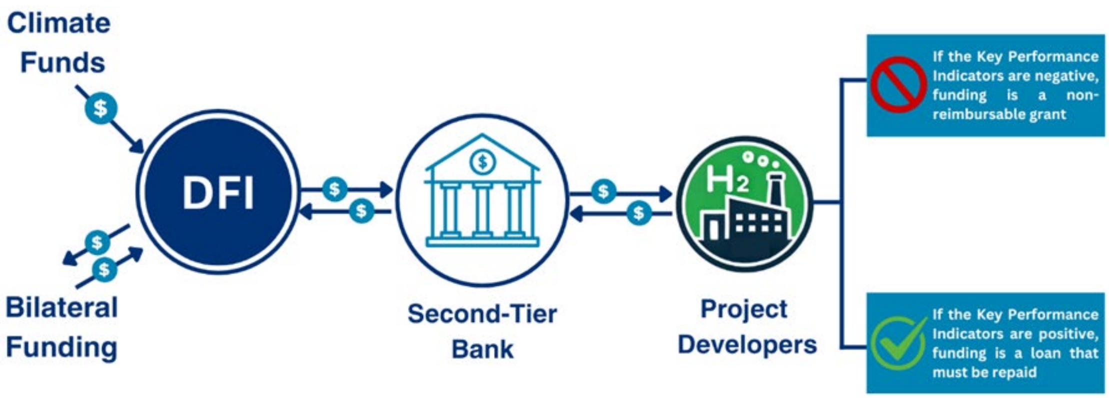
State-owned enterprises (SOEs) are also playing a pivotal role in advancing clean hydrogen across Asia. For example, China's state-owned Huadian Group partnered with Vietnam's Ming Quang to invest over $2 billion in building a green hydrogen facility in Quang Tri province (Vietnam Investment Review , 2024). In Malaysia, Semarak Renewable raised $425 million from Singapore Capital Ventures (Solar Quarter , 2024), and in Indonesia, Samsung and Hyundai, in collaboration with the Global Green Growth Institute, are investing $1.2 billion in a green hydrogen production facility in Northern Sumatra (Fuel Cell Works , 2022).

Latin America and the Caribbean

In LAC, countries are leading the deployment of innovative financial mechanisms to support clean hydrogen projects. Colombia's Non-Conventional Energies and Efficient Energy Management Fund (FENOGE) and Costa Rica's Mitigation Adaptation Facility are examples of such initiatives. International institutions such as the IDB and the World Bank provide significant technical and financial support in the region.

Figure 2 outlines this financial model, which can be adapted by other developing countries to de-risk clean hydrogen projects and attract private sector.

Figure 7-1: Financing Model recommended by IDB, evaluating Terms of Repayment through Project's KPIs, with Second-Tier bank overseeing operation.



Source: IDB (2023)

The IDB, with its strong presence in the region, is assisting the governments of Colombia, Costa Rica, and Brazil in formulating hydrogen strategies and roadmaps. The IDB has supported feasibility studies and market analyses in Costa Rica, Mexico, and Brazil, along with providing financial assistance. Meanwhile, the World Bank is backing Brazil's hydrogen sector with over $90 million in loans for investment in the Ceará green hydrogen hub (World Bank, 2023). In addition, Colombia has benefited from a $750 million low-interest loan from the World Bank to promote institutional reforms for decarbonisation and climate resilience, laying the groundwork for long-term sustainable growth (World Bank , 2024).

In Colombia, the initiative "+H2 Colombia," launched by FENOGE with support from the Ministry of Mines and Energy, began with an initial endowment of $1 million. The programme aims to promote the development and application of green and blue hydrogen throughout the value chain while establishing investment and financing mechanisms, including public loans and grants, to drive the growth of Colombia's hydrogen market. In partnership with the World Bank and other agencies, FENOGE will support pre-feasibility and feasibility studies for 10 selected projects (IEA, 2023).

Brazil is also prioritising clean hydrogen as a key focus for research, development, and innovation. The National Energy Policy Council of Brazil Resolution #2/2021 mandates that 1% of total energy Research, Development, and Innovation funding be allocated to hydrogen projects. This initiative has led to tangible outcomes in technological capacity building, pilot plant development, and the establishment of equipment, vehicles, laboratories, and research centres (Cortés, 2023).

Mexico’s Petroleum Law has also advanced the innovation landscape. The law established the Mexican Petroleum Fund, which manages revenues from hydrocarbon exploration and extraction. Once the fund reaches 3% of GDP, up to 10% of its annual increment can be allocated to science, innovation, and renewable energy (IEA, 2021).

In Costa Rica, development organisations such as GIZ, IDB, and Ad Astra are providing funding support for e-mobility projects, particularly in commercialising clean hydrogen as fuel for heavy-duty trucking, cargo, and transportation systems (Toyota Mobility Foundation, 2020).

Investors are showing growing interest in clean hydrogen start-ups, as evidenced by the $25.4 million raised by India’s Hygenco through private equity (Inc 42 , 2022). The private sector is expanding its role in supporting innovation within the clean hydrogen industry.

Box 7-1: Notable Delivery Mechanisms for Clean Hydrogen Projects- SDG One Fund, Namibia

SDG One Fund, Namibia

The Government of Namibia is developing green hydrogen production facilities in the Kharas region, under the Southern Corridor Development Initiative (SCDI). At COP26, the government declared Hyphen Hydrogen Energy, a joint venture between Nicholas Holdings and Enertag, as the preferred bidder for the development of country's first giga-scale green hydrogen project. The project's investment size is estimated at around $10 billion, nearly equivalent to the country's GDP of approximately $12 billion. Public financing is limited due to fiscal constraints, and the nascent stage of the hydrogen industry presents significant risks. To mitigate the investment risks, the Government of Namibia and Hyphen Hydrogen Energy have worked together for over 16 months to create an enabling policy environment, reaching a concession agreement for 40 years. Additionally, the government has acquired a 24% equity stake option in the project to attract private investors and implement further de-risking measures. Additional funding is expected to be mobilised from debt instruments, with significant interest from DFIs and commercial lenders to provide blended finance instruments. The government has launched the SDG One Fund, an infrastructure fund aimed at mobilizing $1 billion in concessional and commercial capital to support the SCDI. The fund has secured initial financing of nearly $43 million from the Dutch Government through Invest International. Additionally, the government has received a letter of intent from the European Investment Bank to mobilise $542 million, covering the entire equity requirement for the Hyphen Hydrogen Project.

Source: (World Bank ESMAP and OECD, 2024) and National Green Hydrogen Strategy, Namibia

Box 7-2: Notable Delivery Mechanisms for Clean Hydrogen Projects- SIGHT Programme, India

Strategic Interventions for Green Hydrogen Transition (SIGHT), India

To support the development of a green hydrogen ecosystem, the Government of India has launched the ambitious National Green Hydrogen Mission. A key component of the mission is the Strategic Interventions for Green Hydrogen Transition (SIGHT) program, which proposes two financial incentive mechanisms:

1. Promoting the manufacturing of electrolysers
2. Production of green hydrogen and its derivatives

The incentive scheme for electrolyser manufacturing offers subsidy support based on manufacturing capacity, with a base incentive starting at Rs. 4440/kW ($53/kW) in the first year, tapering annually. Incentives will be provided for five years from the start of manufacturing.

The incentive scheme for green hydrogen production has outlined two modes of implementation:

1. Bidding on the least incentive demanded over three years, through a competitive selection process.
2. Solar Energy Corporation of India (SECI) aggregating demand and calling for bids to procure green hydrogen and its derivatives at the lowest cost through a competitive selection process.

This scheme offers a potential template for designing subsidy systems in developing countries, tailored to regional contexts. Eligibility criteria require that green hydrogen production aligns with the 'National Green Hydrogen Standard' to ensure product quality meets global standards. For derivatives, subsidies will be based on the amount of green hydrogen used in their production. The government has defined an equivalence factor for green ammonia at 0.1765 kg of green hydrogen per kg of green ammonia.

Beneficiaries will be selected through a competitive process and will receive direct incentives based on the production of green hydrogen, measured in Rs/kg, for three years from the start of production. Incentives will be capped at $0.60/kg in the first year, $0.48/kg in the second year, and $0.36/kg in the third year.

The programme has been allocated a financial outlay of $2.1 billion.

In conclusion, Figure 7-2 outlines the financial instruments identified across 16 developing countries to fund clean hydrogen projects, based on the World Bank's risk model (2023).

Figure 7-2: Delivery Mechanisms for Clean Hydrogen in Developing Countries.

Delivery Mechanisms for Clean Hydrogen in Developing Countries						
Project Cycle	Scoping	Pre-Feasibility	Feasibility	Definition, Approvals	Construction & Commissioning	Operation
Risk/Return	High					Low
DMs	RD&D Funds, TA, Dev. Equity	Incentives & Rebates	Concessional Finance	Credit enhancement & Guarantees	Traditional Loans	Sustainability/ Transition Loans & Bonds
Categories	Grants (Convertible), Equity	Subsidy	Concessional Debt, Equity	Guarantee	Commercial Debt	
Sources of Finance	Government, Philanthropies, DFIs, MDBs	Government	Philanthropi-es, DFIs, MDBs	Government, Insurers, DFIs, ECAs	DFIs, ECAs, Bank	Asset Owner, Bank, MDBs

Source: Hinicio (2024), (CPL, 2024) and (World Bank, 2023)

Currently, government incentives, including subsidies, tax concessions, and funding from development organisations, are primarily focused on stimulating the supply side of clean hydrogen projects. Comparable demand-side measures have yet to be implemented on a similar scale. Public-private partnerships are playing a catalytic role in driving research and innovation across the hydrogen value chain, though most funding and delivery mechanisms remain focused on production and end-use facilities. Support for innovation in storage and transmission infrastructure has been limited.

Industry experts have expressed concerns about the size and short-term nature of subsidies, which may be insufficient for projects with long-term operational timelines—often extending up to 30 years. Phasing out fossil fuel subsidies, particularly in developing countries, could create fiscal space for clean energy incentives and accelerate the energy transition. In this context, technical assistance from Development Finance Institution and Multilateral Development Banks can play a critical role in developing strategies for phasing out fossil fuels, including frameworks for carbon taxes and related financial instruments.

Based on the current clean hydrogen landscape, experts have provided recommendations to de-risk investments and enhance private sector participation, which can be broadly applied to the context of developing countries (Council on Energy, Environment and Water & Bloomberg, 2024). Figure 7-3. Figure 7-3: Expert recommendations for financing clean hydrogen projects in developing countries.summarises key recommendations for financing clean hydrogen projects.

Figure 7-3: Expert recommendations for financing clean hydrogen projects in developing countries.

Standardize Medium Term Off-take Agreements	FIs can work with project developers, to create standardised medium-term offtake agreements. A governmental nodal agency to facilitate such agreements would be critical. FIs have indicated 10-year offtake agreements would be sufficient.
Mitigate off-take risk with real options	FI's can collaborate with project developers and governments to design projects that connect renewable power generation capacity to the grid. This approach offers an alternative revenue stream, mitigating the impact of offtake risks that could otherwise render planned projects unviable.
Scale use of concessional capital, guarantees, viability gap funding	FIs and project developers can partner with MDBs and donors to attract concessional capital investment in the clean hydrogen industry. Utilizing guarantees and viability gap funding mechanisms can lower the cost of capital, enhancing the financial viability of the projects.
Manage hedging risks with proven hedging products	Currency hedging products can be designed by FIs, MDBs and other organisations for clean hydrogen products focused on export markets.
Invest in project preparation and capacity building	Clean hydrogen production and its supporting infrastructure demand substantial upfront capital and extensive project design, structuring, and financing. Significant funding is needed to prepare projects and advance them toward fundraising. However, financial institutions currently lack the capacity to evaluate clean hydrogen projects due to limited experience in the sector. Therefore, resources are needed to bring together investors from various sectors, such as commodities, infrastructure, and LNG, to share knowledge and develop new evaluation frameworks.

Source: Hinicio, puREsource (2024)

8

Assessment of the sustainable development goals

The clean hydrogen industry has the potential to make a significant contribution to the advancement of Sustainable Development Goals (SDGs) in developing countries, particularly SDG 1 (No Poverty), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action).

8 ASSESSMENT OF THE SUSTAINABLE DEVELOPMENT GOALS

KEY FINDINGS

- The clean hydrogen ecosystem in developing countries holds significant potential to accelerate progress toward achieving the SDGs.
- Innovations in clean hydrogen technology have strong linkages with SDG 1 (No Poverty), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action). Additionally, clean hydrogen development in these regions can contribute to SDG 2 (Zero Hunger), SDG 5 (Gender Equality), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 8 (Decent Work and Economic Growth).
- Developing clean hydrogen industry in developing countries can stimulate local economies, create jobs, and boost GDP. It will also promote sustainable industrialization by establishing new supply chains, advancing infrastructure, fostering research and innovation, and enabling clean hydrogen adoption in heavy industries, further contributing to reduce greenhouse gas emissions.
- To ensure clean hydrogen projects align with environmental and sustainability goals, robust regulatory bodies and frameworks must be established for effective project oversight. Governments and project developers should engage in extensive stakeholder consultations with local leaders and experts to facilitate a just and inclusive transition, ensuring host communities are involved in the projects.
- In the absence of clear regulatory provisions, challenges may arise in managing land and water resources, particularly in fragile and water-stressed regions. Furthermore, without targeted skill development programs for local communities, job opportunities could bypass these populations, limiting the overall impact of clean hydrogen initiatives.

The integration of clean hydrogen technology presents significant opportunities for accelerating progress toward the SDGs, particularly in developing countries. This section attempts to evaluate both the strong and indirect linkages between impact of clean hydrogen transition and key SDGs, grounding these connections in evidence-based theories of change.

Developing countries, characterised by low adaptive capacities, are disproportionately impacted by the adverse effects of climate change. Weak infrastructures in food security, water access, healthcare, and infrastructural system leave these nations highly susceptible to environmental shocks, with millions at risk of being pushed further into poverty. These challenges not only hinder progress toward achieving the SDGs but may also reverse decades of development gains, exacerbating inequality and social instability (Centre for Global Development , 2024).

The production of green hydrogen through electrolysis—powered by renewable energy—directly contributes to reducing greenhouse gas emissions. Its applications across sectors such as transportation, energy production, and residential services will enable further decarbonisation of high-emission industries. This shift positions clean hydrogen as a pivotal technology for advancing, for example, SDG 13 (Climate Action) in regions highly vulnerable to the effects of global warming, facilitating reduced dependence on fossil fuels.

The establishment of hydrogen industries and markets are expected to contribute to boosting GDP and economic growth, directly supporting SDG 8 (Decent Work and Economic Growth) and SDG 1 (No Poverty). In addition, investments in hydrogen technologies attract financial, technological, and social capital (Falcone, P. M., Hiete, M., & Sapio, A. , 2021).

Importantly, the clean hydrogen transition also presents a significant opportunity to advance gender equality (SDG 5). Through targeted policy interventions, women can be upskilled for leadership roles and employment in green jobs, reducing the gender gap in the clean energy sector. Additionally, hydrogen-based innovations are expected to increase access to clean technologies and energy with the potential to reduce indoor air pollution (Mukelabai, Wijayantha & Blanchard , 2022)—a major health risk for women and girls in rural areas—while also addressing time poverty by decreasing the hours spent on traditional cooking methods (Asian Development Bank , 2022).

As cost-competitiveness will be achieved across the clean hydrogen value chain, developing countries are strategising to improve national electrification rates. Clean hydrogen can enhance access to affordable, reliable energy in the nearby rural and remote regions, thus playing a critical role in alleviating energy poverty (SDG 7). This transition supports a broader vision of equitable development, where the benefits of clean hydrogen extend to the most vulnerable populations, ensuring sustainable energy access for all (Pradhan, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. , 2017) & (Falcone, P. M., Hiete, M., & Sapio, A. , 2021).

Therefore, the clean hydrogen technological innovations have the potential to contribute to the following SDGs associated with gender, energy, water, employment, infrastructure development, poverty, and food security (Green Hydrogen Organisation, 2023):

SDG 1: End poverty in all its forms everywhere
SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
SDG 5: Achieve gender equality and empower all women and girls
SDG 6: Ensure availability and sustainable management of water and sanitation for all
SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all
SDG 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all
SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation
SDG 13: Take urgent action to combat climate change and its impacts

Based on preliminary findings, in the context of developing countries, the following SDGs have been identified as having strong and soft linkages with value chain innovations in clean hydrogen[21]:

Table 8-1. Strong and Soft Linkages between SDGs and Value Chain Innovations

Strong Linkage	Soft Linkage
SDG 1 No Poverty	SDG 2 Zero Hunger
SDG 9 Industry, Innovation and Infrastructure	SDG 5 Gender Equality
SDG 13	SDG 6

[21] Strong and soft linkages can be identified between the SDGs and the direct contributions of the innovation in clean hydrogen projects. A *strong linkage* indicates a clear synergy between the relevant SDG indicator and the impacts of innovation in clean hydrogen technology, whereas *soft linkage* indicates an indirect synergy.

Climate Action	Clean Water and Sanitation
	SDG 7 Affordable and Clean Energy
	SDG 8 Decent Work and Economic Growth

Source: puREsource (2024)

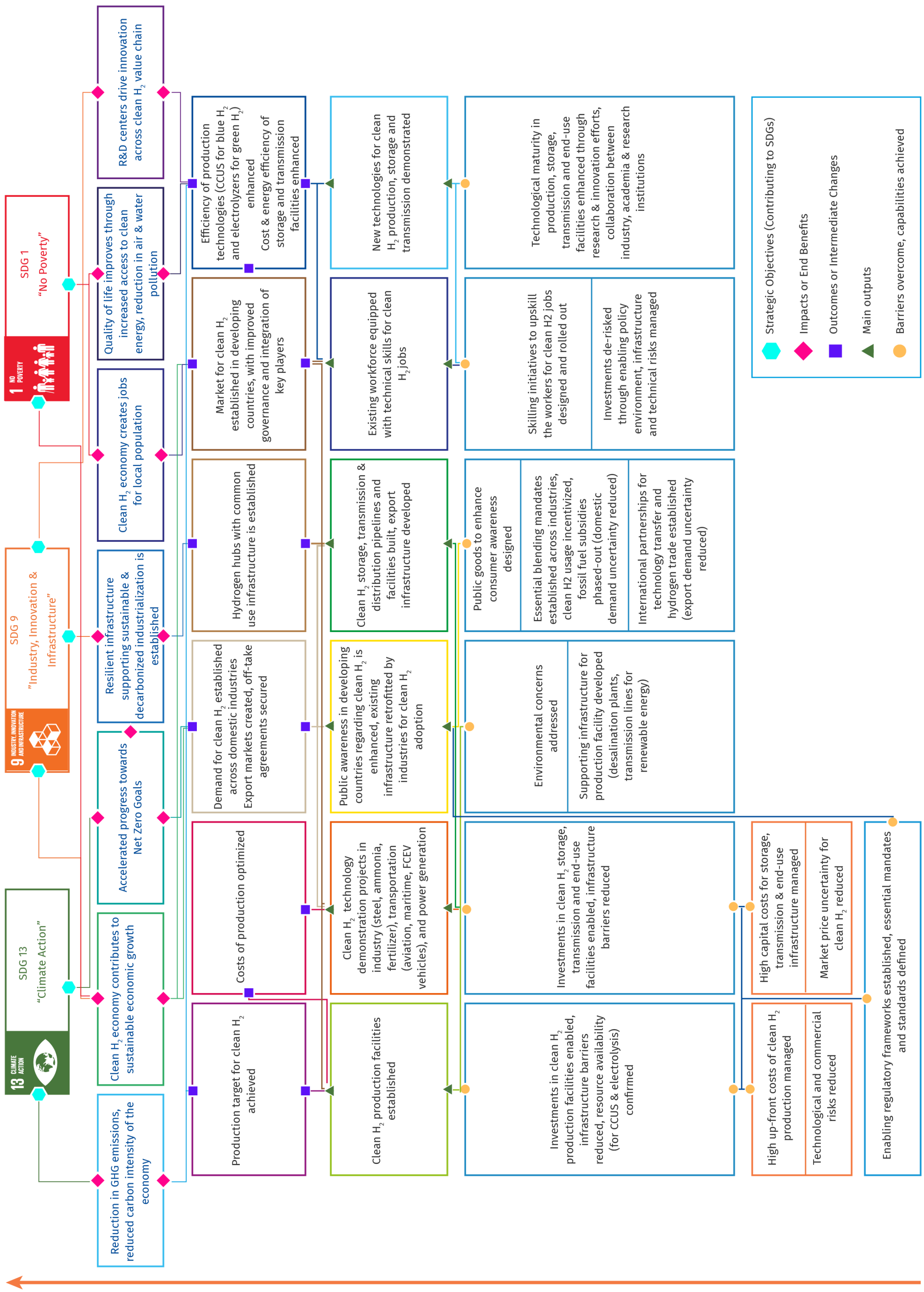
8.1. Theory of Change for Clean Hydrogen Technology in Developing Countries

The impact of a just transition model driven by the clean hydrogen technology in developing countries has been mapped through developing a *theory of change*. To comprehensively evaluate the impacts of development of clean hydrogen industry on progress towards each of the SDGs with strong linkage (SDGs 1,9 and 13), a framework was developed to map a theory of change for clean hydrogen industry in context of developing countries[22].

Further linkages across SDGs (2, 5, 6, 7 & 8) has been explored through qualitative assessments, evaluating the impact of the just transition model stimulated by clean hydrogen industry. Figure 8.2-1 presents the Theory of Change for clean hydrogen industry in the developing countries:

[22] The complete framework used for country-level assessment is presented in Annex 5

Figure 8-1: Theory of Change for Clean Hydrogen Value Chain in Developing Countries



The outlined theory of change is based on a comprehensive assessment of barriers faced by clean hydrogen industries in developing countries, in addition to the analysing government strategies, policy documents and hydrogen roadmaps designed to address these barriers. The identified outputs and outcomes are grounded in global and national projections regarding the impact of the growth of the clean hydrogen sector in these regions.

8.2. Impact on SDGs

Figure 8-1. and Figure 8-2. present findings from the in-depth assessment evaluating how the clean hydrogen ecosystem contributes to the progress towards sustainable development goals.

However, is should be noted that the realisation of these impacts is contingent on project developers adhering to international sustainability best practices to safeguard the interests and well-being of local communities directly impacted by these large-scale projects. While governments are designing hydrogen roadmaps to address critical barriers related to supply, consumption, and infrastructure, effective regulatory frameworks and policy interventions must be complemented by the roles of private sector and Development Finance Institutions, to ensure that projects align with national targets and goals for the SDGs (Green Hydrogen Organisation, 2023).

Direct Impact on Sustainable Development Goals

1 NO POVERTY

SDG 1 "No Poverty"

Development of clean hydrogen industry is anticipated to foster socio-economic progress by generating both high- and low-skilled job opportunities, reducing energy poverty, and driving economic resilience for marginalised and vulnerable communities, contributing to the objectives of SDG 1 (No Poverty). The development of clean hydrogen facilities is expected to create 830.7 full-time equivalent (FTE) jobs per 100 MW during construction and installation, alongside 47.7 FTE jobs per 100 MW for operation and maintenance (Navigant , 2019)). While the skilled positions are expected to be filled by engineers and technicians, administrative, transportation, and service roles will generate demand for local unskilled workers (Navigant , 2019). Government training initiatives are expected to enhance workforce capabilities, equipping them with skills for long-term employment prospects in the clean energy sector.

Moreover, the green transition led by clean hydrogen will reduce dependence on fossil fuels, reduce energy poverty by enhancing access to clean energy, and enhance the quality of life by minimising harmful emissions (Martins, 2024). This transition is expected to positively influence health outcomes and lower healthcare-related costs. Access to modern technologies and improved connectivity through infrastructure development will economically empower communities in the nearby rural and remote areas by boosting the productivity of small businesses, stimulating the growth of new local industries, and promoting agricultural productivity (Casati, et al., 2023). The influx of skilled technicians to the nearby areas will create more indirect jobs, further stimulating local economic growth.

The development of the green hydrogen value chain in Brazil, in the Port and Industrial Complex of Pecém, is expected to contribute significantly to the economic advancement of the state of Ceará, further supporting the poverty alleviation efforts of the government. According to official estimates, Ceará has the fourth lowest GDP per capita in the country, with a poverty rate of 44.2%. The state is also highly vulnerable to the effects of climate change. However, with its abundant renewable energy resources, Ceará has significant potential to create investments and spur economic growth through the development of the green hydrogen value chain in the state (World Bank, 2023). Countries such as India, Malaysia, South Africa, and Namibia have launched skilling initiatives to upskill their workforce for emerging green jobs, while also strategising to enhance rural electrification through the expansion of distribution infrastructure, the development of mini-grids, and the deployment of clean hydrogen fuel cells.

SDG 9 "Industry, Innovation and Infrastructure"

Given the nascent stage of the clean hydrogen industry in developing countries, innovation throughout the clean hydrogen value chain is expected to make a significant impact on progress towards SDG 9—focused on building resilient infrastructure, promoting inclusive and sustainable industrialisation, and fostering innovation. In light of the infrastructure and technical barriers faced by the developing countries, project developers, innovators and governments are devising strategies to establish production, storage, transmission, and end-use facilities for clean hydrogen and retrofitting the existing infrastructure for upgraded use. Along with research & innovation centres to enhance the technological maturity of the hydrogen value chain and an enabling policy environment, end-use applications of clean hydrogen are expected to increase across heavy industries, transportation, and power-generation sectors, paving the way for sustainable and decarbonised industrialisation (Green Hydrogen Organisation, 2023) and (Martins, 2024).

Countries such as India, Namibia, Turkey, Brazil, Malaysia, and Morocco are taking strategic strides in the clean hydrogen industry, establishing core infrastructure, fostering research and innovation, and defining clear decarbonisation roadmaps to drive sustainable industrialisation. In Namibia, three hydrogen hubs are planned to facilitate the development of green hydrogen infrastructure. Morocco is focusing on developing a green hydrogen export industry, with plans to establish maritime transport for synthetic liquid fuels, port infrastructure, and production and storage facilities. In Malaysia, a clean hydrogen supply chain is being developed in the Sarawak region through a joint development agreement between Samsung Corporation, Eneos Corporation, and SEDC Energy, targeting production of 90,000 tons of clean hydrogen per annum. In India, by 2030, the steel industry aims to reduce carbon emission intensity and produce 20 million tons of green steel, 20% blending mandates will be promoted by the government, 1000 trucks, 50 boats, and 10 aircraft will be deployed on clean fuel and production of green ammonia will substitute imports worth $6 billion, accelerating progress towards sustainable industrialisation.

Clean hydrogen plays a pivotal role in decarbonising developing economies, which are often heavily dependent on fossil fuels. Clean hydrogen and its derivatives are expected to drive decarbonisation in hard-to-abate industries, significantly reducing greenhouse gas emissions and the carbon intensity of developing economies. Decarbonisation mandates, coupled with the development of infrastructure for the transmission and end-use of clean hydrogen, drives domestic industrial demand, paving the way for sustainable industrialisation and a reduction in CO_2 emissions (Green Hydrogen Organisation, 2023), (Falcone, P. M., Hiete, M., & Sapio, A. , 2021) and (Martins, 2024).

Developing countries are increasingly recognising clean hydrogen as a crucial driver of their net zero goals and decarbonisation strategies. In Morocco, green hydrogen is expected to replace crude oil, grey ammonia, diesel, and LPG in industrial, transportation, and residential sectors, aiming to cut CO_2 equivalent emissions by 1 million tons by 2030, with an anticipated increase to 11 million tons by 2050. In Latin America, Colombia is targeting a 51% reduction in GHG emissions by 2050, while Costa Rica expects to decrease its GHG footprint by 6 to 13 million tons of CO_2 equivalent annually through the green hydrogen industry. Similarly, Kenya is aiming to lower its CO_2 emissions by at least 250,000 tons per year by 2050, contributing to a 32% reduction in the country's greenhouse gas emissions by the same year.

Indirect Linkages with Sustainable Development Goals

2 ZERO HUNGER — SDG 2 "Zero Hunger"

An important end-use application of clean hydrogen and its derivatives is in the fertiliser industry, where it produces green ammonia. This transition from grey to green ammonia reduces reliance on imported fertilisers and mitigates price volatility stemming from grey ammonia tied to natural gas. The transition decarbonises agriculture, stabilises fertiliser availability and costs, and strengthens food security (Green Hydrogen Organisation, 2023).

In Kenya, the hydrogen strategy has prioritised plans to integrate green ammonia into the fertiliser industry, aiming to improve crop yields and enhance the safety and sustainability of agricultural systems. This initiative also aims to reduce reliance on imported nitrogen fertilisers, encouraging an increase in domestic production to optimise costs, promoting food security.

5 GENDER EQUALITY — SDG 5 "Gender Equality"

Globally, women have limited access to critical resources such as land, credit, technology, decision-making structures, and training, which hampers their ability to adapt to climate change. The transition to clean energy can help address this disparity by reducing domestic burdens, such as fuel gathering tasks, and minimising health risks associated with exposure to fossil and biomass fuels. This will enable women to pursue more opportunities in productive work, education, and leisure (ADB, 2022). Additionally, increased access to skilling and training programs will enhance women's economic participation in the clean energy sector, contributing to closing the gender gap.

In South Africa, the hydrogen strategy has highlighted initiatives to accelerate gender equity through green hydrogen industry. These initiatives include mentorship and networking opportunities, increased investment in training and capacity-building programs for female professionals, and encouraging more women leaders through equal access to promotion, hiring, and leadership roles. Further, the hydrogen strategy has advocated for women-owned businesses to be hired as vendors along the hydrogen and fuel cell value chain.

6 CLEAN WATER AND SANITATION

SDG 6 “Clean Water and Sanitation”

Despite using water as the main input in the production process, the requirement of fresh water in the production process of green hydrogen is 33% less than what is required in fossil fuel energy-related usage (Beswick, Oliveira, & Yan, 2021). Given the lack of availability of freshwater resources in the majority of developing nations, establishing a production facility for clean hydrogen production requires setting up desalination plants. These desalination plants are expected to be designed with sufficient capacity to also produce fresh water for supply to state/private water utilities and ultimately local community members and other affected stakeholders (Green Hydrogen Organisation, 2023).

In Namibia and Morocco, two water-stressed regions, hydrogen projects are expected to set up desalination plants and water treatment plants, which will also supply water to the local communities near the production facilities (Green Hydrogen Organisation, 2023).

7 AFFORDABLE AND CLEAN ENERGY

SDG 7 “Affordable and Clean Energy”

Developing countries, despite being rich in renewable energy resources, often rely on energy imports to meet their demands. Establishing clean hydrogen facilities requires expanding the availability of renewable energy, transmission, and grid infrastructure to ensure a steady supply of clean energy. These renewable energy projects, supporting the clean hydrogen industry, are expected to reduce dependence on energy imports and increase access to clean and affordable energy for local communities in surrounding areas (Green Hydrogen Organisation, 2023).

Countries such as Kenya, Malaysia, Namibia, Brazil, Turkey, and Morocco have emphasised support for renewable energy projects in their hydrogen roadmaps. Namibia has established a Rural Electrification Fund to enhance energy access in rural and remote areas. In Malaysia, rural electrification will be advanced through the deployment of remote and off-grid hydrogen fuel cells. India is focused on powering 50% of its electricity grids with renewable sources and increasing its installed renewable energy capacity by 125 GW to support the green hydrogen industry.

SDG 8 “Decent Work and Economic Growth”

As the clean hydrogen industry emerges in developing countries, innovation and investment across the value chain will create diverse employment opportunities and significantly contribute to economic development. The industry's growth is expected to generate high-skilled jobs in areas such as renewable energy installation, manufacturing of components, and hydrogen production, as well as low-skilled jobs in sectors such as construction and logistics (Navigant , 2019) and (Sattva Consulting, Skill Council for Green Jobs, J.P. Morgan, 2023). Hydrogen roadmaps include skilling initiatives to prepare the workforce for these roles. Additionally, the development of a mature clean hydrogen market will stimulate new green industries such as green ammonia and green steel, further boosting GDP.

Namibia anticipates around 280,000 green jobs and a $4.1 billion GDP contribution by 2030, marking a 32% increase. Morocco's clean hydrogen sector is projected to achieve an annual turnover of $6 billion by 2030. Colombia estimates 7,000–15,000 jobs from the clean hydrogen ecosystem by 2030, while Brazil expects the industry to generate $15–$20 billion in revenues by 2040.

According to the Global Sustainable Development Report (United Nations, 2023), only 12% of SDGs are currently on track worldwide. The emerging clean hydrogen industry in developing countries presents a window of opportunity to accelerate progress toward these goals. Countries are initiating large-scale projects to develop infrastructure for clean hydrogen production and end-use facilities. These initiatives are expected to stimulate local economic growth and improve access to modern, clean energy technologies, particularly in rural and remote areas. Given that a significant portion of the poor and vulnerable population in developing countries resides in rural regions, establishing clean hydrogen facilities near these underserved areas can drive substantial local development, aiding to the poverty alleviation efforts.

The energy transition and industrial decarbonisation driven by clean hydrogen technology are expected to create new jobs. However, in the long term, certain sectors, particularly the fossil fuel industry, will experience job losses, such as those in coal mining or fossil fuel power plant operations (Navigant , 2019). As innovations progress and hydrogen technology matures, employment opportunities are expected to shift from R&D to jobs in the construction and operation of green hydrogen production plants and associated infrastructure (Navigant , 2019). It is projected that two-thirds of hydrogen-related jobs will be tied to renewable electricity, primarily temporary roles concentrated during the engineering and construction phases (Navigant , 2019).

While new opportunities will arise in non-technical services, transportation, operations, and maintenance—creating demand for low-skilled workers—current projections suggest a greater proportion of jobs will be high-skilled (Navigant , 2019). Without government intervention to provide displaced fossil fuel workers, marginalised populations, and host communities with access to skilling and training programs, the potential socio-economic benefits of this green industry may be limited, exacerbating disparities.

Other risks associated with land and water usage must be highlighted. A 1 GW electrolyser requires approximately 2 GW of solar photovoltaic (PV), which would equate to an estimated 26 km² of land (based on an assumption of 75 MW per km²) (UNIDO, IRENA & IDOS , 2023). The large land requirements for clean hydrogen projects have raised concerns among stakeholders about the potential for conflicts, particularly around the forced resettlement and displacement of local and indigenous communities (Müller, Tunn and Kalt , 2022). In regions such as Africa, where the climate is dry and brittle, there is an added risk of soil erosion and installation of large-scale projects could further degrade already vulnerable ecosystems. Additionally, the electrolysis process requires significant amounts of freshwater, posing a challenge in water-stressed countries such as Namibia and Morocco. Installing large facilities in these regions could intensify competition for limited water resources, heightening the risk of conflicts between water users. Furthermore, the construction of desalination plants, often necessary in such regions, brings its own environmental concerns, particularly regarding the disposal of brine. Without proper regulatory safeguards, brine discharge could harm marine ecosystems (Brot für die Welt and Heinrich-Böll-Stiftung , 2022).

Given the potential unintended consequences in the absence of policy interventions, it is essential to conduct thorough stakeholder consultations and establish strong regulatory frameworks to ensure that clean hydrogen projects contribute to the achievement of the SDGs rather than worsening inequalities for local communities. Public-private partnerships, funding mechanisms, and support initiatives that mandate local participation in these projects will help ensure that they are carefully planned, transparently executed, and operated in alignment with environmental and sustainability goals.

9

Conclusions

Successful hydrogen projects in developing countries will be those that balance innovation with local needs and conditions. Projects that secure off-takers for both domestic and export markets, such as ammonia production, and those that address local needs such as clean energy access challenges, will have the greatest impact.

9. CONCLUSIONS AND RECOMMENDATIONS

The present study has demonstrated that the implementation of catalytic conditions has the potential to enhance the capacity of developing countries to advance clean hydrogen projects. These conditions constitute the foundation of a robust and thriving innovation ecosystem. They encompass the following key elements: capacity building within the government; private sector leadership in project development; academia testing, adapting, and building knowledge and human capital; collaboration at national, regional, and international levels; and the integration of environmental and social sustainability as a core tenet of the industry. The following recommendations and key takeaways for ensuring successful projects are presented in the following paragraphs.

- Given the nascent nature of the clean hydrogen industry and its derivatives, investment in clean hydrogen projects in developing countries needs to focus on the adoption of commercial technologies to advance to the commercial stage. Adaptation and implementation of these technologies in different environments and their integration to renewable energy sources are crucial to lower the costs of clean hydrogen and its derivatives and build a sustainable industry.
- Project developers can foster investor confidence by addressing the value chain from production to end-use. This approach ensures that the techno-economic analysis accurately reflects the business case.
- Increase in the presence of off-takers will not only strengthen the commercial viability of clean hydrogen projects for investors but also stimulate local demand and drive wider adoption of clean hydrogen technologies across industries. This growth will facilitate sustainable industrialisation, contributing directly to SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action).
- It is crucial for public entities to be equipped with the necessary technical knowledge and legal and administrative tools to ensure long-term success in the clean hydrogen industry.
- Government incentives, enhanced access to public and private financing, and the presence of strong regulatory bodies will be critical in ensuring that projects are designed in alignment with the local needs, technologies are adapted as per the local context, and the projects are being implemented in conformity to the international best practices to drive progress in sustainable development.
- Optimising existing technologies rather than innovating from low TRLs, has an advantage in progressing to commercial stages more quickly, aligning with market demand in those premium countries.

- It is advisable that, during the design phase of a project, measures be put in place to mitigate the risk of potential issues arising. Some examples of such measures are:
  - Reduce costs related to infrastructure investment wherever possible.
  - To aim at premium markets and address their demand.
  - To evaluate and incorporate elements pertinent to the specific local conditions, such as environmental hazards and community participation.
  - Involve off-takers in the project's design.
  - Build local capacities at all levels, technicians, professionals, local government agencies and companies.

Commercial feasibility

- Projects should aim at local demand and premium markets.
- Commercial technologies are more reliable and can be depleted more quickly.
- Off-taker involvement is key.
- Ensure alignment with local capacities in selecting the project (e.g; manufacturing, mobility, ammonia) in terms of demand and local experience.

Relevant initiatives in place

- Clear regulations ans swift permitting process.
- International contribution shall address local needs.
- Delivery mechanisms addressing both the production of clean hydrogen as well as the demand side.
- Initiatives to the risk projects.
- Local capacity- building.

Clean hydrogen ecosystem

- Public and private collaboration in all stages of project development up to commercial stage.
- Academia and innovators working with the private sector to adapt and adopt technologies and ensure successful outcomes.
- Collaboration from existing or potencial off-takers.

Enabling infraestructure

- Current availability of renewable electricity.
- Port infraestructure in countries with potential to export clean hydrogen and/or derivates.
- Laboratory infraestructure and data on local conditions relevant to clean hydrogen projects.
- Repurposing, reusing, and sharing infraestructure.

Therefore, projects with a catalytic effect shall focus not only on the technological aspects of innovative clean hydrogen projects, but also on the other factors that may facilitate their transition to a commercial stage, ensuring their sustainability and value-add to the local economy. Countries that are well-positioned to lead clean hydrogen projects are presented in the following section.

10

Country Profiles

A detailed examination of these countries has revealed the need for the creation of hydrogen associations, national strategies, innovation programmes, active innovators, financial investment and flagship projects to drive the growth of this sector.

10.COUNTRY PROFILES

This section presents comprehensive insights into the top 16 developing countries poised to lead in the hydrogen value chain. These countries were selected based on their favourable ecosystems for fostering clean hydrogen innovation, making them pioneers in the developing world.

The methodology for selecting 20 potential countries for in-depth analysis can be described as follows:

1. **Initial Filtering Criteria**: The first step involved applying three entry criteria to identify countries showing active engagement in clean hydrogen development. These criteria were:
   - The presence of a national hydrogen strategy or roadmap.
   - The existence of a hydrogen association.
   - Evidence of innovative hydrogen projects in advanced stages of development.

Countries meeting at least one of these criteria were considered for further evaluation, resulting in 47 countries from Africa, Asia, Europe, Latin America, and the Caribbean.

2. **Quantitative Ranking**: A quantitative method was applied to rank these 47 countries based on four key evaluation criteria:

   - Innovators (10%): Number of innovators in the clean hydrogen field.
   - Stakeholders (15%): Presence of hydrogen associations and dedicated authorities.
   - Initiatives (35%): Existence of clean hydrogen national strategies, innovation programs, hydrogen hubs, and financial support.
   - Technology and Projects (40%): Presence of clean hydrogen pilot technologies, lighthouse projects, and project readiness.

Each criterion was subdivided into categories with specific weightings, and countries were scored on a scale from 1 to 5 for each subcategory.

3. **Country Ranking**: A preliminary ranking of countries was developed based on the evaluation criteria and corresponding weighted scores. From this analysis,

the top 20 countries were identified as candidates for potential deep dives. To ensure the reliability of the ranking and weighting system, a sensitivity analysis was also performed.

4. **Group Categorisation**: The 141 countries were categorised into four groups:

   1) Emerging Clean Hydrogen Pioneers: Countries scoring above 3.5.
   2) Active in Hydrogen Development: Countries scoring above 3 but not pioneers.
   3) Mild Hydrogen Activity: Remaining countries that met the preselection criteria.
   4) Low or No Hydrogen Activity: Countries not showing relevant clean hydrogen initiatives.

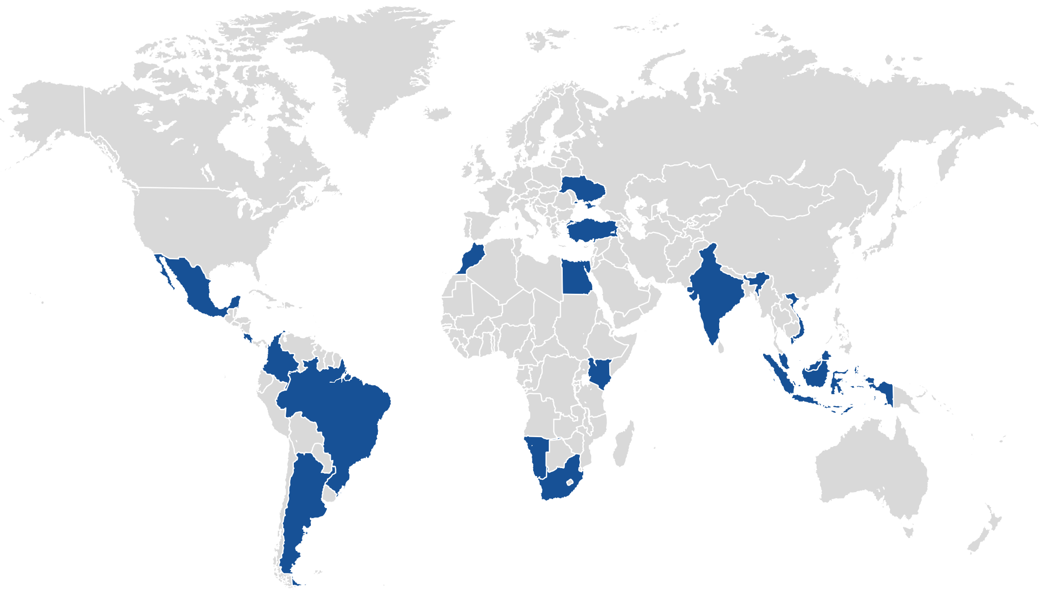
5. **Final Selection**: After considering regional balance and country readiness, 16 emerging clean hydrogen pioneers were selected for deep dives: India, Viet Nam, Indonesia, Malaysia, Colombia, Brazil, Costa Rica, Argentina, Mexico, South Africa, Morocco, Egypt, Namibia, Kenya, Türkiye, and Ukraine.

The profiles of the chosen deep dive countries are organised alphabetically by region. The list is presented in Table 10-1 and represented in Figure 10-1.

Table 10-1: Deep dive countries.

Region	Africa	Asia	Europe	LAC
Countries	Egypt	India	Türkiye	Argentina
	Kenya	Indonesia	Ukraine	Brazil
	Morocco	Malaysia		Colombia
	Namibia	Viet Nam		Costa Rica
	South Africa			Mexico

Figure 10-1. Deep dive countries map



The analysis includes insights into R&D activities and projects, initiatives, delivery mechanisms and an assessment of their alignment with the SDGs.

Before presenting the country profiles, the following table has been included to highlight the key trends identified throughout the report in Africa, Asia, and LAC[23]. This table provides a regional overview of these trends, their opportunities, limitations, and main areas of interest for the clean hydrogen market. These trends will be further reflected in the country profiles of each analysed country[24].

[23] The analysis of these three regions was carried out, considering that the 16 developing countries selected for the deep dives, using the previously outlined methodology, predominantly belong to these three regions.
[24] In the following country profiles, the category to which each country belongs is included (LMIC for *Lower Middle-Income Countries* and UMIC for *Upper Middle-Income Countries*), according to the DAC list of ODA recipients (OECD, 2023).

Table 10-2. Main trends identified by region.

	Africa	Asia	LAC
Key advantages	✓ Proximity to European markets. ✓ Significant domestic demand potential in the mobility sector. ✓ Off-grid fuel cell projects targeting communities with limited access to energy.	✓ Proximity to o-takers in Japan, Singapore, and South Korea. ✓ Domestic industrial demand for clean hydrogen applications. ✓ Clean hydrogen production projects in the late stages of planning.	✓ Export potential to European ✓ markets. ✓ 60% of the electricity generation mix is from renewable sources. ✓ High domestic demand in the fertiliser sector.
Barriers	• Non-industrialised countries, limited energy and technology access. • High dependence on fossil fuels. • Infrastructure deficits. • Political and economic instability.	• Varying levels of infrastructure and technology access through the region. • High dependence on fossil fuels.	• Lack of technical expertise. • Infrastructure limitations. • Potential resistance with local communities.
Financing	• Grants, loans, and debt from foreign entities as the EU, Government of Germany, KfW.	• Government allocations and investments by state-owned enterprises. • Private equity investments by domestic investors for clean hydrogen startups. • Support from ADB and WB.	• Multilateral banks providing financial support and technical assistance, as IDB and WB. • Regulatory support and incentives by Governments.
Regional Initiative	✓ AGHA ✓ AHP	✓ APAC	✓ LCHA ✓ H2LAC ✓ CertHiLAC
Segment Focus	• Clean hydrogen production • Mobility • Chemicals	• Clean hydrogen production • Mobility • Blending	• Clean hydrogen production • Mobility • Ammonia

Source: Hinicio (2024).

Country Profiles

Egypt

MENA - LMIC

The government has introduced incentives like tax rebates and exemptions to attract investment in green hydrogen projects, and partnerships with international stakeholders have resulted in over 20 MoUs for hydrogen development, with expected investments of $40 billion over the next decade.

Key Findings

- **Competitive Advantages:** National and regional regulatory support, EU incentives, advantageous strategic marine infrastructure (Suez Canal), long agreements for ammonia off-take from Fertiglobe, secured hydrogen-related investments until 2030 (American Chamber of Commerce in Egypt, 2022).
- **Electricity Mix**: 12.16% renewable (IEA, 2024).
- **Barriers:** Lack of late-stage projects, financial instability, need for concessional financing, and heavy reliance on the private sector.
- **Strategies:** Financial and fiscal incentives, cooperation with international partners and investors, and centralisation of infrastructure in hydrogen hubs.
- **Financing Mechanisms:** Egypt's Sovereign Fund to catalyse investments and provides financial support for clean hydrogen projects.

High potential clean hydrogen applications

Main National Initiatives

- Egypt Vision (published in 2016, planning horizon until 2030)
- National Strategy for Green Hydrogen (published 2023, planning horizon until 2030)
- National Climate Change Strategy (published 2022, planning horizon until 2050)

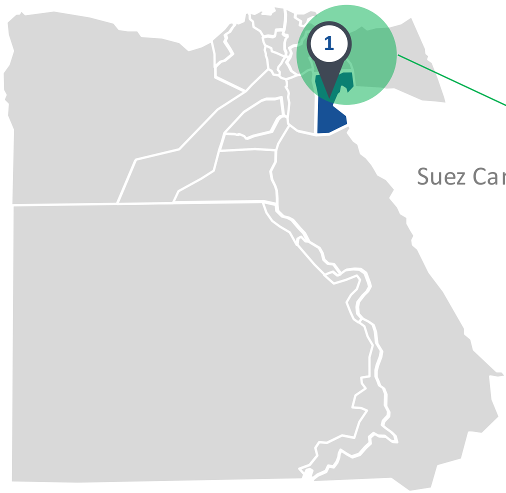
Main International Initiatives	• The Africa Green Hydrogen Alliance • Climate Club • H2Upp • Breakthrough Agenda

Competitive Advantages

Egypt is emerging as a promising hub for clean hydrogen development due to its abundant renewable energy resources, particularly solar and wind, and its strategic location at the Suez Canal. The National Strategy for Green Hydrogen, launched with support from the EBRD, outlines Egypt's ambitions to integrate clean hydrogen into sectors such as industry, transport, and petrochemicals (State Information Service Egypt, 2024). The government has introduced incentives such as tax rebates and exemptions to attract investment in green hydrogen projects, and partnerships with international stakeholders have resulted in over 20 MoUs for hydrogen development, with expected investments of $40 billion over the next decade (Reuters, 2024).

Despite Egypt's port infrastructure and expertise in petrochemicals supporting the clean hydrogen ecosystem, the country still faces challenges in scaling up projects and securing funding for smaller initiatives. However, collaborations, such as between Orascom and ITOCHU for decarbonised ammonia production and Fertiglobe's green ammonia off-take agreement in Germany, indicate progress. The government is also planning to establish an independent electricity transmission grid to facilitate renewable energy use for hydrogen production. With expected investments in clean hydrogen reaching $81.6 billion in the future, Egypt aims to position itself as a key player in the global clean hydrogen market (Green Hydrogen Organisation, 2024).

Main innovative clean hydrogen projects and hubs in Egypt



N°	Project Name	Location	Main Innovators
1	**Scatec ASA's Egypt Green Hydrogen project (*Transformation*)** (Scatec, 2022)	Ain Sokhna	Fertiglobe Scatec

Key Financial Investments

Key Financial Investments: Egypt	
Name of Financing Initiative	Scatec AS's Egypt Green Hydrogen Project
Type of Mechanism	Off-Take Agreement
Year	**2023**
Provision of Funds	-
Timeline	**20 years**

In addition to these efforts, Egypt signed nine framework agreements at COP 27 to develop low-carbon hydrogen projects, securing green hydrogen deals valued at $83 billion. The country also obtained an $80 million equity bridge loan from the European Bank for Reconstruction and Development. To further assist project developers, the government has introduced fiscal incentives, including tax reliefs and subsidies (The National, 2022).

Impacts on SDGs

The government has introduced the 'Golden License' regime, which allows for a single approval, issued by the Cabinet, to establish, operate, and manage green hydrogen projects. To qualify for these incentives, no more than 30% of the workforce may be non-Egyptian, and developers must secure 70% of the project's investment cost from foreign sources and initiate operations within five years of finalising agreements. Additionally, developers are required to prioritise the use of locally produced components when available and must ensure a minimum of 20% local content in their projects.

Moreover, the government is heavily investing in electricity infrastructure and the transmission network, with a goal to increase the share of renewable energy generation to 58% by 2040. These strategic initiatives are expected to accelerate the development of infrastructure for green industries, facilitate sustainable industrialisation, create green jobs, and enhance access to clean and affordable energy.

Kenya

Africa - LMIC

Kenya, with 84.9% of its installed capacity coming from renewable energy. As part of its broader $3.2 billion Global Gateway Fund for the climate and nature initiative, the EU has contributed $13 million. Locally, aims to produce clean hydrogen for local fertiliser demand, reducing reliance on costly imports and decarbonising sectors like aviation. However, substantial challenges, such as infrastructure development, energy access, and high production costs, must be addressed.

Key Findings

- **Competitive Advantages:** Predominantly renewable energy production (including biofuels and waste, wind, and solar) (IEA, 2022), Africa's 7th largest economy, Has East Africa's leading port (Mombasa).
- **Electricity Mix**: 84.9% renewable sources (Energy & Petroleum Regulatory Authority, 2023) (IEA, 2024)
- **Barriers:** Lack of local off takers, lack of deep experience in the hydrogen market, low public investment capacity, only 76.5% population with access to electricity (Our World in Data, 2021)
- **Strategies:** Guidelines for green hydrogen and ammonia, National Green Fiscal Incentives under development (EY Global, 2023).
- **Financing Mechanisms:** The EU and KFW Development Bank have provided grants and concessional financing to support the development of its clean hydrogen industry. As part of its broader $3.2 billion Global Gateway Fund for the climate and nature initiative, the EU has contributed $13 million to enhance the production of clean hydrogen and its derivatives in Kenya.

High potential clean hydrogen applications

Main National Initiatives

- Hydrogen Roadmap (published in 2023, planning horizon until 2032)
- Kenya Vision 2030

Main International Initiatives	• The Africa Green Hydrogen Alliance • European Union Global Technical Assistance Facility (GTAF) • Breakthrough Agenda • Climate Club • International PtX Hub

Competitive Advantages

Kenya's renewable energy landscape, with 84.9% of its installed capacity coming from renewables, positions the country favourably in the emerging clean hydrogen market. The recent launch of the Guidelines on Green Hydrogen and its derivatives, along with supportive policies such as VAT exemptions for renewable energy equipment and Corporate Tax relief, represent significant steps toward establishing a robust regulatory and policy framework (Röd&Partner, 2024). Kenya is focusing on decarbonising its floriculture industry, as it is the 5th largest exporter of flowers (WITS - World Bank, 2021) by targeting the fertiliser sector. The country's fertiliser market is valued at $451.2 million annually (Comtrade, 2024).

A Green Hydrogen Centre of Excellence is currently under development as a multi-functional innovation hub to support Kenya’s growing green hydrogen ecosystem (Endeva, 2023). Organisations such as GIZ, the EU delegation, PtX Hub, GWEC, FFI, Toyota contributed to the process and initiatives such as the $13 million grant from EU for clean hydrogen in the country further reinforce Kenya's potential (The East African, 2023).

Main innovative clean hydrogen projects and hubs in Kenya

N°	Project Name	Location	Main Innovators
1	**A5 Fuel Cell Solution (*End Use*)** (Gencell, 2018)	Across the country	GenCell Energy Adrian Kenya
2	**Sowitec E-MeOH (*Transformation*)** (NTPC, 2023)	Not reported	Sowitec

Delivery Mechanisms		
Delivery Mechanism	**Grants from European Union**	**Germany Hydrogen Finance**
Type of Mechanism	Incentives/ Rebates, Concessional finance	Concessional Finance

Year	**2022**	**2022**
Provision of Funds	**$13 million**	**$65 million**
Timeline	FY 2025-26 to FY 2029-30	2030

Impact of Clean Hydrogen Industry on SDGs

The hydrogen roadmap estimates the creation of at least 25,000 direct jobs between 2028-2032, including both professional and technical jobs. More indirect jobs on the demand will be generated to reduce unemployment and complement the poverty alleviation efforts of Kenya.	By 2030, over $1 billion in direct investments will be mobilisedd to support the development of clean hydrogen infrastructure and promote research and innovation. This will encourage the development of cost-effective and energy-efficient technologies and expand end-use applications across heavy industries, promoting sustainable industrialisation.	It is projected that Kenya will be able to reduce at least 250,000 tons of CO2 annually by 2030 through its transition to clean hydrogen, contributing to a 32% reduction in greenhouse gas emissions by 2030.

Morocco

MENA - LMIC

Morocco has top-ranking load factors to further renewable energy. Its proximity to Europe, offers routes to premium off-takers. Several clean hydrogen projects have been announced, supported by international stakeholders. Its strong fertiliser industry opens the possibility of securing clean hydrogen off-take. The Abu Dhabi National Energy Company announced plans to invest $27.2 billion in a green hydrogen project R&D advancement in the country, promoted by IRESEN and international entities.

Key Findings

- **Competitive Advantages:** High potential for solar (load factors above 90%) and wind energy, direct connection to premium off-takers in Europe, strong governmental support for R&D international cooperation, potential for large scale hydrogen storage in depleted salt caverns and a strong fertiliser industry.
- **Electricity Mix:** 17.5% renewable (IEA, 2024).
- **Barriers**: Seasonality of renewable energy, lack of local expertise, bankability and financing gaps for projects.
- **Strategies**: Foreign direct investment and R&D strategies.
- **Financing Mechanisms:** The Government has estimated that developing a clean hydrogen value chain will require an investment ranging between $38.12 billion to $272 billion.

High potential clean hydrogen applications

Main National Initiatives

- Green Hydrogen Roadmap: a vector for energy transition and sustainable growth (2021, planning horizon until 2050).
- National Sustainable Development Strategy 2030.

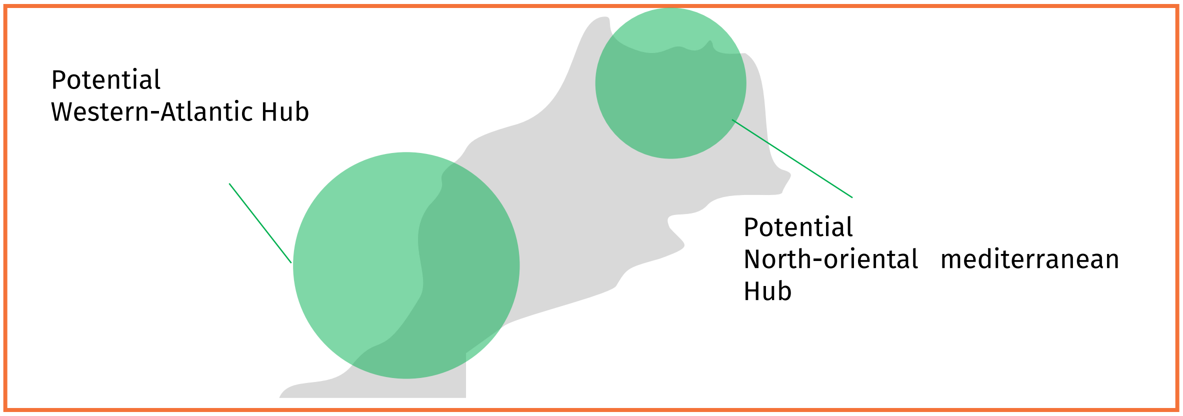
Main International Initiatives	• German Moroccan Energy Partnership (PAREMA), 2012-2024 • Mission Innovation • Climate Club • Breakthrough Agenda • International PtX Hub • Clean Energy Ministerial • H4D • The Africa Green Hydrogen Alliance • H2Upp

Competitive Advantages

Morocco is positioning itself as a leader in the green hydrogen sector through its Green Hydrogen Roadmap, launched in 2021. This strategy aims to promote economic growth and energy security by fostering a robust industrial sector focused on hydrogen, ammonia, and methanol production. Key partnerships, such as the PAREMA initiative with Germany, and institutions such as the Moroccan Agency for Sustainable Energy (MASEN) and IRESEN, are spearheading research and development efforts alongside technological advancements. Morocco's abundant solar and wind resources make it an ideal candidate for Power-to-X (PtX) technologies, with initial projects centred on synthetic ammonia production to support its fertiliser industry and reduce import dependency (Ammonia Energy Association, 2022).

Despite these advancements, Morocco faces challenges in scaling up hydrogen production and ensuring year-round supply due to issues such as seasonal energy intermittency and the need for storage solutions. The country's strategic location near Europe and Africa presents export opportunities, supported by large-scale projects such as the Nigeria-Morocco gas pipeline. Institutions such as IRESEN are also fostering innovation through partnerships and training programs, such as the Green Energy Park, which supports research and capacity building in renewable energies and hydrogen technologies (International PtX Hub, 2024).

Main innovative clean hydrogen projects and hubs in Morocco



N°	Project Name	Location	Main Innovators
1	**4 MW PEM Pilot Hydrogen and ammonia production in Morocco (*Transformation*)** (OCPGROUP, 2024)	Not reported	Fortescue Energy Fortescue Ltd OCP Group
2	**Morocco's First Hydrogen Vehicle (*End-use*)** (IEA, 2023)	Not reported	NamX
3	**Nigeria-Morocco Gas Pipeline (*Transport*)** (Arabian Gulf Business Insight, 2024)	Not reported	NNPC ONHYM

Delivery Mechanisms: Morocco	
Delivery Mechanism	Incentives under National Green Hydrogen Strategy
Type of Mechanism	Incentives, Investment Guarantees, Untied Financial Loan Guarantees, ECA
Year	**2022**
Provision of Funds	**$38.12 billion-$272 billion (Estimated)**
Timeline	NA

Private sector involvement in Morocco's green hydrogen sector is expected to expand significantly. Total Energies, for example, has committed $10 billion to establish facilities in the southern region of the Kingdom, including a 170,000-hectare site (Hydrogen Insight, 2024). In 2024, TAQA Morocco, primarily owned by the Abu Dhabi National Energy Company, announced plans to invest $27.2 billion in a green hydrogen project in the Dakhla-Oued El-Dahab region, as part of efforts to accelerate the country’s energy transition.

Morocco's green hydrogen projects are currently funded primarily through a project finance model. Additionally, the country is likely to benefit from financing opportunities offered by the European Commission and individual European nations, which are aiming to encourage hydrogen imports from North Africa (Invest in African Energy, 2024).

Impact of Clean Hydrogen Industry on SDGs

		
Estimates suggest that by 2030, the industry will generate 2,070 direct and 13,500 indirect green jobs, with these figures projected to rise to 12,000 direct and 60,000 indirect jobs by 2040. Skilling initiatives are being developed to upskill the existing and local workforce to meet the demands of these emerging green jobs.	SDG 9 will be advanced through the development of hydrogen hubs, refuelling stations, and a storage and transmission network to support the green transition. Furthermore, collaboration between industry and academia is expected to drive research and innovation, enhancing technological maturity in the sector.	The clean hydrogen ecosystem is projected to reduce CO_2 equivalent emissions by 1 million tons by 2030. Morocco plans to replace crude oil, grey ammonia, diesel, and LPG in its industrial, transportation, and residential sectors with clean hydrogen, aiming to advance its net-zero ambitions.

Namibia

Africa - UMIC

The country boasts 38.2% of renewable energy, sea access, port infrastructure and proximity to South Africa, which may serve as a potential off-taker. The SDG One Fund aims to raise $1 billion in concessional finance while over $43 million from the German Federal Research Ministry has been allocated. Yet, nearly half of the population has access to electricity, with limited grid infrastructure, and also faces water scarcity, and a limited trained workforce.

Key Findings

- **Competitive advantages**: With renewable electricity, particularly solar PV, accounting for 38.2% of total electricity capacity (IEA, 2024) the potential for growth in this sector is significant. Government support, proximity to key regional markets such as South Africa, and existing port infrastructure, including the Port of Walvis Bay—one of the largest ports on the continent—further bolster the country's capacity for expansion.
- **Electricity mix**: 38.2% renewable (IEA, 2024).
- **Barriers**: Challenges to development include the fact that only 55.2% of the population has access to electricity (Our World in Data, 2021), along with limited grid infrastructure, water scarcity, a small population, and a limited trained workforce. Additionally, more port infrastructure is required, and the country faces high rates of inequality and unemployment.
- **Strategies:** Strong government support and international cooperation mostly from the European Union.
- **Financing Mechanisms:** The SDG One Fund, a blended finance instrument, aims to raise $1 billion in concessional finance to support the clean hydrogen value chain. Additionally, over $43 million in grants and funding from the German Federal Research Ministry has been allocated to pilot projects.

High potential clean hydrogen applications

Mining | Heavy Industry | Mobility | Fertilisers

Main National Initiatives

- Namibia Green Hydrogen and Derivatives Strategy
- Namibia Green Hydrogen Research Institute

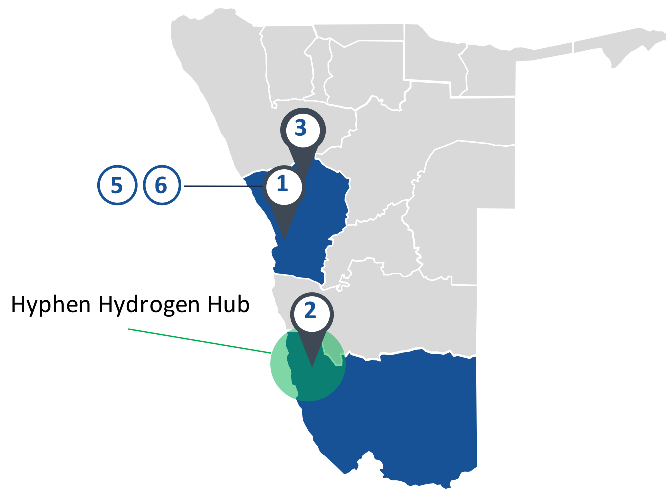
Main International Initiatives	• EU-Namibia Business Forum • Africa Green Hydrogen Alliance • Breakthrough Agenda • International PtX Hub • H4D • Global Clean Hydrogen Programme • H2Upp

Competitive Advantages

With 98.6% of its installed energy capacity coming from renewable sources, Namibia is well-positioned to become a key player in the clean hydrogen market. The country also benefits from significant port infrastructure, such as the Port of Walvis Bay, the 8th largest port in Africa, with a current capacity of 750,000 TEUs, and plans to expand to 1,050,000 TEUs annually (African Development Bank, 2020). Namibia has established important economic agreements, including an off-take deal with a Zimbabwean nitrogen fertiliser plant.

Additionally, the Namibia Green Hydrogen Research Institute will strengthen R&D efforts, further positioning the country as a competitive player in the global clean energy landscape (GH2 Namibia, 2022).The country aims to achieve a hydrogen production target of 10-12 million tons annually by 2050, fostering partnerships with foreign investors, such as a €500 million investment from the European Investment Bank and a recent $9.4 billion agreement with the Hyphen Hydrogen Energy project, which plans to produce 350,000 tonnes of clean hydrogen per year (CLG, 2022).

Main innovative clean hydrogen projects and hubs in Namibia



N°	Project Name	Location	Main Innovators
1	**Hydrogen-Pilot Plant (*End-use*)** (Ministry of Mines and Energy Namibia , 2022)	Erongo Region	Ohlthaver List CMB.Tech
2	**HYPHEN Tsau Khaeb (*Production*)** (Hyphen, 2024)	Tsau Khaeb National Park, Lüderitz	Hyphen
3	**Daures Green Hydrogen Village (*Transformation*)** (EnergyCapital&Power, 2024)	Daures, Erongo	Daures Green Hydrogen University of Namibia University of Stuttgart
4	**Project Oshivela (*End-use*)** (Hyiron, 2024)	Not reported	Hyiron
5	**HyRail Namibia (*End-use*)** (Railwaygazette, 2022)	Walvis Bay, Erongo	Hyphen Technical: Hyphen Hydrogen Energy Traxtion TransNamib University of Namibia

			CMB.Tech
6	**Namport pilot project (*End-use*)** (Namport, 2022)	Walvis Bay, Erongo	Namibian Ports Authority

Delivery Mechanisms		
Delivery Mechanism	**SDG One Fund Namibia**	**Grants and Funding from Germany**
Type of Mechanism	Blended Finance (Commercial/Concessionary Capital), Grants	Grants
Year	**2022**	**2022**
Provision of Funds	The SDG Namibia One Fund aims to mobilise $1 billion to support the development of clean H2 ecosystem in Namibia. 100 % of the initial funding was extended as grant of $43 million by Invest International. In March 2024, USAID extended a $1 million grant. Recently, the Namibian government secured 24% equity in the Hyphen Green Hydrogen Project and mobilised over $580 million from Invest International and the EIB. At COP27, the EIB and the Namibian government signed a $537 million letter of intent, part of which will be invested through the SDG Namibia One Fund.	In total, **~$43 million** was provided in funding by the German Federal Research Ministry. $10.75 million for scholarships and development of a national synthetic fuel strategy, and $32.25 million for 4 catalytic pilot projects.
Timeline	NA	NA

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
The development of Namibia's clean hydrogen industry is expected to create 280,000 jobs by 2030 and 600,000 by 2040, with 30% being direct jobs, 20% indirect, and 50% demand-driven low-skilled roles. The hydrogen roadmap aims to improve access to energy, particularly in rural areas, by installing new transmission lines which will enhance the national electrification rate (currently 45%), reduce energy poverty, and drive local economic development.	The Namibia Green Hydrogen Research Institute will promote research, development and innovation to enhance technological maturity. With the establishment of regulatory mandates for decarbonisation, industries will phase out fossil fuels by promoting the integration of green ammonia, methanol, hot briquetted iron and green steel.	Namibia aims to cut GHG emissions by 91% by 2030 by expanding renewable energy capacity, reducing reliance on energy imports, and lowering CO2 emissions. The adoption of green hydrogen in heavy industries, marine, and aviation sectors will further drive decarbonisation efforts and advance the net zero ambitions of Namibia.

South Africa

Africa - UMIC

Due to its robust petrochemicals industry, South Africa is experienced in the hydrogen market and is one of the region's largest hydrogen consumers. Its commitment to decarbonising the mining industry positions South Africa as a potential regional off-taker for clean hydrogen. The country is a member of several international initiatives focusing on clean hydrogen, and its supply of platinum-group metals benefits innovation in hydrogen technologies.

Key Findings

- **Competitive Advantages:** Technical expertise in petrochemicals, domestic platinum-group metal availability potential for electrolysers, potential local off-take industries, such as the mining sector, existing export infrastructure including the Port of Durban and the Port of Cape Town.
- **Electricity mix**: 10% renewable (IEA, 2024).
- **Barriers:** No domestic adoption mandates, 70% coal energy supply (IEA, 2022), high inequality, poverty and unemployment rates.
- **Strategies:** Local R&D, building on Synergy with existing industries.
- **Financing Mechanisms**: Concessional financing from KfW Development Bank and a $217 million loan to support clean hydrogen projects, particularly those in the pre-feasibility stage. KfW has also partnered with the South African Industrial Development Corporation (IDC), extending $25 million in concessional financing to launch a promotional program aimed at fostering the growth of the green hydrogen industry.

High potential clean hydrogen applications

Mobility | Heavy Industry | Mining | Refining & Petrochemicals

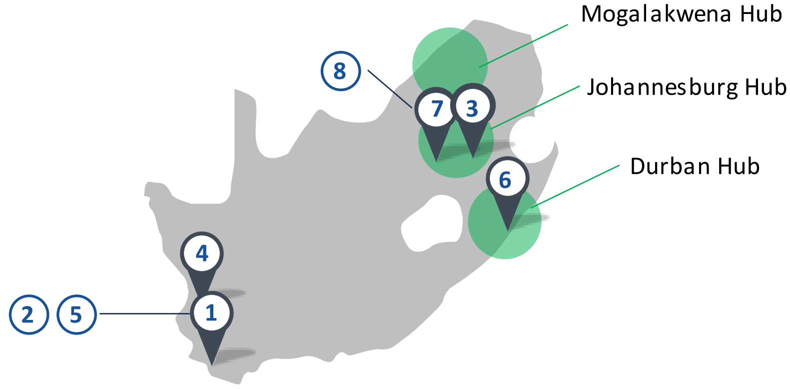
Main National Initiatives	• Hydrogen Society Roadmap for South Africa, published in 2021 • National Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy (2022) & HySA program (2008-2031)
Main International Initiatives	• Partnership with the EU • G20 • Africa Green Hydrogen Alliance • International PtX Hub • JETP • Clean Energy Ministerial • International Partnership for Hydrogen and Fuel Cells in the Economy • H4D • Global Clean Hydrogen Programme • H2Upp

Competitive Advantages

Despite a low renewable energy share of 8.8% as of 2022 (IEA, 2022), South Africa possesses significant competitive advantages for developing a clean hydrogen economy. Its extensive electric grid and well-established export infrastructure, including the two largest ports in Africa—the Port of Durban and the Port of Cape Town—facilitate large-scale projects (PWC, 2018). Additionally, the country's vast reserves of platinum group metals, accounting for 90.1% of global supply, are essential for electrolysis technology (African Export-Import Bank, 2024). South Africa also benefits from a skilled workforce, particularly from its established petrochemical industry, which can support clean hydrogen initiatives aimed at decarbonising domestic industries.

Strategic frameworks such as the Hydrogen Society Roadmap (Department of Science and Innovation, 2022) and the Green Hydrogen Commercialisation Strategy (The Department of Trade Industry and Competition, 2023) guide the country's clean hydrogen efforts. South Africa's clean hydrogen industry is further bolstered by international partnerships and funding, with ongoing innovative projects, including hydrogen hubs identified by companies such as Anglo American (AngloAmerican, 2022). Organisations such as GIZ, PtX Hub, and the World Bank have invested over $2 billion to support these initiatives (World Bank, 2023; CNBC Africa, 2023).

Main innovative clean hydrogen projects and hubs in South Africa



N°	Project Name	Location	Main Innovators
1	**1 kWe HT-PEMFC Combined Heat & Power System (*End-use*)** (HySA, 2017).	Cape Town	HySA South African SME University of Western Cape
2	**2.5 kW FC Generator (*End-use*)** (HySA, 2017)	Cape Town	HySA University of Western Cape
3	**HySHiFT SAF project (*Transformation*)** (Engineering news, 2024)	Secunda, Mpumalanga	HySHiFT Consortium Linde Sasol Enertrag HydRegenEnergy
4	**Clean H2 for Vehicles (*Production*)** (Green Hydrogen Organization, n. d.)	Vredendal, Western Cape	Sakhumnotho Power Keren Energy
5	**Fuel Cell-Battery Hybrid Powered Golf Cart (*End-use*)** (HySA, 2017)	Cape Town	HySA UWC
6	**South Africa's first fuel cell factory (*Production*)** (Engineering news, 2019)	Dube Trade Port, KwaZulu-Natal	CHEM Corporation
7	**Hydrogen refuelling station (*End-use*)** (Green Hydrogen Organization, n. d.)	Johannesburg	Shell Toyota

8	**BMW Hydrogen prototype (*End-Use*)** (BMW Group, 2024)	Johannesburg	BMW Sasol Anglo-American Platinum

Delivery Mechanisms

Delivery Mechanism	**KFW Loan**	**Partnership of KFW with South African Industrial Development Corporation (IDC)**
Type of Mechanism	Concessional finance	Concessional Finance
Year	**2023**	**2023**
Provision of Funds	**$217 million**	**$25 million**
Timeline	FY 2023-24 to FY 2027-28	NA

Impact of Clean Hydrogen Industry on SDGs

The hydrogen roadmap aims to expand off-grid and on-grid transmission infrastructure to improve the energy access in rural areas, reducing energy poverty. The improved access to energy is expected to boost local economic development, increase productivity of small businesses and local industries. By 2040, the industry is projected to create 30,000 jobs annually, contributing to reducing unemployment and improving the quality of life in the region.

Investments in the clean hydrogen ecosystem will drive infrastructure development and support the creation of industrial clusters and hubs. Regulatory frameworks to promote clean hydrogen adoption in the industrial sector is being established, boosting local demand and fostering sustainable industrialisation. Collaborative efforts between research institutions, industry, and academia will enhance technological advancements, contributing to progress toward SDG 9.

South Africa is promoting the substitution of fossil fuels with clean hydrogen in heavy industries, transportation, and aviation fuels leading to reduced GHG emissions and lower carbon intensity of the economy, advancing climate actions.

Asia

India

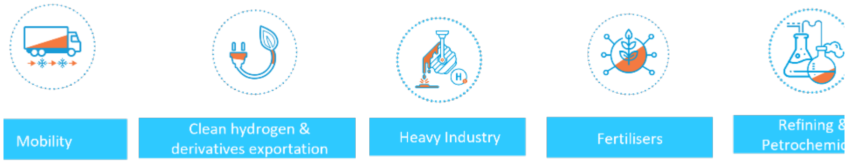
Asia - LMIC

By leveraging its 44.3% of installed renewable capacity, a strong innovation ecosystem, and engagement in international partnerships, India seeks to become a global leader in clean hydrogen production, utilisation and technology manufacturing. A budgetary allocation of $2.35 billion has been extended to the National Green Hydrogen Mission (NGHM), through FY 2029-2030. The European Investment Bank has also committed EUR €1 billion to support the NGHM.

Key Findings

- **Competitive Advantages**: Significant investment in renewable energy, with $68 billion spent in 2023 (IEA, 2024), along with strong national and regional regulatory support. The country's local demand for hydrogen is estimated at 5 MMT annually, with derivatives valued at over $6 billion (Ministry of New and Renewable Energy of India, 2023). Additionally, it boasts an extensive natural gas infrastructure, with a 24,000 km pipeline network, and rapid infrastructure development. International collaboration is also strong, including a free trade agreement with the EU in progress, alongside a robust clean hydrogen innovation ecosystem supported by R&D, demonstrative projects in hydrogen production, end-use applications, and hydrogen technology manufacturing.
- **Electricity Mix**: 44.3 % renewables (IEA, 2024).
- **Barriers:** Lack of infrastructure for conversion, storage, and transport, high production costs and substantial capital expenditure requirements, lack of constant renewable electricity, and high fossil fuels subsidies.
- **Strategies:** Fostering local technology innovation, demand aggregates, gap financing, and the creation of clean hydrogen hubs in regions near industrial facilities and maritime trading routes.
- **Financing Mechanisms:** The World Bank has provided a $3 billion loan aimed at supporting the development of clean hydrogen markets (World Bank, 2024). A budgetary allocation of $2.35 billion has been extended to National Green Hydrogen Mission (NGHM), through FY 2029-2030 (Ministry of New and Renewable Energy of India, 2023). The European Investment Bank has also committed EUR €1 billion to support the NGHM (EIB, 2023).

High potential clean hydrogen applications



Main National Initiatives	• National Green Hydrogen Mission (NGHM) • Strategic Interventions for Green Hydrogen (SIGHT) programme • Uttar Pradesh Green Hydrogen Policy (Invest Up, 2024) • e-FAST India (e-FAST India, s.f.)
Main International Initiatives	• Mission Innovation (est. 2015) • G20 • Breakthrough Agenda • SADC Centre for Renewable Energy and Energy Efficiency (SACREE) • International PtX Hub • Clean Energy Ministerial • H4D • H2Upp

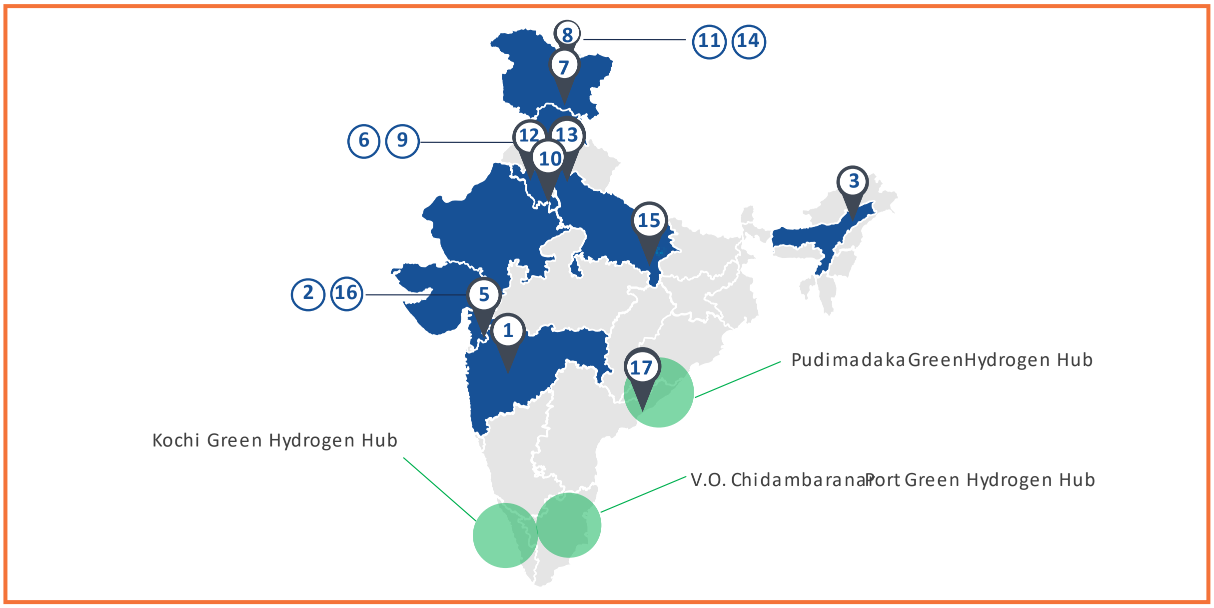
Competitive Advantages

India's competitive advantage in clean hydrogen innovation stems from its long history of innovation, strong financial backing, and a built-in ecosystem, along with its vast potential for renewable energy. The country plans to increase its renewable energy capacity by 150% by 2030, focusing on low-cost solar and wind power, which is expected to reduce the levelised cost of energy (LCOE) by 20% (IEA, 2024). This will enable cost-effective production of clean hydrogen. India is targeting the replacement of its current annual demand of 5 MMT of grey hydrogen in key industrial sectors, including petroleum refining, fertilisers, and steel, with clean hydrogen to ensure strong domestic demand (Ministry of New and Renewable Energy, 2023). The country already has over 20 projects in the clean hydrogen value chain, with an investment of $175 million in the pipeline (Ministry of New and Renewable Energy, 2023).

India's comprehensive strategy, supported by the $2.35 billion National Green Hydrogen Mission (2023-2024), substantial international funding, and strong R&D initiatives from institutions such as the IITs and Council of Scientific and Industrial

Research, positions the country as a global hub for hydrogen innovation, production, and export. Initiatives such as the development of hydrogen hubs and partnerships with global entities further bolster its potential to lead in the clean hydrogen sector.

Main innovative clean hydrogen projects and hubs in India



N°	Project Name	Location	Main Innovators
1	**H2 in gas distribution networks (*Transport*)** (Green Hydrogen Innovation Center, n. d.).	Ahmednagar & Aurangabad, Maharashtra	Bharat Petroleum Corporation Ltd.
2	**H2 blending project (*Transport*)** (NTPC, 2023)	Surat, Gujarat	NTPC Gujarat Gas
3	**Jorhat Pump Station H2 Pilot Plant (*Production*)** (Green Hydrogen Innovation Center, n. d.)	Jorhat, Assam	Oil India Limited
4	**Clean ammonia project (*Transformation*)** (EY, 2024)	Bikaner, Rajasthan	ACME
5	**H2 for Heavy Engineering (*Production*)** (GH2solar, 2023)	Hazira, Gujarat	Gujarat Larsen Toubro
6	**H2 production plant project (*Production*)** (GH2solar, 2023).	Gurugram, Haryana	IISC Bangalore

7	**H2 Fuel Cell-based Microgrid (*End-use*)** (EY, 2024)	Jhakri, Himachal Pradesh	SJVN
8	**H2 Hydrogen Fuel Cell-based Microgrid (*End-Use*)** (EY, 2024).	Alchi, Ladakh	NHPC Uneecops Technologies
9	**Pilot project for hydrogen-based advanced FCEV (*End-Use*)** (Tata AIG, 2023).	Haryana	Toyota Kirloskar Motors
10	**FC Buses Pilot (*End-Use*)** (ESMAP, 2020)	Faridabad, Haryana	IndianOil Tata Motors
11	**H2-based Mobility Station Project (*End-Use*)** (EY, 2024)	Kargil, Ladakh	Gensol
12	**Pilot Project for Conversion of Diesel Locomotives (*End-Use*)** (EY, 2024)	Jind, Haryana	Indian Railways GreenH
13	**Integrated Hydrogen Refuelling Station (*End-Use*)** (EY, 2024).	Greater Noida, Uttar Pradesh	NTPC Jackson
14	**Integrated Refuelling Station for Buses (*End-Use*)** (NTPC, 2023).	Leh, Ladakh	IndianOil NTPC
15	**India's First Hydrogen Fuel Cell Ferry (*End-Use*)** (Riviera, 2024).	Varanasi, Uttar Pradesh	CSL KPIT Technologies CSIR Labs
16	**CCU at IOCL's Koyali Refinery (*Production*)** (H2 Bulletin, 2022).	Gujarat	IndianOil Dastur Energy
17	**RFNBO-compliant green ammonia plant (*Transformation*)** (H2 View, 2024).	Kakinada, Andhra Pradesh	Greenko AM Green Ammonia

Delivery Mechanisms

	SIGHT Programme	Skilling under NGHM	R&D Scheme under NGHM	Incentives and subsidies by Uttar Pradesh	Loan from World Bank
Type of Mechanism	Incentives / Rebates	Incentives/ Rebates, Blended Finance	RD&D Funds, TA	Incentives/ Rebates	Sustainability and Transition Loan
Year	**2023**	**2024**	**2024**	**2024**	**2024**

Provision of Funds	**$2.1 billion**	**$4 million**	**$23 million**	**$604 million**	**$3 Billion**
Timeline	FY 2025-26 to FY 2029-30	Till 2028	Till FY 2025	NA	2023-2027

Impact of Clean Hydrogen Industry on SDGs

By 2030, the clean hydrogen industry in the country is projected to generate 0.6 million jobs, spanning both high- and low-skilled roles, reducing unemployment.

The government committed $175 million for pilot projects to develop infrastructure, and $48 million to boost R&D. By 2030, the steel industry aims to produce 20 Mt of green steel. Clean fuel will power 1,000 trucks, 50 boats, and 10 aircraft. Integration of green ammonia in the fertiliser industry will reduce imports by $6 billion.

Production target of 5 MMT of green hydrogen annually by 2030, will reduce CO_2 emissions by 50 MMT per year.

Indonesia

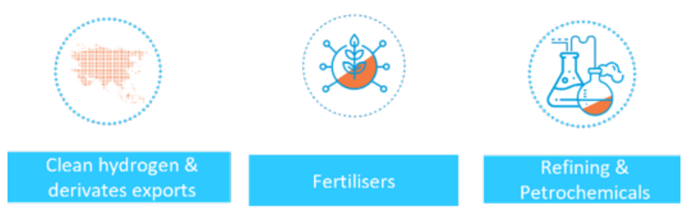
Asia - UMIC

Geothermal and hydropower potential, existing ammonia production plants, and the development of CCUS projects support the country's plans to accelerate clean hydrogen production. The country is expected to focus on exporting to Asian markets and domestic demand. State-owned Pertamina oil and gas company is investing $11 billion in renewable energy projects.

Key Findings

- **Competitive Advantages:** High potential for renewable electricity (wind, solar, geothermal), ammonia production infrastructure, significant CO2 storage capacity, marine export infrastructure, and potential for hydrogen-based micro grids on islands and in isolated areas.
- **Electricity Mix:** 18% renewable (IEA, 2024).
- **Barriers:** Energy transmission lines are difficult to build due to the country's geography. Sites with potential for renewable energy are located mostly in the East, while demand is in the West.
- **Strategies:** International cooperation and targeting Asian premium off-take markets (Japan, South Korea, Singapore).
- **Financing Mechanisms:** The Government of Indonesia has projected the need for up to $25.2 billion in private investments to accelerate the development of the clean hydrogen industry from 2031 to 2060. Pertamina oil & gas company is investing $11 billion to enhance renewable energy capacity and support the transition to a green economy.

High potential clean hydrogen applications



Main National Initiatives

- An Energy Sector Roadmap to Net Zero Emissions in Indonesia (published in 2021, planning horizon until 2060)
- National Hydrogen Strategy (published in 2023, planning horizon until 2060

Main International Initiatives	• Just Energy Transition Partnership • G20 • Climate Club • Breakthrough Agenda • SADC Centre for Renewable Energy and Energy Efficiency (SACREE) • Clean Energy Ministerial • APAC

Competitive Advantages

Indonesia's hydrogen strategy, outlined in the National Hydrogen Strategy, focuses on reducing fossil fuel reliance, developing a domestic hydrogen market, and exporting hydrogen and its derivatives. With significant renewable energy potential—primarily solar and hydropower—Indonesia aims to integrate hydrogen into its energy mix, initially targeting the transportation sector and expanding to industrial applications (Ministry of Energy and Mineral Resources, 2023). Collaborations with international companies, such as Japan's Mitsubishi and TEPCO, as well as the Garuda Hidrogen Hijau Project, highlight the country's growing role in the clean hydrogen economy. However, challenges include high production costs, infrastructure gaps, and energy transmission issues due to Indonesia's complex geography (Trade Economy, 2022).

To overcome these barriers, Indonesia is receiving support through international initiatives such as the $20 billion JETP and financing from institutions such as the World Bank and Asian Development Bank. The long-term goal is to shift from low carbon to clean hydrogen, with state-owned Pertamina playing a central role in scaling up clean energy capacity. Although research and innovation in hydrogen technologies are still nascent, further collaboration and investment are essential for Indonesia to become a key player in the global hydrogen market by 2060 (PLN, 2023).

Main innovative clean hydrogen projects and hubs in Indonesia

N°	Project Name	Location	Main Innovators
1	**Sumba (*Production*)** (HDF, 2024)	East Nusa Tenggara	HDF Energy
2	**GH2 pilot project from geothermal (*Production*)** (Green Hydrogen Innovation Center, n. d.)	Ulubelu	PERTAMINA

Key Financial Investments

Key Financial Investments: Indonesia			
Financial Mechanism	**Private Investments**	**Investments from Pertamina**	**Partnership of Global Green Growth Institute with Samsung and Hyundai**
Type of Mechanism	Project Finance	Concessional Finance	Concessional Finance
Year	**2021**	**2021**	**2021**
Provision of Funds	**$25.2 billion (Estimated)**	**$11 billion**	**$1.2 billion**
Timeline	NA	NA	NA

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
No clear estimates available	Progress toward SDG 9 will be propelled by enhanced R&D efforts to improve fuel cell and electrolyser efficiency, clean hydrogen production and storage technologies. This will be supported by infrastructure development through pilot projects. The application of clean hydrogen is expected to expand into power generation, transportation, industrial fuels, and residential and commercial sectors, promoting sustainable industrialisation.	Indonesia plans to reduce emissions by 29% by 2030 and achieve net-zero by 2060, targeting a reduction of 512 million tons of carbon emissions from 2021 to 2030. The government aims to decrease reliance on fossil fuels by enhancing renewable energy capacity, which will further lower emissions and reduce the economy's carbon intensity.

Malaysia

Asia - UMIC

Malaysia will leverage the country's hydropower resources, particularly in the Sarawak H2 Hub, natural gas reserves, proximity to Southeast Asia, and experience in the petrochemical industry to reach 100 MW of installed electrolyser capacity by 2025 and 500 MW by 2030. secured substantial investments: $425 million with China Hydropower; and $425 million financial package.

Key Findings

- **Competitive Advantages:** Malaysia benefits from abundant hydro resources in Sarawak, a well-established gas industry, local expertise, and strong partnerships with developed Asian countries. While the country is actively pursuing CCUS due to its oil and gas sector, it has yet to announce hydrogen or ammonia production initiatives tied to CCUS technology.
- **Electricity Mix**: 18.5% renewable (IEA, 2024).
- **Barriers:** Low renewable energy generation, uncompetitive clean hydrogen compared to fossil fuels, low local demand, no hydrogen-specific framework, and low technical maturity of clean hydrogen projects.
- **Strategies:** Investment in local technology research and innovation, investment in renewable energy infrastructure, reduction of fossil fuel subsidies, and targeting of premium off-take markets (Japan and South Korea).
- **Financing Mechanisms** In 2024, Semarak Renewable Energy Sdn Bhd successfully secured substantial investments through a $425 million agreement with China Hydropower, and an additional $425 million financial package through Singapore Capital Ventures and Chalfouh LLC.

High-potential clean hydrogen applications

Main National Initiatives

- Hydrogen Economy & Technology Roadmap (published in 2023, planning horizon until 2050)
- National Energy Transition Roadmap (published in 2023, planning horizon until 2050)

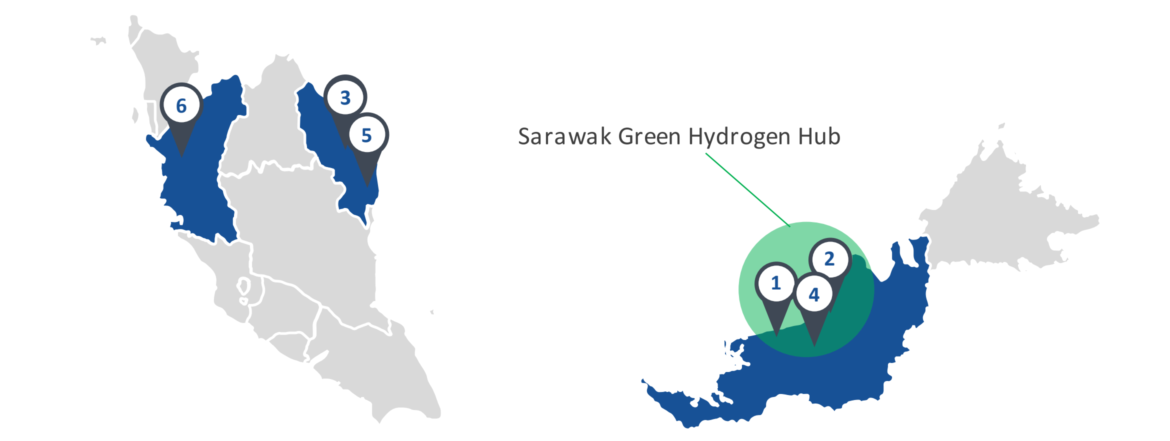
Main International Initiatives	• Economic Research Institute for ASEAN and East Asia • ASEAN Centre for Energy • UNIDO

Competitive Advantages

Malaysia launched its Hydrogen Economy and Technology Roadmap (HETR) in 2023 to guide the country towards a hydrogen-based economy, with targets for 100 MW of installed electrolyser capacity by 2025 and 500 MW by 2030. By 2030, Malaysia aims to produce 50,000 tons of clean hydrogen annually, primarily for export, with production costs expected to decrease from USD 5/kg in 2025 to USD 2/kg by 2030. The hydrogen sector is projected to contribute over USD 1.5 billion to Malaysia's GDP by 2030, improving energy security and export potential. A key component of this strategy is the Sarawak Hydrogen Hub, expected to begin operations by 2027, leveraging the region’s hydro capacity and strategic location to supply markets such as South Korea and Japan (Ministry of science, technology and innovation of Malaysia, 2023).

Despite promising advancements, challenges remain, particularly the high cost of hydrogen energy compared to subsidised fossil fuels. The government plans to phase out subsidies and potentially introduce a carbon tax to enhance competitiveness. Malaysia is also addressing regulatory gaps and production cost issues to attract investment. Key projects include Petronas' solar-powered electrolyser technology, the Sarawak Hydrogen Hub, and floating solar initiatives by the national electricity company, TNB. Additionally, mobile hydrogen refuelling stations and hydrogen kiosks for public transportation are under development, with expected operations by 2025 (Paultan, 2024). Collaborations with Japan and Korea will be crucial for technology transfer and market expansion.

Main innovative clean hydrogen projects and hubs in Malaysia



N°	Project Name	Location	Main Innovators
1	**Hydrogen Plant (*Production*)** (Norgesportalen, 2023)	Sarawak	SEDC Energy Sumitomo Corporation Eneos
2	**Samalaju Hydrogen Plant (*Transport*)** (Norgesportalen, 2023)	Samalaju Sarawak	SEDC Energy H2X Global Thales New Energy
3	**Mobile Hydrogen Refuelling Station (*End-use*)**	Terengganu	Nanomalaysia MOSTI Petronas Toyota
4	**H2Biscus (*Transformation*) (Offshore Energy, 2023)**	Sarawak	Samsung Engineering Lotte Chemical Korea National Oil Corporation SEDC Energy
5	**Repower Retired CCGT (*End-use*)** (Norgesportalen, 2023)	Paka Terengganu	TNB Petroliam Nasional Bhd
6	**Floating PV H2 project (*Production*)** (Hydrogen Insight, 2024)	Perak	Semarak Renewable EnergyPowerChina

Key Financial Investments

Key Financial Investments: Malaysia		
Financial Mechanism	**Investments through Singapore Capital Ventures**	**Investments from China Hydropower (PowerChina's Subsidiary)**
Type of Mechanism	Private Finance	Private Finance
Year	**2024**	**2024**
Provision of Funds	**$425 million**	**$425 million**
Timeline	FY 2024-25 to FY 2049-50	NA

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
The hydrogen roadmap includes plans to expand grid infrastructure and develop remote and off-grid hydrogen fuel cells to improve electricity access in rural areas, addressing energy poverty. Enhanced connectivity will stimulate local economic development, increase agricultural productivity, and strengthen the resilience of vulnerable communities. Additionally, reducing harmful emissions and providing access to modern energy systems will enhance overall quality of life, reducing health related costs.	Advancements in SDG 9 will be propelled by developing green infrastructure—such as transmission networks, refueling stations, and hydrogen hubs—and enhancing research and innovation to improve efficiency in the hydrogen ecosystem. This growth is expected to promote broader applications in the industrial and transportation sectors, significantly contributing to decarbonisation and fostering sustainable industrialisation.	Estimates indicate that the clean hydrogen ecosystem could reduce GHG emissions by 3-4% by 2030 and potentially by 15% in the long term. Expanding the capacity of renewable energy sources—such as solar, hydroelectric, biomass, and ocean thermal energy conversion (OTEC)—will further lower carbon intensity and decrease reliance on fossil fuels, supporting Malaysia's net-zero goals.

Vietnam

Asia - LMIC

Vietnam is targeting the clean hydrogen demand of Southeast Asian markets. The country recently adopted its Hydrogen Energy Strategy to enhance energy security and meet its national climate change goals, leveraging its renewable potential, as well as its land and water availability. A $2.4 billion clean hydrogen facility is being developed by a Chinese state-owned enterprise. Yet, it faces subsidised electricity prices.

Key Findings

- **Competitive Advantages:** High potential for renewable electricity, land & water availability, widely available biogenic CO2, significant foreign investments and project announcements indicate growing interest and potential.
- **Electricity Mix:** 49.1% renewable (IEA, 2024).
- **Barriers:** High investment costs, absence of subsidies, unclear regulatory environment, high electricity prices and variable renewable energy supply, and low local demand.
- **Strategies:** The development of a policy framework with financial and fiscal incentives, focus on international investment, and plans to adopt hydrogen technologies into electricity production, transportation, industrial processes, residential use.
- **Financing Mechanisms**: A $2.4 billion clean hydrogen facility is being developed by a Chinese state-owned enterprise, the Green Solutions Group has invested over $328 million in concessional financing, bonds, and projects.

High potential clean hydrogen applications

Clean hydrogen & derivates exports | Heavy Industry | Fertilisers | Refining & Petrochemicals

Main National Initiatives

- National Hydrogen Energy Development Strategy (published in 2024, planning horizon until 2050)

Main International Initiatives

- JETP
- International PtX Hub

Competitive Advantages

Vietnam adopted its Hydrogen Energy Strategy in 2024, focusing on producing clean hydrogen via electrolysis powered by renewable energy and from natural gas with carbon capture and storage (CCS) technologies. This approach aims to meet both domestic energy needs and export demands, integrating hydrogen into electricity production, transportation, industrial processes, and residential use. The strategy prioritises hydrogen co-firing in power plants, hydrogen-powered transportation, and replacing grey hydrogen with clean hydrogen in fertiliser production and petrochemical refining (Vietnam Briefing, 2024). Key initiatives include JETP, launched in 2022, to mobilise $15.8 billion for renewable energy and clean hydrogen development, alongside the Asian Development Bank's $2.1 billion dollar Resource Mobilisation Plan, which supports these efforts (Asian Development Bank, 2024).

Institutional barriers, including the lack of regulatory standards and safety procedures, are hindering development, while subsidised electricity prices make electrolysis less competitive. Additionally, improvements in transmission infrastructure are essential to prevent energy waste caused by line congestion. Vietnam is still in the early stages of hydrogen technology development, with foreign investments and pilot projects playing a crucial role in building capacity (S&P Global, 2024).

Main innovative clean hydrogen projects and hubs in Viet Nam

N°	Project Name	Location	Main Innovators
1	**Tra Vinh Green Hydrogen project (*Transformation*)** (S&P Global, 2024)	Tra Vinh	The Green Solutions Econnect Energy

2	**Thang Long Hydrogen Project (*Production*)** (World Economic Forum, 2023)	Ke Ga Cape	Enterprize Energy Viet Namese Institute of Energy
3	**Pilot hydrogen supply in Petrolimex petroleum stations for buses *(End-use)*** (S&P Global, 2024)	Not Reported	Petrolimex
4	**Transition Pha Lai 1 coal plant (*End-use*)** (S&P Global, 2024)	Chi Linh Town Hai Duong Province	Pha Lai Thermal Power JSC

Key Financial Investments

Key Financial Investments: Viet Nam

Financial Mechanism	Investments by Huadian Group	Investments by Green Solutions Group
Type of Mechanism	Concessional finance, Equity	Project Finance (Debt and Equity), Concessional Finance, Bonds
Year	2024	2021
Provision of Funds	$2.4 billion	$328 million
Timeline	FY 2023-24 to FY 2027-28	NA

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
The clean hydrogen economy is expected to create between 62,000 and 92,000 jobs per year. Local economic development will also drive the creation of demand-side indirect jobs, which are jobs generated in sectors that support or benefit from the increased demand for goods and services related to clean hydrogen. This growth will contribute to reducing unemployment.	Viet Nam's clean hydrogen strategy focuses on supporting pilot projects and enhancing R&D to develop the clean hydrogen ecosystem. It aims to promote the production of blue and green hydrogen through efficient infrastructure and technology, alongside mobilising investments and offering incentives. This technological advancement will facilitate the use of clean hydrogen in key industries such as steel, chemicals, cement, and oil refining, driving sustainable industrialisation.	Vietnam's clean hydrogen strategy aims to transition from fossil fuels to green hydrogen, significantly reducing CO2 and GHG emissions to achieve carbon neutrality and net-zero goals by 2050. The government is also promoting modern scientific technologies to support a circular and low-carbon economy.

Europe

Türkiye

Europe/Asia - UMIC

Türkiye has leveraged its strategic geographical position next to Europe, a 41.7% of renewable energy mix, and local expertise to become a clean energy export hub. The South Marmara Hydrogen Shore (HYSouthMarmara), a clean hydrogen hub proposed by the Turkish government, secured $40 million in concessional finance.

Key Findings

- **Competitive Advantages:** High potential for solar, wind, geothermal and biowaste energy, national and regional regulatory support, EU incentives, strong R&D environment with publicly funded research institutes and universities, and proximity to major EU consumer economies.
- **Electricity Mix:** 41.7% renewable (IEA, 2024).
- **Barriers:** Difficulty in securing financial support for scaling up projects, lack of action plan, no current incentives in tax reduction, and a need for development of standards and regulatory frameworks for the hydrogen economy.
- **Strategies:** Local R&D and targeting of premium export markets, especially from the EU.
- **Financing Mechanisms:** The South Marmara Hydrogen Shore project has secured $40 million in concessional finance from the European Union to enhance the production of clean hydrogen and its derivatives.

High-potential clean hydrogen applications

Main National Initiatives

- Türkiye Hydrogen Technologies Strategy and Roadmap
- EU Horizon Hydrogen Valley

Main International Initiatives

- Climate Club
- G20
- Breakthrough Agenda

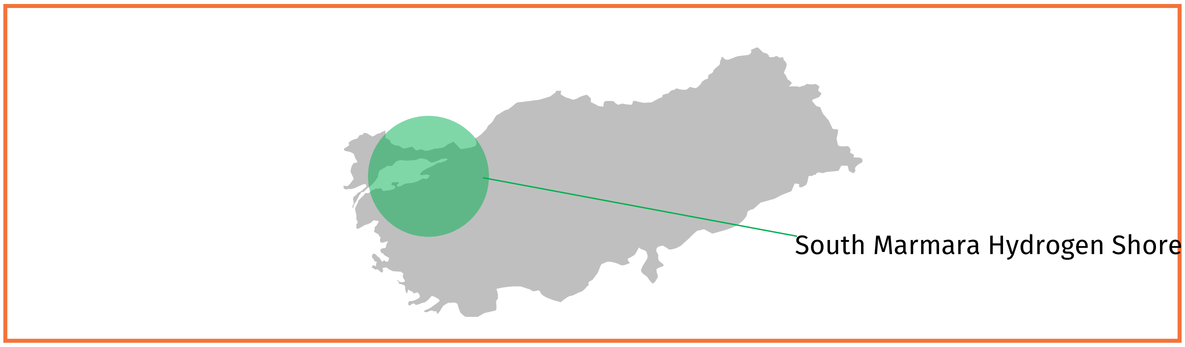
- H2Upp

Competitive Advantages

Türkiye is positioning itself as a key player in the global hydrogen economy, leveraging its strategic location, extensive natural gas pipeline network, and renewable energy potential. The country aims to develop local technologies, such as electrolysers and fuel cells, and promote the use of clean hydrogen in energy-intensive sectors such as steel, chemicals, and transportation. Türkiye's National Hydrogen Strategy and Roadmap, published in January 2023, sets ambitious targets for electrolyser capacity and public-private collaboration, aiming for hydrogen demand to exceed 1–1.5 million tonnes by 2030 and 2–2.5 million tonnes by 2050 (Ministry of Energy and Natural Resources of Türkiye, 2023).

Although, an Action Plan is still needed, and financial support remains a barrier to scaling up projects. Current hydrogen production in Türkiye primarily comes from natural gas through SMR, but there is increasing interest in producing hydrogen from renewable sources via electrolysis. Pilot projects, including those by companies such as TÜPRAŞ and GAZBİR-GAZMER, are underway to develop clean hydrogen applications, reflecting growing investment momentum in the sector. Türkiye's hydrogen market is expected to evolve with new business models and leading players emerging across the value chain, supported by funding from the EU and bilateral agreements with Asian countries (PwC, 2022).

Main innovative clean hydrogen projects and hubs in Türkiye



N°	Project Name	Location	Main Innovators
1	**Hydrogen Fuel Cell Vehicle Project (*End-Use*)** (Green Hydrogen Innovation Center, n. d.)	Not Reported	Karsan BMW

2	**Hydrogen Fuel Cell Train Project (*End-Use*)** (Green Hydrogen Innovation Center, n. d.)	Not Reported	TÜVASAŞ Alstom
3	**Hydrogen Fuel Cell Bus Project (*End-Use*)** (Green Hydrogen Innovation Center, n. d.)	Not Reported	Bozankaya ZF Friedrichshafen
4	**Hydrogen Mobility Project (*End-Use*)** (Green Hydrogen Innovation Center, n. d.)	Not Reported	İGDAŞ Air Liquide
5	**Hydrogen Storage and Transportation Project (*Transportation*)** (Green Hydrogen Innovation Center, n. d.)	Not Reported	Borusan EnBW Enerji Siemens Energy

Delivery Mechanisms: Türkiye

Delivery Mechanism	**EU Investments to South Marmara Hydrogen Shore Project**
Type of Mechanism	Concessional Finance
Year	**2022**
Provision of Funds	**$40 million**
Timeline	2023-2028

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
No clear estimates available	Türkiye's hydrogen strategy outlines comprehensive plans for green infrastructure development and financial support to accelerate R&D. The creation of hydrogen hubs and innovation centres will contribute to advancing SDG 9, while regulatory frameworks aimed at promoting clean hydrogen adoption across industries will strengthen decarbonisation efforts and support sustainable industrialisation.	The clean hydrogen industry in Türkiye is expected to reduce GHG emissions by 21% by 2030, driving decarbonisation in the industrial sector and lowering the economy's overall carbon intensity. The government aims to expand renewable energy capacity through green hydrogen, reducing dependence on energy imports and contributing to climate action by cutting emissions.

Ukraine

Europe - UMIC

Ukraine has significant potential for clean hydrogen production due to its renewable energy resources, water availability, and logistical access. Additionally, Ukraine's proximity to European industrial centres positions it well for exporting clean energy and securing hydrogen off-take. Despite Russia's invasion, Ukraine is receiving support from various stakeholders to develop its hydrogen market.

Key Findings

- **Competitive Advantages:** High potential for solar and wind energy, availability of land, water and biogenic CO2, strategic location for EU exports, and local expertise in gas industry.
- **Electricity Mix:** 15.7% renewable (IEA, 2024).
- **Barriers:** Geopolitical instability and ongoing conflict with Russia, limited investment platforms, and difficulties coordinating between localities.
- **Strategies:** International cooperation, centralisation of projects, investment in clean hydrogen infrastructure (pipelines) for distributing to EU markets.
- **Financing Mechanisms:** Grant through the InnovateUkraine, funded by UK International Development, to spearhead the H2U Renewable Hydrogen Project in the Odesa Region.

High potential clean hydrogen applications

Main National Initiatives

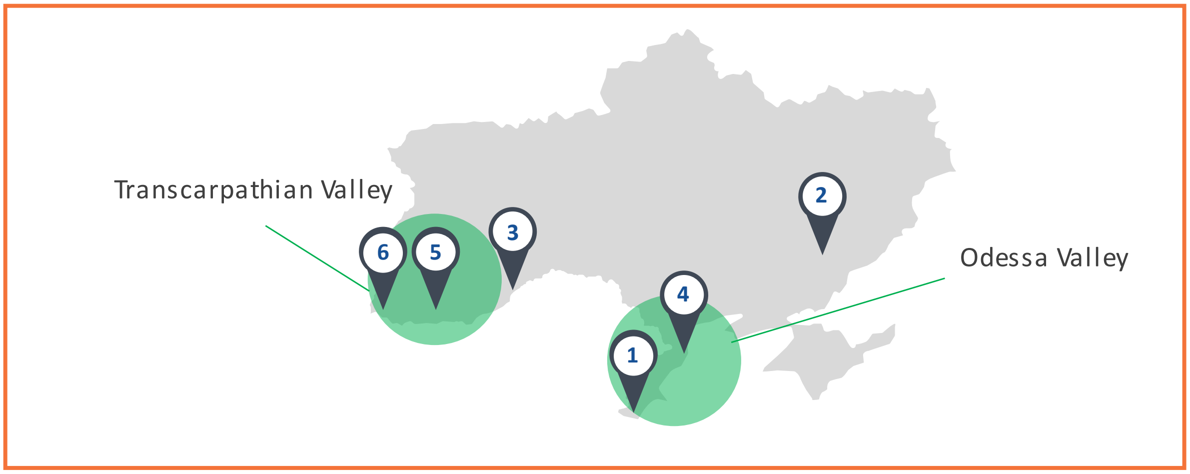
- Hydrogen Strategy for Ukraine
- Energy Strategy of Ukraine 2035 RG
- Central European Hydrogen Corridor: Planned hydrogen pipeline of 1225 km length, connecting Ukraine, Slovakia, Czechia and Germany, targeted implementation by 2030

Main International Initiatives	• Climate Club • H4D • Central European Hydrogen Corridor • Innovate Ukraine by the United Kingdom

Competitive Advantages

Ukraine's Draft Roadmap for Hydrogen Production and Use, published in 2021, envisions the country becoming a major exporter of clean hydrogen to the EU, leveraging its strategic geographical location. Key projects include the East Central European Hydrogen Corridor and collaborations with international partners such as Oxford University and Canada on green ammonia and building materials (University of Oxford, 2024). Naftogaz is constructing a hydrogen pipeline to the EU, and regions such as the Transcarpathian and Odessa Valleys are being explored for hydrogen production.
Despite the ongoing war, Ukraine's renewable energy potential remains significant, with an estimated 44.96 million tonnes of renewable hydrogen production capacity annually. Projects such as the H2U Hydrogen Valley in Zakarpattia and the Black Sea Hydrogen Valley are working to harness wind, solar, and hydroelectric resources for hydrogen production and export. The DniproHES hydroelectric power plant continues pilot hydrogen production despite damage from the conflict.

Main innovative clean hydrogen projects and hubs in Ukraine



N°	Project Name	Location	Main Innovators
1	**Danube Hydrogen Valley (*Production*)** (Ministry of Energy of Ukraine, n. d.)	Odessa region	Danube Hydrogen Valley
2	**5 MW Pilot Project (*Transport*)** (Ministry of Energy of Ukraine, n. d.)	Zaporiyia and Dnipropetrovsk regions	DTEK LLC – Public Private Partnership with German and Ukrainian industrial stakeholders
3	**Clean hydrogen production from Hydropower (*Production*)** (Ministry of Energy of Ukraine, n. d.)	Vinnytsia and Chernivtsi regions	PJSC “Nizhnodnistrovska HPP”
4	**Odessa Valley (*Transportation*)** (Hydrogen Ukraine, 2024)	Odessa	H2U
5	**Transcarpathian Valley** (Hydrogen Ukraine, 2024)	Transcarpathian (Zakarpattia) region	H2U
6	**Renewable hydrogen production plant in Trans Carpathian region (*Production*)** (Ministry of Energy of Ukraine, n. d.)	Vynohradiv District, Trans Carpathian region	LLC “SPE GEOTHERMIKA”

Delivery Mechanisms: Ukraine

Delivery Mechanism	**H2U Hydrogen Valley**
Type of Mechanism	Concessional Finance, Project Finance
Year	**-**
Provision of Funds	**NA**
Timeline	2021-22 to 2049-2050

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
No clear estimates available	In Ukraine, the development of new green industries and infrastructure for clean hydrogen production, storage and transmission, including hydrogen valleys and corridors will advance progress towards SDG 9.	The country is pushing towards wider adoption of clean hydrogen across heavy industries, transportation to reduce GHG emissions in the economy, along with promoting sustainable industrialisation. By 2035, Ukraine is targeting to source 50% of its power from renewable energy sources and 50% from nuclear sources. Clean hydrogen economy is expected to facilitate this energy transition, enhancing the access to clean energy across the country.

LAC

Argentina
LAC - UMIC

Argentina will capitalise on its abundant renewable wind potential, vast land area, sea access, port infrastructure, and expertise in natural gas. The country has launched a national hydrogen strategy, initiated environmental assessments for hydrogen projects, and introduced a low-carbon hydrogen bill in Congress. IDB's $350 million loan supports emission reduction strategies with a 20-year term, although there it faces macroeconomic instability.

Key Findings

- **Competitive Advantages**: Patagonia offers high potential for renewable electricity, complemented by Argentina's strong innovation in hydrogen production and technology manufacturing. The country also benefits from vast land resources, sea access, port infrastructure, and extensive experience in the natural gas sector.
- **Electricity Mix:** 33.5% renewable (IEA, 2024).
- **Barriers:** Economic and political instability, price and off-take uncertainty, lack of country-level regulation, and lack of current local electrolysers availability.
- **Strategies:** International investment, targeting of premium export markets, public coordination platforms, and investment in local R&D.
- **Financing Mechanisms:** IDB's $350 million loan supports emission reduction strategies with a 20-year term and a 5.5-year grace period.

High potential clean hydrogen applications

Main National Initiatives

- National Strategy for the Development of the Hydrogen Economy (published 2023, planning horizon until 2050)
- National Plan for Sustainable Transport (published 2022)

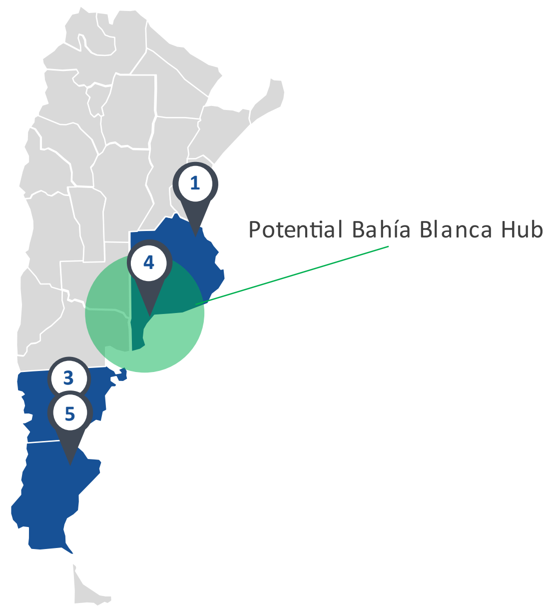
Main International Initiatives	• National Plan for Science, Technology and Innovation (published 2023, planning horizon until 2030) • Climate Club • G20 • PtX International Hub • Clean Energy Ministerial • CertHiLAC • LAC Clean Hydrogen Action • H2Upp

Competitive Advantages

The National Strategy for the Development of the Hydrogen Economy, launched in 2023, aims to integrate hydrogen into the country's energy mix, focusing on sustainable transport and innovation. The strategy, supported by international partners such as the International PtX Hub, builds on Argentina's hydrogen research efforts and regulatory frameworks established since 2006. However, challenges such as off-take uncertainties, pricing, and the need for hydrogen-specific regulations hinder rapid market entry (PLATAFORMA H2 ARGENTINA, 2024).

Key initiatives such as the H2 Argentinian Platform and collaborations with international organisations such as CertHiLAC are helping drive the sector forward. Y-TEC, the R&D arm of YPF, is leading advancements in clean hydrogen, supported by partnerships with the Government Agency for the Promotion of Science and Technology CONICET (Y-TEC, 2024). Argentina's goal is to produce over 1 million tons of clean hydrogen annually by 2030, with a focus on reducing production costs and boosting export potential. The government aims to create 50,000 jobs and generate USD 15 billion in exports by 2050, making clean hydrogen a cornerstone of its green economy (European Commission, 2023).

Main innovative clean hydrogen projects and hubs in Argentina



N°	Project Name	Location	Main Innovators
1	**Alkaline electrolyser prototype (*Production*)** (Secretaria de Asuntos Estratégicos Argentina, 2023)	Buenos Aires	Y-TEC
2	**Renewable Falcon, Phase I (*Transformation*)** (ESMAP, 2024)	Not reported	Not reported
3	**HyChico (*Production*)** (Hychico, 2024)	Comodoro Rivadavia	Hychico
4	**ENARSA Bahía Blanca (*Production*)** (Energía Estratégica, 2023)	Bahía Blanca	ENARSA
5	**Pico Truncado experimental plant (*Production*)** (Secretaria de Asuntos Estratégicos Argentina, 2023)	Pico Truncado	ENARSA Santa Cruz Municipalidad de Pico Truncado

Key Financial Investments and Partnerships

Key Financial Investments and Partnerships: Argentina				
Financial Mechanism/ Partnerships	The Pampas Project	IDB Loan for Sustainable and Resilient Growth	H2AR Consortium	MoU between Argentina and European Union
Type of Mechanism	Project Finance	Loan	Industrial Partnership	Bilateral Partnership
Year	-	2023	2020	2023
Provision of Funds	$8.4 billion (Estimated)	$350 million	NA	NA
Timeline	NA	20-year repayment term (2023-2053), 1-year disbursement period and 5.5-year grace period	NA	NA

SDG Assessments

Impact on SDGs

Argentina's hydrogen roadmap emphasises the establishment of large-scale production hubs and integrated infrastructure to enhance connectivity between these hubs, universities, and local technological centres. This initiative, which includes the development of road corridors and ports, aims to advance SDG 9 in the country. Additionally, Argentina's emerging hydrogen industry is expected to boost economic growth, creating 82,000 qualified jobs by 2050. The country aims to supply 5% of the global hydrogen market by 2050, fostering a vibrant export market that will further drive economic expansion.

Brazil

LAC - UMIC

Having recently launched its National Hydrogen Program, several projects have been announced, mostly in the north of Brazil. With an 89.1% or renewable, a significant port infrastructure with access to Europe, extensive oil and gas expertise, and ample land resources. Brazil is also focusing on the creation of educational centres, ensuring a skilled workforce. The Port of Rotterdam has invested over $80 million, and the World Bank has provided $90 million.

Key Findings

- **Competitive advantages**: High potential for renewable electricity, supported by regulatory incentives, technical standards, and certification. Strong prospects for transforming industrial hubs into hydrogen hubs, with robust export infrastructure, local expertise, and an R&D mandate requiring 1% of total revenue from electricity companies for research.
- **Electricity Mix:** 89.1% of renewable energy (IEA, 2024).
- **Barriers:** Uncertainty in off-take agreements, project suspensions, and high risk in project financing.
- **Strategies:** Financial incentives, mandatory R&D, and production aggregation in hydrogen hubs.
- **Financing Mechanisms:** Private investment is driving hydrogen export facilities at the Pecém Complex in Ceará and Port do Açu in Rio de Janeiro. The Port of Rotterdam has invested over $80 million, while the World Bank has provided $90 million to develop the green hydrogen value chain through shared infrastructure at the Port and Industrial Complex of Pecém.

High potential clean hydrogen applications


Clean hydrogen & derivates exports


Fertilisers


Refining & Petrochemicals

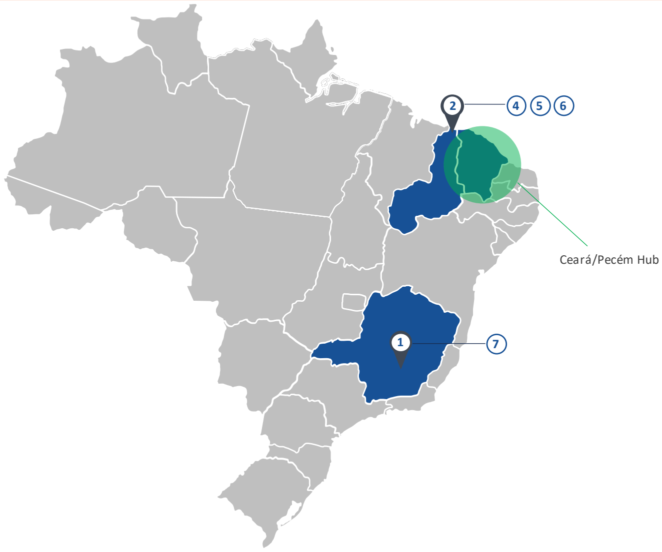
Main National Initiatives	• National Hydrogen Program (PNH2), published in 2021, includes a three-stage plan up to 2035 • Law 14,948 of 2024, recently approved legal framework with special incentives regime “Rehydro” • Brazilian National Energy Plan 2050 • Certification scheme by the Chamber of Electricity
Main International Initiatives	• Mission Innovation • G20 • International PtX Hub • Clean Energy Ministerial • H4D • Clean Energy Marine Hubs • International Partnership for Hydrogen and Fuel Cells in the Economy • H2Upp

Competitive Advantages

Brazil's clean hydrogen sector is expanding rapidly, driven by its vast renewable energy potential and strategic port infrastructure. The National Hydrogen Program (PNH2) and the Brazilian National Energy Plan 2050 outline a roadmap for developing the hydrogen market, with major projects such as the Port of Pecém aiming to position Brazil as a key exporter to the European Union. The regulatory framework has advanced with laws promoting hydrogen development and a certification system. However, financial challenges persist, particularly in securing off-take agreements and funding for large-scale projects (Mattos Filho, 2024).

Brazil’s renewable energy potential, including solar, wind, and hydropower, makes it attractive for hydrogen production, with recent developments in R&D supported by international partnerships. Initiatives such as the iH2 Brasil Green Hydrogen Innovation Program and major projects such as the Uberaba Green Fertilizer Project aim to reduce reliance on imported fertilisers by harnessing green hydrogen (Green Hydrogen Platform - German Brazilian Alliance, 2022). These efforts are part of Brazil's strategy to decarbonise its industrial and agricultural sectors while leveraging its natural resources for domestic use and export.

Main innovative clean hydrogen projects and hubs in Brazil



N°	Project Name	Location	Main Innovators
1	**Uberaba Green Fertiliser (*Transformation*)** (H2 Business news, 2024)	Uberaba, Minas Gerais	Promigas
2	**Solatio project (*Production*)** (PV magazine, 2024)	Paranaiba, Piauí	Solatio
3	**Project Iracema (*Transformation*)** (Ammonia Energy Association, 2024)	Port of Pecém, Ceará	Casa dos Ventos
4	**AES Brazil Project (*Transformation*)** (Solar quarter, 2024)	Port of Pecém, Ceará	AES Brazil
5	**Pecém Green Hydrogen Hub (*Production*)** (H2 Business news, 2024)	Port of Pecém, Ceará	Fortescue
6	**Base one (*Production*)** (IRENA, 2022).	Ceará	Enegix
7	**GH2 Cars production and distribution (*End-use*) (Green Car Congress, 2019)**	Minas Gerais	Grove Hydrogen Automotive Co. Ltd.

Key Financial Investments and Partnerships

Key Financial Investments and Partnerships: Brazil				
Financial Mechanism/ Partnerships	Private Investments and International Partnerships	Global Gateway Flagship Project on Hydrogen	Partnership between Germany and Brazil	Financial Assistance by the World Bank
Type of Mechanism	Traditional Loans/Equity/Concessional Finance	Concessional Finance	Bilateral Agreement	Project Financing
Year	2018 onwards	2023	2023	2024
Provision of Funds	Port of Rotterdam has invested over $81.4 million in Pecém Complex. the Port do Açu expects $196 million investments for thermal power plants and pipelines. Further, Shell Brazil plans to invest $60-$120 million in R&D at Port do Açu. Through International Partnerships, Brazil aims to mobilise investments worth $39 million from Germany, $15 billion from Australia, $11 billion from France, and $10 billion from the Netherlands and Portugal.	$2.16 billion (Commitment)	$3.84 million	$90 million
Timeline	NA	NA	NA	NA

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
The development of the green hydrogen value chain in the Pecém Port and Industrial Complex is expected to boost local economic growth in state of Ceará, which has the fourth lowest income per capita and a poverty rate of 44.2%. This initiative will support Brazil's economic development and poverty alleviation efforts.	Investments in research centres and pilot projects for green infrastructure will promote innovation in the clean hydrogen value chain, expanding its end-use applications and developing solutions for energy storage. This will foster sustainable industrialisation and support progress toward SDG 9.	By 2040, wind and solar are expected to become the dominant sources of electricity, contributing 47% to total installed capacity and resulting in reduced emissions and lower carbon intensity. With 87.6% of the power sector already utilising renewables, the green hydrogen industry will further support the country's Net Zero goals by 2050.

Colombia

LAC - UMIC

Clean hydrogen production has strong government support, investments from state-owned and private companies, local off-takers, and experience in the oil and gas industry. However, communities from La Guajira have expressed opposition to clean hydrogen projects. The country needs to strengthen transmission infrastructure and invest in port facilities. The Ecopetrol Group has committed $2.5 billion hydrogen production project by 2040.

Key Findings

- **Competitive Advantages:** High potential for renewable electricity in La Guajira Region, Law 2099 tax benefits, existing grey hydrogen demand and experience, maritime export infrastructure, widely available biogenic CO2, and a developing innovation ecosystem.
- **Electricity Mix**: 68.2% renewable (IEA, 2024).
- **Barriers:** Off-take uncertainty, lack of local bank support, lack of standards, and challenging environmental and social permitting.
- **Strategies:** Fiscal and financial incentives and building local technology and expertise.
- **Financing Mechanisms:** $2.5 billion commitment by the Ecopetrol Group to develop a green hydrogen production project in Colombia by 2040.

High potential clean hydrogen applications

- Clean hydrogen & derivates exports
- Mobility
- Fertilisers
- Refining & Petrochemicals

Main National Initiatives

- National Hydrogen Roadmap (2021)
- Law 2099 (2021): Green and blue H2 and CCUS qualify for tax benefits.
- FENOGE can finance H2 projects.

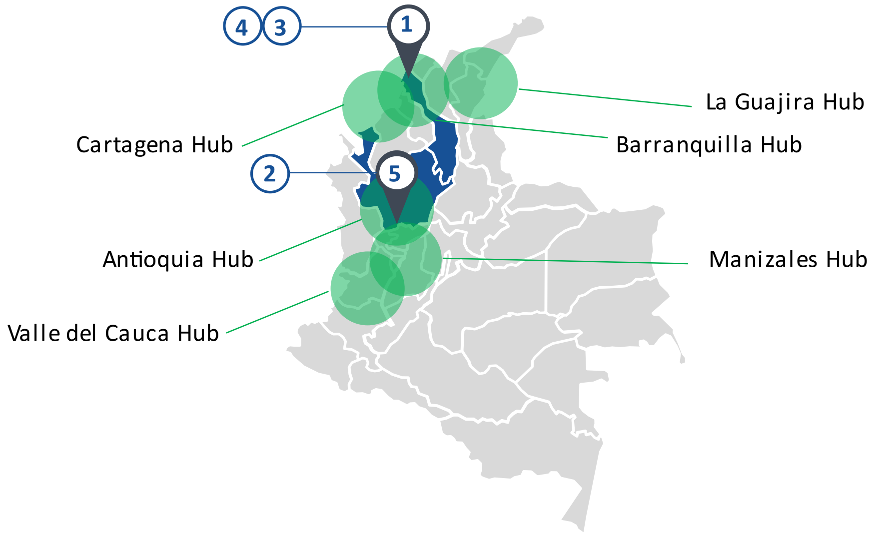
Main International Initiatives	• Climate Club • LAC Clean Hydrogen Action • CertHiLAC • International PtX Hub • H4D • H2Upp

Competitive Advantages

Colombia has launched a 30-year Hydrogen Roadmap to guide its energy transition and economic growth through clean hydrogen development. The roadmap is divided into four key areas: production, demand, exports, regulation, and socialisation (FENOGE, 2024). It leverages the country's renewable energy potential, particularly in the La Guajira region, and its geographic location with access to both the Atlantic and Pacific Oceans, which positions Colombia as an export hub for clean hydrogen within the LAC region. Law 2099 of 2021 provides a regulatory framework that promotes non-conventional energy sources such as green and blue hydrogen by offering tax benefits and incentives to attract investment. The Government's +H2 COLOMBIA programme further supports hydrogen knowledge dissemination, the identification of key projects, and the creation of innovative investment and financing mechanisms (FENOGE, 2024).

Despite these advancements, Colombian project developers face significant barriers, particularly around financing for studies and engineering due to uncertainties with off-take agreements. Local banks have also been slow to support hydrogen projects (FENOGE, 2024). The roadmap aims to scale electrolyser capacity from 77 kW to 1-3 GW by 2030 and reduce hydrogen production costs by 2050 (FENOGE, 2024). Industrial sectors such as refining, fertilisers, and chemicals are expected to be the early adopters of clean hydrogen, with transport expected to account for 64% of domestic demand by 2050 (MEC-H2, 2022). Key companies such as Promigas, Ecopetrol, and Opex (Hevolucion) are leading hydrogen production and mobility efforts, while universities such as Universidad de Antioquia, Universidad de la Guajira, and Universidad de la Sabana develop capacity building and technological innovation (MEC-H2, 2022).

Main innovative clean hydrogen projects and hubs in Colombia



N°	Project Name	Location	Main Innovators
1	**GH2 Pilot plant for gas pipeline mixed with NG in Pilot Phase (*Transport*) (El Colombiano, 2023)**	Cartagena	Promigas
2	**Hevolucion's ammonia project (*Transformation*)** (Opex, 2022)	Not reported	Hevolución (Opex)
3	**Refinery project (*Production*)** (Ecopetrol, 2022)	Cartagena/Barranca	Ecopetrol
4	**Mobile laboratory prototype of hydrogen and natural gas mixing** (Ecopetrol, 2022)	Cartagena	Ecopetrol
5	**Hevolucion's mobility project (*End-use*)** (Opex, 2022)	Medellin	Hevolución (Opex)

Key Financial Investments and Partnerships

Key Financial Investments: Colombia					
Financial Mechanism	Investments by Ecopetrol	World Bank Loan for Climate Action	+H2 Initiative (FENOGE Fund)	World Bank Loan	Partnership with Germany
Type of Mechanism	Project Finance	Concessionary Loan	Public loans, Grants, TA	Concessionary Loan	Bilateral Agreement
Year	2022	2022	2022	2024	2023
Provision of Funds	$2.5 billion	$1 billion	$1 million (Initial Endowment)	$750 million	$222.3 million
Timeline	Till 2040	NA	NA	NA	NA

In addition to the investments and partnerships mentioned earlier, Colombia has entered several key agreements to advance its clean hydrogen industry. At COP 27, the Ministry of Mines and Energy and the European Investment Bank signed a Declaration of Intent to support Colombia's just energy transition, with a focus on green hydrogen and other green technologies.

Pash Global, an impact investor, and ERIH Holdings, a global renewable investment company, have formed a joint venture to develop green hydrogen and ammonia projects with a combined electrolyser capacity of 5 GW by 2030, covering Colombia, Italy, Spain, Türkiye, Greece, and Serbia. Additionally, the Japan Bank for International Cooperation and Empresas Públicas de Medellín (EPM), a public utility company, signed an MoU to promote cooperation in hydrogen and its derivatives, such as ammonia.

Further, an MoU was signed between the Colombian government and Fraunhofer-Gesellschaft, aiming to lead joint research on expanding Colombia's hydrogen sector, focusing on clean hydrogen, green ammonia, methanol, and green fertilisers.

Impact of Clean Hydrogen Industry on SDGs

1 NO POVERTY	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	13 CLIMATE ACTION
The clean hydrogen ecosystem is expected to create 7,000 to 15,000 direct and indirect jobs between 2020 and 2030. Skilling initiatives will provide the workforce with essential skills for this emerging industry, ensuring local communities can participate and benefit from new economic opportunities.	Between 2020 and 2030, $2.5 to $5.5 billion will be mobilised for clean hydrogen projects, focusing on infrastructure development and R&D. A regulatory framework will be established to mandate the adoption of clean hydrogen in heavy industries. The green hydrogen strategy aims for 40% low-carbon hydrogen usage in the industrial sector to accelerate sustainable development.	Colombia aims to reduce GHG emissions by 51% by 2030 to mitigate CO2 emissions. The introduction of low-carbon hydrogen is projected to cut over 13 million tons of CO2 by 2050, with emissions reductions primarily driven by the adoption of renewable energy in the industrial sector.

Costa Rica

LAC - UMIC

Costa Rica's progress in clean hydrogen for mobility, targeting the premium tourism market, has positioned the country as a leader in hydrogen development and innovation in Central America. Costa Rica's progress in clean hydrogen for mobility, targeting the premium tourism market, has positioned the country as a pioneering country in Central America. The Mitigation Action Facility Donors have contributed $27.14 million in concessionary finance, while the IDB is providing technical assistance to the government.

Key Findings

- **Competitive Advantages**: Decarbonised electricity mix, high renewable energy potential, national and regional regulatory support with financial incentives and technical standards, local expertise and innovators, and a strong start-up ecosystem, especially in sustainable mobility.
- **Electricity mix**: 95% renewable (IEA, 2024).
- **Barriers:** Financing barriers, lack of investor confidence, high dependence on initiatives as NAMA, and need for clear investment guidelines.
- **Strategies:** Targeting premium applications in green products and services, use of NAMA facility for pilot projects, and international collaborations.
- **Financing Mechanisms:** IDB provided technical assistance to help the government develop its green hydrogen strategy and identify existing gaps. Additionally, the Mitigation Action Facility Donors have contributed $27.14 million in concessionary finance to support clean hydrogen.

High potential clean hydrogen applications

- Clean hydrogen & derivates exports
- Mobility
- Fertilisers

Main National Initiatives

- National Green Hydrogen Strategy Costa Rica (published 2022, up to 2050)
- National Decarbonisation Plan (published in 2018, up to 2050)

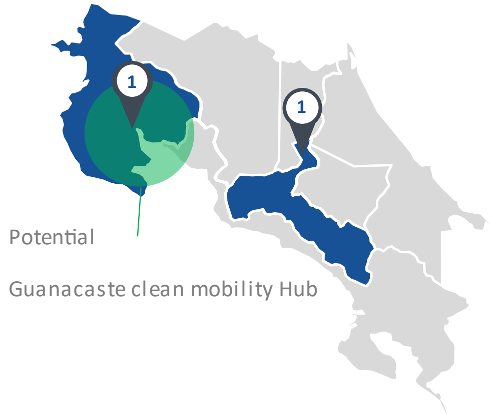
Main International Initiatives	• Interinstitutional Action Plan to promote the use of hydrogen in the transport sector (published in 2018 by the Hydrogen Commission) • National Energy Plan (published in 2015, up to 2030) • Alliance for Hydrogen of Costa Rica • NAMA Facility • Climate Club • Clean Energy Ministerial • H4D • LAC Clean Hydrogen Action

Competitive Advantages

Costa Rica stands out for its renewable energy matrix, with over 99% of electricity generated from renewable sources, creating a strong foundation for clean hydrogen projects, particularly in the mobility sector. The country's National Green Hydrogen Strategy (2022), aligned with the National Decarbonisation Plan, sets a comprehensive framework for hydrogen production, utilisation, and export until 2050. Other key initiatives include the Hydrogen Commission's Interinstitutional Action Plan to integrate hydrogen into the transport sector and Decree № 44318-MINAE, which declares green hydrogen investment as a public interest. Costa Rica also collaborates internationally, with partnerships such as the Alliance for Hydrogen of Costa Rica and its participation in platforms such as the Climate Club and LAC Clean Hydrogen Action.

Costa Rica's renewable energy potential, estimated to exceed 230 TWh/year by 2040 (PtX Hub, 2021), offers significant opportunities for clean hydrogen production. The country has implemented delivery mechanisms such as the $3.1 million Non-Sovereign Guaranteed initiative to strengthen the hydrogen ecosystem (IDB, 2021). Projects such as Ad Astra's "Costa Rica Hydrogen Transportation Ecosystem" which began in 2018, and ProNova Energy's collaboration for hydrogen mobility solutions, further illustrate this progress (ProNova Energy, 2022). The NAMA Facility, supported by GIZ and other partners, will also help Costa Rica address financing barriers and enhance knowledge transfer, supporting sectors such as transportation and heavy industry (Mitigation Action Facility, 2022).

Main innovative clean hydrogen projects and hubs in Costa Rica



N°	Project Name	Location	Main Innovators
1	**1 MW Pilot project to upgrade existing environment (*End-use*)** (Cordonnier & Saygin, Green hydrogen opportunities for emerging and developing economies: Identifying success factors for market development and building enabling conditions., 2022)	Guanacaste & San José	ProNova Energy: Ad Astra Rocket Company Mesoamerica Cavendish

Delivery Mechanisms: Costa Rica		
Delivery Mechanism	**Assistance from IDB (Non-Sovereign Guarantees)**	**Mitigation Adaptation Facility Donors**
Type of Mechanism	TA	Incentives, Commercial Finance, Concessional Funds and Grants
Year	**2018**	**2024**
Provision of Funds	**$0.82 million**	**$27.14 million**
Timeline	NA	2024-2030

Impact of Clean Hydrogen Industry on SDGs

		
The green hydrogen industry is projected to create 18,000 jobs from 2022 to 2030, with the potential to expand to 180,000 to 220,000 full-time jobs by 2050 as the value chain matures. These increased employment opportunities, coupled with skilling initiatives, will provide local communities with access to new economic opportunities, contributing to improve the quality of life.	Investments in the clean hydrogen ecosystem will foster the emergence of new green industries focused on producing technologies such as electrolysers and fuel cells. The development of supporting infrastructure, including electricity transmission networks, hydrogen pipelines, storage facilities, and export infrastructure, will contribute to advancing SDG 9 in the country.	The widespread adoption of clean hydrogen in Costa Rica is expected to reduce CO2 emissions by 225,000 tons annually. By 2050, the green hydrogen industry could decrease GHG emissions by 6 to 13 million tons of CO2 equivalent per year, enhancing the country's climate action efforts.

Mexico

LAC - UMIC

Mexico has announced several clean hydrogen projects, supported by its favourable geographical location, sea access, and proximity to key markets. The country is exploring various innovative hydrogen solutions, including salt caverns for storage, clean ammonia production, and mobility pilot projects. However, a clear policy and regulatory framework is still needed.

Key Findings

- **Competitive advantages**: High potential for renewable electricity, potential local end-users, close connection to premium off-take markets (US & Canada), universities highly involved in R&D, and existing oil & gas and manufacturing capacities.
- **Electricity mix:** 22.3% renewable (IEA, 2024).
- **Barriers:** Lack of national clean hydrogen policies and regulations, financing barriers, lack of human resources, oil & gas reliance, and insufficient port infrastructure.
- **Strategies:** Regional government initiatives, cooperation with international partners and investors, and revising NDC for 30% GHG emissions reduction by 2030.
- **Financing Mechanisms:** The Helax Istmo project, being developed by Copenhagen Infrastructure Partners in collaboration with Mexican authorities, is expected to secure $10 billion in funding by 2029-2030.

High potential clean hydrogen applications

Main National Initiatives

- Mexican Hydrogen Association (AMH) proposal for national hydrogen roadmap (published in 2022, not yet ratified by the government)
- Guidelines for green hydrogen: published by SENER (National Energy Secretariat) in 2024, points out general focus points for the development of clean hydrogen in Mexico, not yet regulated

Main International Initiatives	• Mission Innovation • G20 • LAC Clean Hydrogen Action • CertHiLAC • Clean Energy Ministerial • International PtX Hub • H2Upp

Competitive Advantages

Mexico's geographic location offers a strategic advantage for exporting clean hydrogen and its derivatives, supported by its existing manufacturing and oil and gas industries. Its proximity to key markets, particularly the United States, and its extensive coastline make it an ideal hub for hydrogen exportation (H2LAC Index, 2024). Mexico is already home to 11 hydrogen projects, backed by private sector involvement, including two key hydrogen associations, the Mexican Hydrogen Association and the Mexican Hydrogen Society, which foster collaboration between academia, industry, and government (SMH, 2024). Additionally, Mexico's participation in international clean energy initiatives, such as the G20 and Clean Energy Ministerial, highlights its commitment to developing the hydrogen industry. However, barriers such as a lack of port infrastructure, financial constraints, and the absence of a comprehensive hydrogen framework must be addressed for full-scale export potential (Climate Action Tracker, 2020).

Mexico's renewable energy capacity, currently at 35 GW, underpins its potential to produce green hydrogen, especially with an electrolysis demand projected to exceed 11 GW by 2050 (Green Hydrogen Innovation Center, n. d.). State-owned enterprises such as PEMEX and CFE are expected to play a major role, leveraging their expertise in fossil fuels to drive hydrogen production. The country's solar resources could lower green hydrogen production costs to as low as USD 1-1.4 per kilogram by 2050. Moreover, Mexico is advancing clean hydrogen technology, especially in the transport sector, with pilot projects for heavy-duty trucks and bus fleets (TyT Mexico, 2023). With continued investment in electrolysis capacity and renewable energy, Mexico could significantly reduce emissions in key industrial sectors and support job creation as fossil fuel industries decline (Green Hydrogen Innovation Center, n. d.).

Main innovative clean hydrogen projects and hubs in Mexico

N°	Project Name	Location	Main Innovators
1	**Tarafert Urea & Green Ammonia (*Transformation*)** (Tarafert, 2024)	Durango	Tarafert
2	**Marengo I (*Transformation*)** (H2LAC, 2023)	Campeche	Campeche Government GIZ Mexico MexCo Hy2Gen
3	**Green Hydrogen cement project (*End-Use*)**	Not reported	Holcim
4	**Nel A-150 electrolyser plant (*Production*)** (Green Hydrogen Innovation Center, n. d.)	Not reported	Instituto Mexicano del Petróleo Nel Hydrogen Electrolyser (Nel ASA) Pemex
5	**Delicias Solar (*Production*)** (Piedepagina, 2024)	Guanajato	Dhamma Energy
6	**Energía Los Cabos (*End-Use*)** (HDF, 2024)	Baja California Sur	HDF Energy

Key Investments and Partnerships

Key Financial Investments: Mexico		
Financial Mechanism	**Investments by Copenhagen Infrastructure Partners and Mexican Authorities (Project Helax Istmo)**	**H2Gen's Ammonia Project in Campeche State**
Type of Mechanism	TA, Development Equity	NA
Year	**2023**	**2023**
Provision of Funds	$10 billion (Estimated)	$1.22 billion (Estimated)
Timeline	FY 2025-26 to FY 2029-30	NA

ANNEXES.

ANNEX 1. BIBLIOGRAPHY

- 3E News. (2023). Balkan Hydrogen Cluster presented in Moldova the possibilities of hydrogen in the green transition. Available at: https://3e-news.net/en/a/view/44023/balkan-hydrogen-cluster-presented-in-moldova-the-possibilities-of-hydrogen-in-the-green-transition
- Abdelkareem et al. (2024). Hydrogen from waste metals: Recent progress, production techniques, purification, challenges, and applications. Available at: https://www.sciencedirect.com/science/article/pii/S2772737823000330
- Abdulkadir et al. (2024). A concise review on surface and structural modification of porous zeolite scaffold for enhanced hydrogen storage. Available at: https://www.sciencedirect.com/science/article/pii/S1004954124000697
- ABH2 (2024). Associação Brasileira de Hidrogênio. Available at: https://abh2.org/sobre
- Abu Dhabi Sustainability Week. (2023). These 4 startups are paving the way to a green hydrogen future. Available at: https://abudhabisustainabilityweek.com/Leadership/Expert-Insights/Paving-the-way-to-a-green-hydrogen-future
- Achomo et al. (2024). Experimental studies on hydrogen production from steam reforming of methanol integrated with metal hydride-based hydrogen purification system. Available at: https://www.sciencedirect.com/science/article/pii/S0360319924002106

- Acko (2024). Hydrogen Cars in India: Expected Date & Overview. Available at: https://www.acko.com/car-guide/hydrogen-cars-in-india/
- Ad Astra. (s.f.). Trucks and buses – Costa Rica.
- Africa Climate Ventures (2023). Available at: https://africaclimateventures.com/
- African Energy (2022). Egypt 'harvests' green hydrogen mega deals in the COP27 marketplace. Available at: https://www.africa-energy.com/news-centre/article/egypt-harvests-green-hydrogen-mega-deals-cop27-marketplace
- AGBI. (2024). $25bn Morocco-Nigeria gas pipeline gains momentum. Available at: https://www.agbi.com/oil-and-gas/2024/05/25bn-morocco-nigeria-gas-pipeline-gains-momentum/
- AGBI. (2024). Morocco offers new incentives for green hydrogen investors. Available at: https://www.agbi.com/renewable-energy/2024/03/morocco-offers-new-incentives-for-green-hydrogen-investors/#:~:text=Morocco%20has%20launched%20new%20incentives,Akhannouch%2C%20said%20in%20a%20statement.
- Agora. (2024). 12 Insights on Hydrogen – Brazil Edition. Available at: https://www.agora-energiewende.org/publications/12-insights-on-hydrogen-brazil-edition-1
- Agora Energiewende and Instituto E+ Transição Energética (2024). 12 Insights on Hydrogen- Brazil edition. Available at: https://www.agora-industry.org/fileadmin/Projekte/2023/2023-24_IND_H2_Insights_BRA/A-IND_322_12-Insights-H2-Brazil_EN_WEB.pdf

- AHK Philippinen (2024). Green Hydrogen Information Hub. Available at: https://philippinen.ahk.de/en/initiatives/green-hydrogen-knowledge-hub
- Albania Energy Association (2023). Available at: https://aea-al.org/#home
- Alcantar, G. G., & Trejo, T. L. (2007). Nutrición de cultivos. México.
- Aleksayan et al. (2024). Fabrication and characterization of highly responsive hydrogen sensor based on Fe2O3:ZnO nanostructured thin film. Available at: https://www.sciencedirect.com/science/article/pii/S2665917423003203
- Alrwashdeh et al. (2022). Visualization of water accumulation in micro porous layers in polymer electrolyte membrane fuel cells using synchrotron phase contrast tomography. Available at: https://www.sciencedirect.com/science/article/pii/S2666016422000822
- Ambrose et al. (2016). Prospects for introducing hydrogen fuel cell vehicles in Malaysia. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0360319915312945?via%3Dihub
- Ammonia Energy Association (2022). Renewable ammonia in Vietnam. Available at: https://ammoniaenergy.org/articles/renewable-ammonia-in-vietnam/
- Ammonia Energy Association (2023). Hy2gen announces new ammonia project in Mexico. Available at: https://ammoniaenergy.org/articles/hy2gen-announces-new-ammonia-project-in-mexico/
- Ammonia Energy Association (2024). Renewable ammonia exports from Brazil: Project Iracema. Available at:

https://ammoniaenergy.org/articles/renewable-ammonia-exports-from-brazil-project-iracema/

- Ammonia Energy Association. (2022). Green ammonia in Morocco: an update. Available at: https://ammoniaenergy.org/articles/green-ammonia-in-morocco-an-update/
- Ammonia Energy Association. (2023). Ammonia bunkering in Egypt & beyond. Available at: https://ammoniaenergy.org/articles/ammonia-bunkering-in-egypt-beyond/
- Ammonia Energy Association. (2023). Headway in ACWA Power's renewable ammonia projects. Available at: https://ammoniaenergy.org/articles/headway-in-acwa-powers-renewable-ammonia-projects/
- Ammonia Energy Association. (2024). Renewable ammonia exports from Brazil: Project Iracema. Available at: https://ammoniaenergy.org/articles/renewable-ammonia-exports-from-brazil-project-iracema/
- Ammonia Energy Association. (2024). Egypt launches new hydrogen incentives. Available at: https://ammoniaenergy.org/articles/egypt-launches-new-hydrogen-incentives/
- Argos (2023). GRACIAS A INNOVADOR PROYECTO, ARGOS HONDURAS ROMPE RÉCORD DE PRODUCCIÓN. Available at: https://argos.co/gracias-a-innovador-proyecto-argos-honduras-rompe-record-de-produccion/

- Argus Media (2024). Philippines sets out incentives for green H2. Available at: https://www.argusmedia.com/en/news-and-insights/latest-market-news/2533367-philippines-sets-out-incentives-for-green-h2
- Argus. (2023). Petrobras plans switch to renewable H2 in refineries. Available at: https://www.argusmedia.com/en/news-and-insights/latest-market-news/2509236-petrobras-plans-switch-to-renewable-h2-in-refineries
- Argus. (2024). Several of Brazil's main ports launched the Alliance for Decarbonization initiative, aimed at reducing emissions and boosting use of cleaner maritime fuels such as biobunkers and green hydrogen. Available at: https://www.argusmedia.com/en/news-and-insights/latest-market-news/2551498-brazilian-ports-ally-for-decarbonization-goals
- Asahi (2023). Biofuel-hydrogen tourist ship. Available at: https://asia.nikkei.com/Spotlight/Environment/Climate-Change/Japan-s-first-biofuel-hydrogen-tourist-ship-to-set-sail-in-2024
- Asia Nikkei. (2023). Singapore taps Vietnam, Indonesia and Malaysia for low-carbon energy. Available at: https://asia.nikkei.com/Business/Energy/Singapore-taps-Vietnam-Indonesia-and-Malaysia-for-low-carbon-energy#:~:text=Low%2Dcarbon%20energy%20sources%20include,like%20Vietnam%2C%20Malaysia%20and%20Indonesia.
- Asian Development Bank (2022). Accelerating Gender Equality in the Renewable Energy Sector. Available at: https://www.adb.org/sites/default/files/publication/830311/gender-equality-renewable-energy-sector.pdf

- Atlas Agro. (2024). A new era for sustainable fertilizers. Available at: https://www.atlasagro.ag/
- atome. (2022). Costa Rica. Available at: https://www.atomeplc.com/projects/costa-rica/
- Autodesk (n.d.). Drones impulsados por hidrógeno marcan el camino a un transporte aéreo sostenible. Available at: https://www.autodesk.com/latam/customer-stories/h2go-hydrogen-powered-drones#:~:text=Un%20dron%20alimentado%20por%20hidr%C3%B3geno,%2C%20duradero%2C%20eficiente%20y%20seguro
- Automotive News Europe (2023). BMW, Sasol seek to develop South African fuel cell car ecosystem. Available at: https://europe.autonews.com/automakers/bmw-and-partners-plans-fuel-cell-infrastructure-south-africa.
- AVAADA (2023). Annual Report for the Financial Year 2022-23. Available at: https://avaada.com/csepl/img/CSEPL-Annual%20Report-2022-23.pdf.
- Azerbaijan Renewable Energy Agency (2024). Available at: https://area.gov.az/az
- Azmilaw (2023). The Use of Hydrogen in the Energy System in Malaysia and the Relevant Laws and Regulations. Available at: https://www.azmilaw.com/insights/the-use-of-hydrogen-in-the-energy-system-in-malaysia-and-the-relevant-laws-and-regulations/#:~:text=Financial%20Incentives&text=As%20part%20of%20the%20national,fuel%20cell%20vehicles%20in%20Malaysia.

- Baher et al. (2024). Syngas production by ultrarich oxy-natural gas combustion in a pilot-scale porous burner. Available at: https://www.sciencedirect.com/science/article/pii/S036031992305348X.
- Ballard (2018). Ballard Announces Planned Deployment of 500 Fuel Cell Commercial Trucks in Shanghai. Available at: https://www.ballard.com/about-ballard/newsroom/news-releases/2018/02/14/ballard-announces-planned-deployment-of-500-fuel-cell-commercial-trucks-in-shanghai#:~:text=VANCOUVER%2C%20CANADA%20and%20SHANGHAI%2C%20CHINA,technology%20%E2%80%93%20in%20Shanghai%2C%20China.
- Bangkok Post (2023). Eppo prepping hydrogen pilot project. Available at: https://www.bangkokpost.com/business/general/2603058/eppo-prepping-hydrogen-pilot-project.
- Bangladesh Solar and Renewable Energy Association (2023). Available at: https://bsreabd.org/
- Bank Negara Malaysia. (2024). Regulatory Sandbox. Available at: https://www.bnm.gov.my/sandbox
- Barathy et al. (2024). Enhanced response of WO3 thin film through Ag loading towards room temperature hydrogen gas sensor. Available at: https://www.sciencedirect.com/science/article/pii/S0045653524004387
- Bazilian, M., Cuming, V., Kenyon, T. (2020). Local-content rules for renewables projects don't always work. Available at: https://doi.org/10.1016/j.esr.2020.100569
- Bentec. (2023). Green Hydrogen Community Development Toolkit.

- Bloomberg. (2024). Financing Green Hydrogen in India.
- BMW Group (2024). Anglo American Platinum, BMW Group South Africa and Sasol take next step in collaboration with pilot fleet of BMW iX5 Hydrogen fuel cell electric vehicles.. Available at: https://www.press.bmwgroup.com/south-africa/article/detail/T0439748EN/anglo-american-platinum-bmw-group-south-africa-and-sasol-take-next-step-in-collaboration-with-pilot-fleet-of-bmw-ix5-hydrogen-fuel-cell-electric-vehicles?language=en
- BMWK (2024). Germany and Algeria set up hydrogen taskforce. Available at: https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2024/02/20240208-germany-and-algeria-set-up-hydrogen-taskforce.html#:~:text=Federal%20Minister%20Robert%20Habeck%3A%20Germany,thus%20create%20new%20local%20value.
- BMWK. (2019). Regulatory sandboxes: experimental areas for new energy technologies. Available at: https://www.bmwk-energiewende.de/EWD/Redaktion/EN/Newsletter/2019/07/Meldung/topthema.html
- BMWK. (2021). Northern Germany Regulatory Sandbox (Norddeutsches Reallabor). Available at: https://www.bmwk.de/Redaktion/EN/Hydrogen/Examples/Norddeutsches-Reallabor.html
- bnamericas (2023). Holcim lanzará su primer proyecto latinoamericano de hidrógeno en México. Available at: https://www.bnamericas.com/es/noticias/holcim-lanzara-su-primer-proyecto-latinoamericano-de-hidrogeno-en-mexico

- bnamericas (2024). Atlas Agro inicia fase de ingeniería para la construcción de la primera fábrica de fertilizantes nitrogenados verdes de Brasil. Available at: https://www.bnamericas.com/es/noticias/atlas-agro-inicia-fase-de-ingenieria-para-la-construccion-de-la-primera-fabrica-de-fertilizantes-nitrogenados-verdes-de-brasil
- Braun, J.F., Frischmuth, F., Gerhardt, N., Pfennig, M., Schmitz, R., Wietschel, M., Carlier, B., Réveillère, A., Warluzel, G., Wesoly, D. (2023). Clean Hydrogen Deployment in the Europe-MENA Region from 2030 to 2050: A Technical and Socio-Economic Assessment. Available at: https://publica.fraunhofer.de/bitstreams/608fe924-4877-4c7a-a190-4cb19f146399/download
- Breakthrough Agenda (2023). The Breakthrough Agenda Report: Accelerating Sector Transitions Through Stronger International Collaboration. Available at: https://breakthroughagenda.org/wp-content/uploads/2023/11/THEBREAKTHROUGHAGENDAREPORT2023.pdf
- Brown, A., & Nis, G. (2022). China's Nascent Green Hydrogen Sector: How policy, research and business are forging a new industry. MERICS China Monitor. Available at: https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new#:~:text=China's%20push%20into%20green%20hydrogen,ramping%20up%20of%20the%20industry.
- Brot für die Welt and Heinrich-Böll-Stiftung (2022). Green Hydrogen: Key success criteria for sustainable trade and production. Available at: https://hk.boell.org/sites/default/files/importedFiles/2022/11/17/green-hydrogen-bericht.pdf

- Businesswire (2016). Nel ASA: Awarded Contract for Electrolyser Plant in Mexico and Celebrates Delivery to Country Number 60. Available at: https://www.businesswire.com/news/home/20161212006321/en/Nel-ASA-Awarded-Contract-for-Electrolyser-Plant-in-Mexico-and-Celebrates-Delivery-to-Country-Number-60
- Caiafa, Clara, Amaro Olimpio Pereira Jr, Henny Romijn, and Heleen de Coninck. (2023). Estimating Economic Co-Benefits from Export-Oriented Renewable Hydrogen Projects in a Developing Country Context. The Case of Ceará, Brazil. Available at: https://www.wifo.ac.at/jart/prj3/wifo/resources/person_dokument/person_dokument.jart?publikationsid=71227&mime_type=application/pdf
- Casati et al. (2023). Clean energy access as an enabler for social development: A multidimensional analysis for Sub-Saharan Africa. Available at: https://www.sciencedirect.com/science/article/pii/S0973082622002344
- Ceca Magán (2022). Hydrogen take-off in Latin America: Chile, Mexico, Colombia y Brasil. Available at: https://www.cecamagan.com/en/blog/hydrogen-take-latin-america-chile-mexico-colombia-brasil
- Cemex Ventures (2023). Deep Dive: HiiROC x Cemex Ventures. Available at: https://www.cemexventures.com/es/deep-dive-hiiroc-x-cemex-ventures/
- Center on Global Energy Policy Columbia. (2023). China's Hydrogen Strategy: National vs. Regional Plans. Available at: https://www.energypolicy.columbia.edu/publications/chinas-hydrogen-strategy-national-vs-regional-plans/

- Central Bank of Egypt. (2023). Regulatory Sandbox. Available at: https://www.cbe.org.eg/en/financial-technology/regulatory-sandbox
- Centre for Global Development (2024). The Socioeconomic Impact of Climate Change in Developing Countries in the Next Decade. Available at: https://www.cgdev.org/sites/default/files/socioeconomic-impact-climate-change-developing-countries-next-decades.pdf
- ChemAnalyst (2024). Sarawak Nears Completion of $4.2 Billion Green Hydrogen Venture. Available at: https://www.chemanalyst.com/NewsAndDeals/NewsDetails/sarawak-nears-completion-of-4-2-billion-green-hydrogen-venture-25481
- Chen et al. (2024). Anatase TiO2 aerogel with high specific surface areas and porous network structures for ultra-fast response hydrogen sensor. Available at: https://www.sciencedirect.com/science/article/pii/S0360319923041149
- China Daily (2023). China's first hydrogen fuel cell ship completes maiden voyage. Available at: https://newscenter.lbl.gov/2023/10/06/six-ways-berkeley-lab-is-bringing-clean-hydrogen-to-the-world/.
- China Daily (2023). Hydrogen Fuel cell power boat. Available at: https://www.chinadaily.com.cn/a/202310/12/WS6527650ba31090682a5e820a.html
- Chozhavendhan et al. (2020). A review on feedstock, pretreatment methods, influencing factors, production and purification processes of bio-hydrogen production. Available at: https://www.sciencedirect.com/science/article/pii/S2666016420300360

- Clean Energy Ministerial (2022). 3M Company. Available at: https://www.cleanenergyministerial.org/content/uploads/2022/03/cem-em-casestudy-3m-global.pdf
- Clean Energy Ministerial (2022). NTPC Limited, Sipat. Available at: https://www.cleanenergyministerial.org/content/uploads/2022/09/cem-em-casestudy-ntpcsipat-india.pdf
- Clean Energy Ministerial (2022). PT Pertamina Hulu Energi West Madura Offshore (PHE WMO). Available at: https://www.cleanenergyministerial.org/content/uploads/2022/09/cem-em-casestudy-huluenergi-indonesia.pdf
- Clean Energy Ministerial (2023). 14th Clean Energy Ministerial. Outcomes and announcements. Available at: https://www.cleanenergyministerial.org/content/uploads/2023/09/cem14-factsheet-final-v20230905.pdf
- Clean Energy Ministerial (2023). PT Angkasa Pura I. Available at: https://www.cleanenergyministerial.org/content/uploads/2023/06/cem-em-casestudy-igusti-indonesia.pdf
- Clean Energy Ministerial (2023). PT PLN Nusantara Power Muara Karang Power Plant. Available at: https://www.cleanenergyministerial.org/content/uploads/2023/06/cem-em-casestudy-nusantara-indonesia.pdf
- Clean Energy Ministerial (2023). PT Semen Tonasa. Available at: https://www.cleanenergyministerial.org/content/uploads/2023/06/cem-em-casestudy-sementonasa-indonesia.pdf

- Clean Energy Wire (2023). Germany to support Colombia's energy transition with extra €200m. Available at: https://www.cleanenergywire.org/news/germany-support-colombias-energy-transition-extra-eu200m

- Clean Hydrogen Joint Undertaking (2023). Program Review Report 2023. Available at: https://op.europa.eu/en/publication-detail/-/publication/00f833fa-7ec4-11ee-99ba-01aa75ed71a1/language-en/format-PDF/source-296436320

- Clean Hydrogen Joint Undertaking, Mission Innovation (2024). The Hydrogen Valley Platform. Available at: https://h2v.eu/hydrogen-valleys

- Clean Hydrogen JU. (2022). GOING GLOBAL. An update on Hydrogen Valleys and their role in the new hydrogen economy.

- Clean Hydrogen Partnership (2021). Strategic Research and Innovation Agenda 2021 – 2027. Available at: https://www.clean-hydrogen.europa.eu/document/download/8a35a59b-a689-4887-a25a-6607757bbd43_en?filename=Clean%20Hydrogen%20JU%20SRIA%20-%20approved%20by%20GB%20-%20clean%20for%20publication%20%28ID%2013246486%29.pdf

- Clean Hydrogen Partnership. (2023). South Marmara Hydrogen Shore. Available at: https://www.clean-hydrogen.europa.eu/projects-dashboard/projects-repository/hysouthmarmara_en

- Client II (2022). CoalCO2-X. Available at: https://bmbf-client.de/en/projects/coalco2-x.

- Climate Champions. (2022). Africa Green Hdrogen Alliance. Available at: https://climatechampions.unfccc.int/africa-green-hydrogen-alliance/
- Columbia Center on Global Energy Policy (2024). National Hydrogen Strategies and Roadmap Tracker. Available at: https://www.energypolicy.columbia.edu/publications/national-hydrogen-strategies-and-roadmap-tracker/
- Consejo Económico y Social de Argentina (2021). Hacia una Estrategia Nacional Hidrógeno 2030. Available at: https://www.argentina.gob.ar/sites/default/files/segundo_documento_ces_hidrogeno.pdf
- Cordonnier, J., & Saygin, D. (2022). Green hydrogen opportunities for emerging and developing economies: Identifying success factors for market development and building enabling conditions. Available at: https://read.oecd.org/10.1787/53ad9f22-en?format=pdf
- Cortés (2023). Renewable Hydrogen in Latin America and the Caribbean: Opportunities, Challenges and Pathways. Available at: https://h2mex.org/wp-content/uploads/RENEWABL-HYDROGEN-IN-LATIN-AMERICA-AND-THE-CARIBBEAN.pdf
- Council on Energy, Environment and Water & Bloomberg. (2024). Financing Green Hydrogen in India: Private Sector Considerations to Strengthen India’s Enabling. Bloomberg.
- CPL. (2024). Financing Industrial Decarbonization.
- CWP (2024). Our Projects. Available at: https://cwp.global/projects/

- CWP Global. (2023). White Paper Series: Good Green Hydrogen Contracting The reduction of cost of capital for green hydrogen projects and Bilateral Investment Treaties. GH2 Organisation.
- Daures Green (2024). Daures Green Hydrogen Village. Available at: https://daures.green/
- Daures Green Hydrogen Village. (2024). Daures Green Hydrogen Village Project Team. Available at: https://daures.green/project-team/
- Dbpedia (n.d.). About: Teleghan solar hydrogen energy system. Available at: https://dbpedia.org/page/Taleghan_solar_hydrogen_energy_system
- Department for Energy Security & Net Zero. (2023). Joint statement of intent between Brazil and the United Kingdom to co-chair a Brazil-UK Hydrogen Hub. Available at: https://www.gov.uk/government/publications/hydrogen-hub-brazil-uk-joint-statement-of-intent/joint-statement-of-intent-between-brazil-and-the-united-kingdom-to-co-chair-a-brazil-uk-hydrogen-hub
- Department of Science and Innovation of the Republic of South Africa (2022). Hydrogen Society Roadmap for South Africa 2021. Available at: https://www.dst.gov.za/index.php/resource-center/reports/strategies-and-reports/3574-hydrogen-society-roadmap-for-south-africa-2021
- Ding et al. (2024). Efficiently unbiased solar-to-ammonia conversion by photoelectrochemical Cu/C/Si-TiO2 tandems. Available at: https://www.sciencedirect.com/science/article/pii/S0926337324000468
- Ding, Wu (2024). Hydrogen fuel cell electric trains: Technologies, current status, and future. Available at: https://doi.org/10.1016/j.jaecs.2024.100255

- Dolan, C. et al (2019). 2019 Fuel Cell Technologies Market Report. Available at: https://publications.anl.gov/anlpubs/2021/08/166534.pdf
- Dpumbi et al. (2022). Tannery wastewater treatment by electro-Fenton and electro-persulfate processes using graphite from used batteries as free-cost electrode materials. Available at: https://www.sciencedirect.com/science/article/pii/S2666016422000123
- Dr. Divine Tuinese Novieto (2018). The potential to generate solar hydrogen for cooking applications: Case studies of Ghana, Jamaica and Indonesia. Available at: https://scholar.google.com/citations?view_op=view_citation&hl=en&user=P4Xce8YAAAAJ&citation_for_view=P4Xce8YAAAAJ:9yKSN-GCB0IC
- Duoc et al. (2024). Hydrogen gas sensor based on self-heating effect of SnO2/Pt thin film with ultralow power consumption. Available at: https://www.sciencedirect.com/science/article/pii/S0360319924006025
- EASA (n.d.). Hydrogen and its potential in aviation. Available at: https://www.easa.europa.eu/en/light/topics/hydrogen-and-its-potential-aviation
- EBRD. (2021). EBRD and IRESEN to boost renewables, green hydrogen and new technologies. Available at: https://www.ebrd.com/news/2021/ebrd-and-iresen-to-boost-renewables-green-hydrogen-and-new-technologies.html
- Economic Times (2023). Climate-tech startup NewTrace raises $5.6 Million in funding. Available at: https://economictimes.indiatimes.com/tech/funding/climate-tech-startup-newtrace-raises-5-6-million-in-funding-from-sequoia-others/articleshow/100656277.cms?from=mdr

- Ecopetrol (2022). Innovación, Desarrollo e Investigación. Available at: https://www.ecopetrol.com.co/wps/portal/Home/es/ResponsabilidadEtiqueta/Medio%20ambiente/cambio-climatico-et/tecnologia-e-investigacion.
- Ecopetrol. (2022). The Ecopetrol Group initiated green hydrogen production in Colombia. Available at: https://www.ecopetrol.com.co/wps/portal/Home/en/news/detail/Noticias-2021/green-hydrogen-production
- El colombiano (n.d.). Hidrógeno, la apuesta de Promigas para la descarbonización. Available at: https://www.elcolombiano.com/amp/sostenibilidad/hidrogeno-la-apuesta-de-promigas-para-la-descarbonizacion-AO21946134.
- El Colombiano. (2023). Hidrógeno, la apuesta de Promigas para la descarbonización. Available at: https://www.elcolombiano.com/sostenibilidad/hidrogeno-la-apuesta-de-promigas-para-la-descarbonizacion-AO21946134
- Elixir Energy (2021). Hydrogen & Green Energy. Available at: https://elixirenergy.com.au/hydrogen/.
- Enegix (2021). Powering humanity. Available at: https://www.enegix.energy/
- Energetica India (2024). Uttar Pradesh Government Approves Green Hydrogen Policy. Available at: https://www.energetica-india.net/news/uttar-pradesh-government-approves-green-hydrogen-policy
- Energía estratégica (2023). ¿Cómo avanza ENARSA con el hidrógeno verde en Argentina?. Available at: https://www.energiaestrategica.com/como-avanza-enarsa-con-el-hidrogeno-verde-en-argentina/

- Energia estrategica (2024). Nepos Energy busca desarrollar su primer proyecto de hidrógeno verde en Ecuador para el 2025. Available at: https://www.energiaestrategica.com/nepos-energy-busca-desarrollar-su-primer-proyecto-de-hidrogeno-verde-en-ecuador-para-el-2025/
- Energy & Commerce (2023). Pacífico Mexinol va por la planta de metanol más grande del mundo en Sinaloa. Available at: https://energyandcommerce.com.mx/pacifico-mexinol-va-por-la-planta-de-metanol-mas-grande-del-mundo-en-sinaloa/
- Energy news (2024). Peru Invests $2.5 Billion in New Green Hydrogen Plant. Available at: https://energynews.biz/peru-invests-2-5-billion-in-new-green-hydrogen-plant/.
- Energy World. (2023). India's PLI schemes under the Green Hydrogen ecosystem - A perspective. Available at: https://energy.economictimes.indiatimes.com/news/renewable/indias-pli-schemes-under-the-green-hydrogen-ecosystem-a-perspective/101372149
- EnergyCapital&Power (2024). Daures Green Hydrogen Village Advances in Namibia. Available at: https://energycapitalpower.com/daures-green-hydrogen-village-namibia/
- EnergyLab Cambodia (2024). Accelerating Clean Energy in Cambodia. Available at: https://energylab.asia/
- ENGIE Impact (2021). South Africa Hydrogen Valley Final Report. Available at: https://www.dst.gov.za/index.php/resource-center/reports/strategies-and-reports/3508-hydrogen-valley-feasibility-study-report-october-2021

- ENGIE. (2021). Department of Science and Innovation. Available at: https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf
- Engineering news (2019). South Africa's first fuel cell factory. Available at: https://www.engineeringnews.co.za/article/chem-to-set-up-south-africas-first-fuel-cell-factory-in-the-dube-tradeport-2019-09-11#:~:text=CHEM%20has%20established%20a%20subsidiary,it%20will%20build%20the%20factory.
- Engineering news (2024). HySHiFT sustainable aviation fuel project, South Africa – update. Available at: https://www.engineeringnews.co.za/print-version/hyshiftsustainable-aviation-fuel-project-south-africa-update-2024-04-19#:~:text=The%20project%20aims%20to%20produce,liquid%2C%20or%20PTL%2C%20kerosene.
- Engineering News Online (2019). "CHEM to Set Up South Africa's First Fuel Cell Factory in the Dube TradePort.". Available at: https://www.engineeringnews.co.za/article/chem-to-set-up-south-africas-first-fuel-cell-factory-in-the-dube-tradeport-2019-09-11#:~:text=CHEM%20has%20established%20a%20subsidiary,it%20will%20build%20the%20factory.
- Engineering Post (2024). NEECA goes forward with Green Hydrogen Policy. Available at: https://enggpost.com/neeca-goes-forward-with-green-hydrogen-policy/
- Eni (2023). Eni inaugurates the Oyo Centre of Excellence for Renewable Energy and Energy Efficiency with the Republic of Congo and UNIDO. Available at:

https://www.eni.com/en-IT/media/news/2023/04/eni-inaugurates-oyo-centre-excellence-renewable-energy-with-congo.html

- Es Hidrogeno (2023). LA ELECTRÓLISIS CON AGUA DE MAR ES POSIBLE. Available at: https://eshidrogeno.com/electrolisis-agua-mar/
- Eshidrogeno (2024). EPM APUESTA POR EL BLENDING CON HIDRÓGENO VERDE. Available at: https://eshidrogeno.com/blending-con-hidrogeno-verde/.
- ESMAP (2024). Scaling Hydrogen Financing for Development. Available at: https://www.esmap.org/Hydrogen_Financing_for_Development.
- ESMAP, WBK (2020). Green Hydrogen in developing countries. Available at: https://www.esmap.org/green-hydrogen-in-developing-countries.
- ESMAP. (2020). Green Hydrogen in developing countries. Available at: https://www.esmap.org/green-hydrogen-in-developing-countries
- ESMAP. (2022). Sufficiency, Sustainability, and Circularity of Critical Materials for Clean Hydrogen.
- ESMAP. (2024). Scaling Hydrogen Financing for Development. Available at: https://www.esmap.org/Hydrogen_Financing_for_Development
- ET Government. (2024). NTPC Green Energy to set up India's largest green hydrogen production facility near Vizag. Available at: https://government.economictimes.indiatimes.com/news/psu/ntpc-green-energy-to-set-up-indias-largest-green-hydrogen-production-facility-near-vizag/107904362
- European Bank (2024). Pilot Uzbek Green Hydrogen Project. Available at: https://www.ebrd.com/work-with-us/projects/psd/54561.html#:~:text=Project%20Description&text=3%2C000%2

0tonnes%20of%20renewable%20hydrogen,EBRD%2Dfinanced%20Uzbekistan%20Bash%20WPP.

- European Commission (2023). In Brazil, President von der Leyen announces EUR 10 billion of Global Gateway investments in Latin America and the Caribbean. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ac_23_3265
- European Commission (2023). Press Release: EU and Argentina step up cooperation on clean energy transition and energy security. Available at: https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_23_3859/IP_23_3859_EN.pdf
- European External Action Service (2023). The EU and Namibia set the roadmap to a future of renewable hydrogen and sustainable critical raw materials value chains. Available at: https://www.eeas.europa.eu/delegations/namibia/eu-and-namibia-set-roadmap-future-renewable-hydrogen-and-sustainable-critical-raw-materials-value_en?s=112
- European Investment Bank (2022). EIB at Cop 27: EIB and the Colombian Government commit to supporting energy transition. Available at: https://www.eib.org/en/press/all/2022-471-eib-at-cop27-eib-and-the-colombian-government-commit-to-supporting-energy-transition
- European Investment Bank. (December de 2022). New study confirms €1 trillion Africa’s extraordinary green hydrogen potential. Available at: https://www.eib.org/en/press/all/2022-574-new-study-confirms-eur-1-trillion-africa-s-extraordinary-green-hydrogen-potential
- EIB (2024). Press Release: India: EIB backs green hydrogen deployment and joins India Green Hydrogen Alliance. Available at: https://www.eib.org/en/press/all/2023-045-eib-backs-green-hydrogen-

deployment-in-india-and-joins-india-hydrogen-alliance#:~:text=Today%20in%20Mumbai%20Kris%20Peeters,1%20billion%2C%20subject%20to%20Indian

- European Parliament. (2022). Artificial intelligence act and regulatory sandboxes.
- EY (2024). India's Green hydrogen revolution - An ambitious approach. Available at: https://static.pib.gov.in/WriteReadData/specificdocs/documents/2024/may/doc2024510336301.pdf.
- Falcone, P. M., Hiete, M., & Sapio, A. (2021). Hydrogen economy and sustainable development: Review and Policy Insights. Current Opinion in Green and Sustainable Chemistry, Vol 31.
- Fasheun et al. (2024). Dark fermentative hydrogen production from cassava starch: A comprehensive evaluation of the effects of starch extrusion and enzymatic hydrolysis. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0360319923027271?via%3Dihub
- FCH2RAIL (2021). First hydrogen train on the Spanish railway network. Available at: https://fch2rail.eu/
- Forbes (2023). Green Hydrogen can help India meet its net-zero ambitions. Available at: https://www.forbesindia.com/article/innovation/green-hydrogen-can-help-india-meet-its-netzero-ambitions-how-long-before-a-real-impact-is-seen/87937/1

- Fortescue. (2024). OCP and Fortescue to partner to develop green energy, hydrogen and ammonia in Morocco. Available at: https://fortescue.com/news-and-media/news/2024/04/08/ocp
- Fraunhofer ISE (2023). The Fraunhofer-Gesellschaft and Colombia's Ministry of Mines and Energy sign a memorandum of understanding for future research projects on expanding the hydrogen sector. Available at: https://www.ise.fraunhofer.de/en/press-media/news/2023/the-fraunhofer-gesellschaft-and-colombias-ministry-of-mines-and-energy-sign-a-memorandum-of-understanding-for-future-research-projects-on-expanding-the-hydrogen-sector.html
- Fu et al. (2020). Alternative route for electrochemical ammonia synthesis by reduction of nitrate on copper nanosheets. Available at: https://www.sciencedirect.com/science/article/pii/S2352940720300688
- fuelcelltrucks (n.d.). DONGFENG: 500 H2 trucks. Available at: https://fuelcelltrucks.eu/project/dongfeng/.
- Fuel Cell Works (2022). GGGI, Samsung and Hyundai to join $1.2 bn green hydrogen project in Indonesia. Available at: https://fuelcellsworks.com/news/gggi-samsung-hyundai-to-join-1-2-bn-green-hydrogen-project-in-indonesia
- Gei Power (2024). Our Projects. Available at: https://www.gei-power.com/our-projects/.
- GEM.WIKI (2024). Lam Takhong wind farm. Available at: https://www.gem.wiki/Lam_Takhong_wind_farm
- GEM.WIKI (2024). Pha Lai Power Complex. Available at: https://www.gem.wiki/Pha_Lai_Power_Complex

- Gencell (2019). GenCell Launches Fuel Cells in the Philippines to Deliver Clean, Reliable Power to Mitigate Impact of Frequent Power Outages. Available at: https://www.gencellenergy.com/app/uploads/2019/05/Philippines_Launch_PR.pdf.
- Gencell. (2018). ADRIAN KENYA SELECTS NEW GENCELL A5 FUEL CELL SOLUTION TO . Available at: https://www.gencellenergy.com/app/uploads/2019/12/PressRelease-AdrianKenya-2.7.18.pdf
- Georgian Oil & Gas corporation (2023). Georgia starts producing green hydrogen. Available at: https://www.gogc.ge/en/press-article/georgia-starts-producing-green-hydrogen-/29
- German Council on Foreign Relations. (2024). Just Energy Transition Partnerships. Available at: https://dgap.org/en/research/glossary/climate-foreign-policy/just-energy-transition-partnerships#:~:text=Just%20Energy%20Transition%20Partnerships%20(JETPs,help%20it%20in%20this%20regard.
- GGGI (2022). NP15 Green Hydrogen Value Chain and Green Ammonia Plant in Nepal. Available at: https://gggi.org/project/np15-green-hydrogen-value-chain-and-green-ammonia-plant-in-nepal/
- GH2 Namibia (2024). Namibia Green Hydrogen Projects. Available at: https://gh2namibia.com/h2-projects/
- GH2 Organisation. (2024). Off-take Agreements and Pricing. GH2 Organisation.

- GH2SOLAR (2023). India Starts Green Hydrogen Pilot Projects to Meet its 2030 Goal. Available at: https://www.gh2solar.com/india-starts-green-hydrogen-pilot-projects-to-meet-its-2030-goal/.
- GHIC (2023). Paraguay. Available at: https://isa-ghic.org/countries/paraguay.
- GHIC (2023). Perú. Available at: https://isa-ghic.org/countries/peru.
- GHIC (2024). CHINA. Available at: https://isa-ghic.org/countries/china.
- GHIC (2024). Green Hydrogen Innovation Center. Available at: https://isa-ghic.org/.
- GHIC (2024). South Africa. Available at: https://isa-ghic.org/countries/south-africa.
- GHIC. (2024). India. Available at: https://isa-ghic.org/
- GHIC. (2024). Indonesia. Available at: https://isa-ghic.org/
- GIZ (2023). H2Uppp Southeast Asia's Green Hydrogen and Power-to-X Conference showcases regional clean energy potential. Available at: https://www.thai-german-cooperation.info/en_US/h2uppp-southeast-asias-green-hydrogen-and-power-to-x-conference-showcases-regional-clean-energy-potential/
- GIZ (2023). Hidrógeno verde en México: el potencial de la transformación. Available at: https://www.energypartnership.mx/fileadmin/user_upload/mexico/media_elements/reports/Hidro%CC%81geno_AE_Tomo_VII.pdf
- GIZ (2024). Press Release: Mexican-German Energy Partnership. Available at: https://www.giz.de/en/worldwide/123800.html

- GIZ. (2024). NAMA Support Project.
- Global Cement. (2023). Holcim Mexico to trial hydrogen injection in cement kilns. Available at: https://www.globalcement.com/news/item/16717-holcim-mexico-to-trial-hydrogen-injection-in-cement-kilns
- Global Hydrogen Review. (2023). Hyphen and Development Bank of Southern Africa close €5 million funding facility. Available at: https://www.globalhydrogenreview.com/hydrogen/07122023/hyphen-and-development-bank-of-southern-africa-close-5-million-funding-facility/
- GMG (2024). Bolivia contará con una planta de producción de hidrógeno y amoniaco verde en Oruro. Available at: https://www.gentemotivandogente.com/index.php/en/rse-blog/5054-bolivia-contara-con-una-planta-de-produccion-de-hidrogeno-y-amoniaco-verde-en-oruro#:~:text=La%20empresa%20H2%20Bolivia%20lidera,agua%2C%20medio%20ambiente%20y%20econom%C3%ADa.
- Gökhan & Yeşilyurt (2019). Anode bleeding experiments to improve the performance and durability of proton exchange membrane fuel cells. Available at: https://www.sciencedirect.com/science/article/pii/S036031991930775X#abs0015
- Government of Canada. (2024). Canada-India 2024-25 collaborative industrial research and development call for proposals. Available at: https://nrc.canada.ca/en/irap/about/international/?action=view&id=187#sectors-focus

- Green Car Congress (2019). "Grove Hydrogen Automotive and State Government of Minas Gerais Brazil Announce Hydrogen Vehicle Cooperation Program.". Available at: https://www.greencarcongress.com/2019/04/20190424-grove.html
- Green Energy Park. (2018). Green Energy Park. Available at: https://www.greenenergypark.ma/
- Green Hydrogen Innovatio Center. (n. d.). Green Hydrogen Innovatio Center. Available at: https://isa-ghic.org/
- Green Hydrogen Innovation Center (2024). Country Information Page: Brazil. Available at: https://isa-ghic.org/countries/brazil
- Green Hydrogen Innovation Center. (n. d.). Green Hydrogen Innovation Center. Available at: https://isa-ghic.org/
- Green Hydrogen Organisation (2024). The Africa Green Hydrogen Alliance. Available at: https://gh2.org/africa-green-hydrogen-alliance-agha
- Green Hydrogen Organisation (2024). The GH2 Country Portal. Available at: https://gh2.org/countries
- Green Hydrogen Organisation. (2023). Green Hydrogen Contracting Guidance: Achieving sustainable development with green hydrogen. Green Hydrogen Organisation.
- Green Hydrogen Organisation. (s.f.). APAC Green Hydrogen Alliance. Available at: https://gh2.org/apac-alliance
- Green Hydrogen Organization (GH2) (2023). Achieving sustainable development with green hydrogen. Available at: https://gh2.org/sites/default/files/2023-

05/GH2_Contracting%20Guidance_Sustainable%20development%20outcomes_v3%20%281%29_0.pdf

- Green Hydrogen Organization (GH2) (2023). The Africa Green Hydrogen Finance Accelerator Forum. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0360319924001228#:~:text=The%20Algerian%20Strategy%20on%20Green,its%20consumption%20of%20petroleum%20products.
- Green Hydrogen Organization (n.d.). South Africa. Available at: https://gh2.org/countries/south-africa
- Green Hydrogen Platform - German Brazilian Alliance. (2022). Green Hydrogen Innovation Program: iH2 Brasil. Available at: https://www.h2verdebrasil.com.br/en/green-hydrogen-innovation-program/
- Green Scooters South Africa (2022). Available at: https://www.greenscooterza.com/about
- GREEN, OFF-GRID POWER TO 800 TELECOM BASE STATIONS. Available at: https://www.gencellenergy.com/app/uploads/2019/12/PressRelease-AdrianKenya-2.7.18.pdf.
- Greenstat Hydrogen Sri Lanka (2023). About Greenstat Hydrogen Sri Lanka. Available at: https://greenstat.lk/about-us/#hydrogen
- Greentology (2024). Proponen planta piloto de amoniaco verde e hidrógeno a partir de aguas residuales. Available at: https://greentology.life/2024/02/02/proponen-planta-piloto-de-amoniaco-verde-e-hidrogeno-a-partir-de-aguas-residuales/.

- Guan et al. (2024). Effect of graphene aerogel as a catalyst layer additive on performance of direct methanol fuel cell. Available at: https://www.sciencedirect.com/science/article/pii/S0016236123031174
- Gupta, Ashish. (2019). "IOC Bets on Hydrogen Fuel Cells.". Available at: https://www.fortuneindia.com/technology/ioc-bets-on-hydrogen-fuel-cells/103695
- H2 Bulletin (2022). Dastur completes CCU study at the IOCL Koyali Refinery in India. Available at: https://h2bulletin.com/dastur-completes-ccu-study-at-the-iocl-koyali-refinery-in-india/
- H2 Bulletin (2024). Hydrogen Associations. Available at: https://www.h2bulletin.com/knowledge/hydrogen-associations/
- H2 Business news (2024). Arranca el desarrollo de la primera planta de fertilizantes nitrogenados verdes de Brasil. Available at: https://h2businessnews.com/desarrollo-planta-fertilizantes-nitrogenados-verdes-brasil/.
- H2 Chile. (2023). LAC Clean Hydrogen Action renueva compromisos y anuncia nuevo secretariado. Available at: https://h2chile.cl/2023/10/lac-clean-hydrogen-action-renueva-compromisos-y-anuncia-nuevo-secretariado/
- H2 Perú (2023). Bases y recomendaciones para la elaboración de la Estrategia de Hidrógeno Verde en el Perú. Available at: https://h2.pe/uploads/PLAYBOOK-1.3.1.4-2.pdf
- H2 Perú (2023). Hoja de ruta del Hidrógeno verde en el Perú al 2050. Available at: https://h2.pe/uploads/Li%CC%81nea-de-tiempo.jpg

- H2 Vector (2023). LOHC – Liquid Organic Hydrogen Carrier. Available at: https://www.h2vector.com/noticias/lohc-liquid-organic-hydrogen-carrier
- H2business news (2023). Fortescue recibe la primera licencia para producir hidrógeno verde en Brasil. Available at: https://h2businessnews.com/fortescue-recibe-la-primera-licencia-para-producir-hidrogeno-verde-en-brasil/
- H2LAC (2023). México: Campeche contará con la primera planta de amoníaco verde. Available at: https://h2lac.org/noticias/mexico-campeche-contara-con-la-primera-planta-de-amoniaco-verde/
- H2LAC (2023). Unigel invertirá US $1.500 millones para la producción de hidrógeno verde a nivel industrial en Brasil. Available at: https://h2lac.org/noticias/unigel-invertira-us-1-500-millones-para-la-produccion-de-hidrogeno-verde-a-nivel-industrial-en-brasil/
- H2LAC (2024). Asociados de la Plataforma. Available at: https://h2lac.org/asociados/
- H2LAC Index. (2024). México. Available at: https://h2lacindex.com/es/country/mexico#main
- H2LAC. (2022). Who we are. Available at: https://h2lac.org/quienes-somos/
- H2LAC. (2023). Convocatoria regional de innovación H2 Verde LATAM. Available at: https://h2lac.org/convocatoria-regional-de-innovacion-h2-verde-latam/
- H2LAC. (January de 2024). Identificación Hubs H2 Verde en Colombia. Available at: https://h2lac.org/archivos/identificacion-hubs-h2-verde-en-colombia/
- H2.SA, GIZ (2023). Emerging themes and priorities of green hydrogen research to support public and private sector objectives. Available at:

https://greenhydrogensummit.org.za/wp-content/uploads/2024/04/GIZ_Sanedi_H2-report.pdf

- H2U. (2024). HYDROGEN VALLEYS. Available at: https://h2u.ua/en/projects/
- Hardman & Tal (2018). Who are the early adopters of fuel cell vehicles? Available at: https://www.sciencedirect.com/science/article/abs/pii/S036031991832490X?via%3Dihub
- HD Photovoltaics (2020). Available at: https://www.hdfotovoltaica.com/?lang=en
- HDF (2024). Pacific Trade Invest supports Hydrogen Power Fiji to develop its first green hydrogen power plant project in the Pacific. Available at: Press release | HDF | Game-changing hydrogen power (hdf-energy.com).
- HDF (2024). Proyecto. Available at: https://www.energia-loscabos.com/proyecto
- HDF Energy (2024). RENEWSTABLE SUMBA. Available at: https://www.renewstable-sumba.com/.
- HDF Energy. (2024). Renewstable hydrogen power plant. Available at: https://www.hdf-energy.com/en/h2-infrastructure/
- Hidrogeno verde para Bolivia (2024). GH2 Car in Oruro. Available at: https://www.facebook.com/story.php/?story_fbid=441279778290794&id=100072263253039.
- Hidrojen Teknolojileri Derneği (2024). Available at: https://www.hidrojenteknolojileri.org/

- HintCo (2024). H2Global's Pilot Auction Results. Available at:
- Hychico (2024). Planta de hidrógeno Hychico. Available at: https://hychico.com.ar/planta-de-hidrogeno/
- Hydrocarbon Engineering. (2020). NEUMAN & ESSER acquires HYTRON. Available at: https://www.hydrocarbonengineering.com/clean-fuels/20112020/neuman-esser-acquires-hytron/
- Hydrogen Central (2022). Burkina Faso Wants to Experiment with Green Hydrogen. Available at: https://hydrogen-central.com/burkina-faso-experiment-green-hydrogen/#google_vignette
- Hydrogen Central (2022). COP27- Egypt signs eight framework agreements for hydrogen projects, including an $8 billion green hydrogen factory. Available at: https://hydrogen-central.com/cop27-egypt-signs-eight-framework-agreements-hydrogen-projects-including-8-billion-green-hydrogen-factory/
- Hydrogen Council & McKinsey & Company, 2021b, Hydrogen Insights (2021). An updated perspective on hydrogen investment, market development, and momentum in China. Available at: https://hydrogencouncil.com/wp-content/uploads/2021/07/Hydrogen-Insights-July-2021-Executive-summary.pdf
- Hydrogen Council (2022). The liquefied hydrogen carrier. Available at: https://hydrogencouncil.com/en/toward-a-new-era-of-hydrogen-energy-suiso-frontier-built-by-japans-kawasaki-heavy-industries/
- Hydrogen economy and sustainable development goals: Review and policy insights (2021). Available at: https://www.sciencedirect.com/science/article/pii/S2452223621000626

- Hydrogen Egypt (2023). Available at: https://www.hydrogenegypt.com/
- Hydrogen Insight (2023). Angola will start shipping green hydrogen to Germany in 2024, becoming first African exporter,' says ambassador. Available at: https://www.hydrogeninsight.com/production/angola-will-start-shipping-green-hydrogen-to-germany-in-2024-becoming-first-african-exporter-says-ambassador/2-1-1435866
- Hydrogen Insight (2023). EU Promises investments of €2bn in Brazilian green hydrogen. Available at: https://www.hydrogeninsight.com/production/eu-promises-investments-of-2bn-in-brazilian-green-hydrogen/2-1-1466536
- Hydrogen Insight (2023). Shanghai plans offshore wind-powered green hydrogen pilot by 2026. Available at: https://www.hydrogeninsight.com/production/shanghai-plans-offshore-wind-powered-green-hydrogen-pilot-by-2026/2-1-1540130.
- Hydrogen Insight (2024). Chinese scientists produce green hydrogen directly from seawater at floating offshore pilot project. Available at: https://www.hydrogeninsight.com/innovation/chinese-scientists-produce-green-hydrogen-directly-from-seawater-at-floating-offshore-pilot-project/2-1-1461905.
- Hydrogen Insight (2024). Malaysia's largest green hydrogen project to begin construction this year after closing $400m in finance. Available at: https://www.hydrogeninsight.com/production/malaysias-largest-green-hydrogen-project-to-begin-construction-this-year-after-closing-400m-in-finance/2-1-1602253.
- Hydrogen Insight (2024). World's longest hydrogen pipeline, covering 700km, set for construction work this year at a cost of $845m. Available at:

https://www.hydrogeninsight.com/production/worlds-longest-hydrogen-pipeline-covering-700km-set-for-construction-work-this-year-at-a-cost-of-845m/2-1-1605339.

- Hydrogen Insight. (2024). Malaysia's largest green hydrogen project to begin construction this year after closing $400m in finance. Available at: https://www.hydrogeninsight.com/production/malaysias-largest-green-hydrogen-project-to-begin-construction-this-year-after-closing-400m-in-finance/2-1-1602253
- Hydrogen Insight. (2024). World's longest hydrogen pipeline, covering 700km, set for construction work this year at a cost of $845m. Available at: https://www.hydrogeninsight.com/production/worlds-longest-hydrogen-pipeline-covering-700km-set-for-construction-work-this-year-at-a-cost-of-845m/2-1-1605339
- Hydrogen Insights. (2023). Egypt agrees deal for $4bn Suez Canal green hydrogen project. Available at: https://www.hydrogeninsight.com/production/egypt-agrees-deal-for-4bn-suez-canal-green-hydrogen-project/2-1-1500084
- Hydrogen Ukraine (2024). Projects. Available at: https://h2u.ua/ua/proekty/
- hyiron (2024). Project Oshivela - Namibia. Available at: https://hyiron.com/oshivela/
- Hyphen (2024). Projects. Available at: https://hyphenafrica.com/projects/.
- Hyphen Africa. (2023). Hyphen Hydrogen Energy and SDG Namibia One Fund Agree on Equity Stake in Country’s First Gigawatt-scale Green Hydrogen Project. Available at: https://hyphenafrica.com/press/hyphen-hydrogen-

energy-and-sdg-namibia-one-fund-agree-on-equity-stake-in-countrys-first-gigawatt-scale-green-hydrogen-project/

- Hyphen Hydrogen Energy. (2024). Southern Corridor Development Initiative (SCDI) Namibian Green Hydrogen Project. Available at: https://hyphenafrica.com/projects/
- Hyphen. (2024). Hyphen Hydrogen Energy Project Status Update. Available at: https://hyphenafrica.com/news/hyphen-hydrogen-energy-project-status-update/
- Hyphen. (2024). Projects. Available at: https://hyphenafrica.com/projects/
- HySA (2017). Prototypes. Available at: https://www.hysasystems.com/index.php/products/prototypes.
- Hytron. (2020). Acquisition of HYTRON Energy & Gas strengthens NEA GROUPs' leading position in the field of hydrogen solutions. Available at: https://www.hytron.com.br/c%C3%B3pia-about-us
- IDB (2023). Argentina Promotes Sustainable, Resilient Growth with IDB Assistance. Available at: https://www.iadb.org/en/news/argentina-promotes-sustainable-resilient-growth-idb-assistance
- IDB. (2021). Support for the Development of the National Hydrogen Strategy towards a Decarbonized Economy. Available at: https://www.iadb.org/en/project/CR-T1239
- IDB. (2023). CertHiLAC: Sistema de certificación de hidrógeno limpio para América Latina y el Caribe. Available at:

https://blogs.iadb.org/energia/es/certhilac-sistema-de-certificacion-de-hidrogeno-limpio-para-america-latina-y-el-caribe/

- IDB. (2023). Unlocking Green and Just Hydrogen in Latin America and the Caribbean.
- IEA (2019). The future of hydrogen. Available at: https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf
- IEA (2022). An Energy Sector Roadmap to Net Zero Emissions in Indonesia. Available at: https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia
- IEA (2023). Global Hydrogen Review 2023. Available at: https://iea.blob.core.windows.net/assets/ecdfc3bb-d212-4a4c-9ff7-6ce5b1e19cef/GlobalHydrogenReview2023.pdf
- IEA (2023). Hydrogen patents for a clean energy future. Available at: https://iea.blob.core.windows.net/assets/1b7ab289-ecbc-4ec2-a238-f7d4f022d60f/Hydrogenpatentsforacleanenergyfuture.pdf
- IEA (2024). Hydrogen production projects interactive map. Available at: https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map
- IEA (2024). IEA CCUS Projects data base 2024. Available at: https://www.iea.org/data-and-statistics/data-product/ccus-projects-database.
- IEA (2024). Large-scale alkaline water electrolyzer. Available at: https://ak-green-solution.com/en/

- IEA (2024). List of participants Energy Innovation Forum. Available at: https://cdn-assets.inwink.com/ae3ea879-542b-4f2b-92f2-b53329b95952/2222db12-62c3-47d2-a6ef-88ddbd2e9681?sv=2018-03-28&sr=b&sig=YwYz5ymxe7Eo97xayuhOKL67l2K7160luKJA7Zr7CKg%3D&se=9999-12-31T23%3A59%3A59Z&sp=r&rscd=inline%3B%20filename%3D%22Innovation%2520Forum_LoP_%2520for%2520WEB_FINAL_AS%2520ATTENDED.pdf%22
- IEA. (2019). The Future of Hydroen.
- IEA. (2023). Lagging policy support and rising cost pressures put investment plans for low-emissions hydrogen at risk.
- IEA (2023). +H2 Colombia. Available at: https://www.iea.org/policies/16978-h2-colombia
- IEA. (2024). World Energy Investment . International Energy Agency.
- IIT Delhi (2021). Press Release: IIT Delhi researchers operate clean fuel hydrogen from water at low cost; demonstrates successful pilot-plant. Available at: https://home.iitd.ac.in/news-hydrogen-fuel.php#:~:text=In%20the%20study%2C%20researchers%20from,hydrogen%20fuel%20for%20industrial%20consumption.
- IIT Madras (2024). What's the Hydrogen Valley Innovation Hub at IIT Madras? Available at: https://www.iitm.ac.in/happenings/press-releases-and-coverages/whats-hydrogen-valley-innovation-hub-iit-madras#:~:text=But%20for%20H2ICE%2C%20relatively%20less,workshops%2C%20besides%20publishing%20research%20papers.
- Inc 42 (2022). Cleantech startup Hygenco raises $25 Mn funding from Neev II Fund. Available at: https://inc42.com/buzz/neev-ii-fund-invests-25-mn-in-cleantech-startup-hygenco/

- India Hydrogen Alliance (2022). IH2A, Kerala Government to work on Kochi Green Hydrogen KGH2 Hub. Available at: https://ih2a.com/announcements/ih2a-kerala-government-to-work-on-kochi-green-hydrogen-kgh2-hub/
- Indonesia Business Post (2024). Pertamina Geothermal Energy explores massive production of green hydrogen. Available at: https://indonesiabusinesspost.com/risks-opportunities/pertamina-geothermal-energy-explores-massive-production-of-green-hydrogen/
- Indonesia IHS . (2024). Pertamina, TEPCO to develop green hydrogen, ammonia in North Sulawesi. Available at: https://www.indonesia-ihs.com/news-4.php
- Innovation Village. (s.f.). Global acquisitions: The art of it all and how startups can position to benefit. Available at: https://innovationvillage.africa/global-acquisitions-the-art-of-it-all-and-how-startups-can-position-to-benefit/
- Institute for Global Environmental Strategies (2023). Green Hydrogen Feasibility in Developing Countries. Available at: https://www.iges.or.jp/sites/default/files/inline-files/4-4_Kawnish_Kirtania_Green_Hydrogen_Feasibilty.pdf.
- Institute for Global Environmental Strategies (IGES), Japan (2023). Green Hydrogen Feasibility in Developing Countries. Available at: https://www.iges.or.jp/sites/default/files/inline-files/4-4_Kawnish_Kirtania_Green_Hydrogen_Feasibilty.pdf
- Institute of Energy, University of Dhaka, Bangladesh (2021). Production of Green Hydrogen in Bangladesh and its Levelized Cost. Available at: https://jase.du.ac.bd/uploads/articles/202162/63668ec427451.pdf

- International Journal of Hydrogen Energy (2024). Algeria's journey towards a green hydrogen future: Strategies for renewable energy integration and climate commitments. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0360319924001228#:~:text=The%20Algerian%20Strategy%20on%20Green,its%20consumption%20of%20petroleum%20products.
- International PtX Hub. (2024). PtX Hub in Morocco. Available at: https://ptx-hub.org/morocco/
- IPHE (2024). International Partnership for Hydrogen and Fuel Cells in the Economy. Available at: https://www.iphe.net/
- IRENA (2022). Geopolitics of the Energy Transformation: The Hydrogen Factor. Available at: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen
- IRENA (2023). Water for hydrogen production. Available at: https://www.irena.org/Publications/2023/Dec/Water-for-hydrogen-production
- IRENA. (2022). Geopolitics of the Energy Transformation: The Hydrogen Factor. Available at: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen
- IRENA-WTO (2023). International Trade and Green Hydrogen. Available at: https://www.wto.org/english/res_e/webcas_e/rss_e.htm
- IRESEN. (2024). Institut de Recherche en Energie Solaire et Energies Nouvelles. Available at: https://iresen.org/
- IRESEN. (2024). Who are we? Available at: https://iresen.org/institu

- IT Power Consulting Private Limited (2017). Renewable Energy Roadmap for Afghanistan. Available at: https://policy.asiapacificenergy.org/sites/default/files/Renewable%20Energy%20Roadmap%20for%20Afghanistan%20RER2032.pdf
- Green H2 World (2024). Indus Towers and IIT Madras spearhead green hydrogen and BMS research. Available at: https://www.greenh2world.com/news/indus-towers-and-iit-madras-spearhead-green-hydrogen-and-bms-research
- Jafari Raad (2022). Hydrogen storage in saline aquifers: Opportunities and challenges. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1364032122007286
- Japan Bank for International Cooperation (2024). Press Release: JBIC signs MoU with Empresas Públicas de Medellín E.S.P. of Republic of Colombia. Available at: https://www.jbic.go.jp/en/information/press/press-2024/press_00004.html
- Jiang et al. (2024). Metallic Cu-incorporated NiFe layered double hydroxide nanosheets enabling energy-saving hydrogen generation from chlorine-free seawater electrolysis coupled with sulfion upcycling. Available at: https://www.sciencedirect.com/science/article/pii/S0016236124006549
- Jondhle et al. (2023). An artificial intelligence and improved optimization-based energy management system of battery-fuel cell-ultracapacitor in hybrid electric vehicles. Available at: https://www.sciencedirect.com/science/article/pii/S2352152X23024775
- Jumaat & Khalid (2024). A comprehensive review of challenges, prospects and future perspectives for hydrogen energy development in Malaysia. Available at:

https://www.sciencedirect.com/science/article/abs/pii/S0360319923057415#:~:text=Apart%20from%20the%20national%20hydrogen,as%20a%20sustainable%20energy%20carrier.

- Kakoki (2024). ICI type steam reforming. Available at: https://www.kakoki.co.jp/english/products/p-003/index.html
- Kandasamy, Nefise, Eroglu, Karaca, Tofoli, Gökalp (2023). Hydrogen production using aluminum-water splitting: A combined experimental and theoretical approach. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0360319923017986?via%3Dihub
- Kazmier, Robin (2018). Central America's First Hydrogen-Fueled Bus Hits the Road in Costa Rica. Tico Times. Available at: https://ticotimes.net/2018/04/18/central-americas-first-hydrogen-fueled-bus-hits-the-road-incosta-rica
- Kekul, Ilbas & Karyeyen (2024). Hydrogen concentration effects on a swirl-stabilized non-premixed burner using ammonia. Available at: https://www.sciencedirect.com/science/article/pii/S0360319923025934
- KfW (2021). Request for Information: Project opportunities for the production, consumption, transport or storage of green hydrogen and derivatives in South Africa. Available at: https://www.csir.co.za/sites/default/files/Documents/Green-hydrogen-RFI-2021.pdf
- Khan & Al-Ghamdi (2023). Hydrogen economy for sustainable development in GCC countries: A SWOT analysis considering current situation, challenges, and

prospects. Available at: https://www.sciencedirect.com/science/article/pii/S0360319922057500

- Kover, A (2023). Six Ways Berkeley Lab is Helping to Bring Clean Hydrogen to the World. Available at: https://newscenter.lbl.gov/2023/10/06/six-ways-berkeley-lab-is-bringing-clean-hydrogen-to-the-world/
- Kumar, Muthukumar (2024). Experimental investigation on hydrogen transfer in coupled metal hydride reactors for multistage hydrogen purification application. Available at: https://www.sciencedirect.com/science/article/pii/S0306261924004598
- Kuterbekov et al. (2024). Energy, exergy and thermo-economics analyses of hybrid solar, steam turbine and biomass gasification system for hydrogen production by polymer membrane electrolyzer. Available at: https://www.sciencedirect.com/science/article/pii/S2666202723002719
- Li et al. (2024). Exploring the potential Ru-based catalysts for commercial-scale polymer electrolyte membrane water electrolysis: A systematic review. Available at: https://www.sciencedirect.com/science/article/pii/S007964252400063X
- Li, Du et al. (2022). Novel layered triple hydroxide sphere CO2 adsorbent supported copper nanocluster catalyst for efficient methanol synthesis via CO2 hydrogenation. Available at: https://www.sciencedirect.com/science/article/pii/S0021951722000999
- Liang et a. (2023). High methanol tolerant proton exchange membranes based on novel coupling-type sulfonated poly(phenylquinoxaline) for direct methanol fuel cells. Available at: https://www.sciencedirect.com/science/article/pii/S0376738823005768

- Liu et al. (2024). Development of advanced anion exchange membrane from the view of the performance of water electrolysis cell. Available at: https://www.sciencedirect.com/science/article/pii/S2095495623006721
- Liu, Liu (2024). Experimental investigation of the effect of ammonia substitution ratio on an ammonia-diesel dual-fuel engine performance. Available at: https://www.sciencedirect.com/science/article/pii/S0959652623044323
- Liu, Tian et al. (2024) A defective NiCo-pentlandite/black phosphorus heterostructure for efficient water splitting electrocatalysis. Available at: https://doi.org/10.1039/d3ma01070h
- Liu, Wang et al. (2024). Reheat effect on the improvement in efficiency of the turbine driven by pulse detonation. Available at: https://www.sciencedirect.com/science/article/pii/S2214914723002209
- Liu, Wu et al. (2023). Effect of the loading mode and temperature on hydrogen embrittlement behavior of 15Cr for steam turbine last stage blade steel. Available at: https://www.sciencedirect.com/science/article/pii/S036031992204705X
- Lu et al. (2023). Yolk-shell composite oxides with binuclear Co(II) sites toward low-overpotential nitrate reduction to ammonia. Available at: https://www.sciencedirect.com/science/article/pii/S1385894723056279
- Luo et al. (2024). Plasma-induced nitrogen vacancy-mediated ammonia synthesis over a VN catalyst. Available at: https://www.sciencedirect.com/science/article/pii/S1359734524004968

- Makhmudova, K. (2023). EBRD supporting Azerbaijan with assessment of hydrogen production potential. Trend. Az. Available at: https://en.trend.az/other/commentary/3690275.html

- Malleswararao et al. (2022). Experiments on a novel metal hydride cartridge for hydrogen storage and low temperature thermal storage. Available at: https://www.sciencedirect.com/science/article/pii/S0360319922011570

- Martins (2024). Hydrogen and the Sustainable Development Goals: Synergies and Trade-Off. Available at: https://www.sciencedirect.com/science/article/pii/S1364032124005227
- Mattos Filho. (2024). Bill establishing legal framework for low-carbon hydrogen signed into law in Brazil. Available at: https://www.mattosfilho.com.br/en/unico/bill-low-carbon-hydrogen-brazil/#:~:text=If%20the%20bill%20is%20approved,Brazil%20between%202028%20and%202032.

- McKinsey (2021). How hydrogen combustion engines can contribute to zero emissions. Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-hydrogen-combustion-engines-can-contribute-to-zero-emissions

- Medeiros et al. (2023). Technology mapping of direct seawater electrolysis through patent analysis. Available at: https://www.sciencedirect.com/science/article/pii/S0360319923065515

- MED-GEM. (2024). REEN HYDROGEN CAMP: FROM THEORY TO ACTION » • Unlocking Potential with GH2 Summer School & Hackathon. From 1st to 6th July 2024, Benguerir. Available at: https://med-gem.eu/GH2CampPressRelease

- Mekasuwandumrong et al. (2024). Photocatalytic liquid-phase selective hydrogenation of furfural to furfuryl alcohol without external hydrogen on graphene-modified TiO2 with different polymorphs. Available at: https://www.sciencedirect.com/science/article/pii/S2666016424000872
- Mexico Business News (2023). H2V2 Mexico to enter joint venture to produce green hydrogen. Available at: https://mexicobusiness.news/energy/news/h2v2-mexico-enter-joint-venture-produce-green-hydrogen
- Mexico Business News (2023). Mexico, US sign agreement to promote the hydrogen industry. Available at: https://mexicobusiness.news/energy/news/mexico-us-sign-agreement-promote-hydrogen-industry
- Mexico business news (2024). Green Hydrogen Projects Garner US$20 Billion Investment in Mexico. Available at: https://mexicobusiness.news/energy/news/green-hydrogen-projects-garner-us20-billion-investment-mexico
- Mexico Energy Partners (2024). Available at: https://mexicoenergyllc.com.mx/
- Minister of Energy of Ukraine (2021). Draft Roadmap for production and use of hydrogen in Ukraine. Available at: https://unece.org/documents/2021/03/reports/draft-roadmap-production-and-use-hydrogen-ukraine
- Ministry of New and Renewable Energy (2023). R&D Roadmap for Green Hydrogen Ecosystem in India. Available at: https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/10/202310131572744879.pdf

- Ministère de l’Energie et des Mines Algérie (2023). Stratégie Nationale du Développement de l’Hydrogène en Algérie. Available at: https://www.cerefe.gov.dz/fr/2024/02/01/strategie-nationale-du-developpement-de-lhydrogene-en-algerie/
- Ministerio de Ambiente y Energía de Costa Rica (2022). Estrategia Nacional de Hidrógeno Verde de Costa Rica 2022-2050. Available at: https://energia.minae.go.cr/wp-content/uploads/2020/04/Estrategia-Nacional-de-H2-Verde-Costa-Rica.pdf
- Ministério de Minas e Energia do Brazil (2021). Programa Nacional do Hidrogênio. Available at: https://www.gov.br/mme/pt-br/assuntos/noticias/mme-apresenta-ao-cnpe-proposta-de-diretrizes-para-o-programa-nacional-do-hidrogenio-pnh2/HidrognioRelatriodiretrizes.pdf
- Ministério de Minas e Energia do Brazil (2023). Plano de Trabalho Trienal (PNH2). Available at: https://www.gov.br/mme/pt-br/assuntos/noticias/PlanodeTrabalhoTrienalPNH2.pdf
- Ministerio de Minas y Energía de Colombia (2021). Hoja de Ruta del Hidrógeno en Colombia. Available at: https://www.minenergia.gov.co/documents/5862/Colombias_Hydrogen_Roadmap_2810.pdf
- Ministerio de Minas y Energía de Ecuador (2022). Hoja de Ruta del Hidrógeno Verde en el Ecuador. Available at: https://www.recursosyenergia.gob.ec/wp-content/uploads/2023/08/Hoja-de-Ruta-del-Hidrogeno-Verde-en-Ecuador.pdf
- Ministre de l'Energie, des Mines et de l'Environnement du Royaume du Maroc (2021). Feuille de route hydrogène vert: vecteur de transition energetique et

de croissance durable. Available at: https://www.mem.gov.ma/Lists/Lst_rapports/Attachments/36/Feuille%20de%20route%20de%20hydrog%C3%A8ne%20vert.pdf

- Ministry of Energy and Petroleum ok Kenya (2023). Green Hydrogen Strategy and Roadmap for Kenya. Available at: https://www.eeas.europa.eu/sites/default/files/documents/2023/GREEN%20HYDROGEN%20EXEC_0209_0.pdf

- Ministry of Energy of the Republic of Uzbekistan (2021). Measures for the development of retrievable and water energy. Available at: https://lex.uz/ru/docs/5362035

- Ministry of Energy of Ukraine (n.d.). Hydrogen economy. Available at: https://spain.mfa.gov.ua/storage/app/sites/72/hydrogen-slide-green-project-slide-minenerg.pdf.

- Ministry of Energy of Ukraine. (2024). Projects. Available at: https://spain.mfa.gov.ua/storage/app/sites/72/hydrogen-slide-green-project-slide-minenerg.pdf

- Ministry of Information Technologies and Communications of Colombia. (2023). Available at: https://www.mintic.gov.co/portal/inicio/Sala-de-prensa/Noticias/281130:MinTIC-estructurara-10-sandbox-regulatorios-para-acelerar-los-ecosistemas-de-innovacion-en-Colombia#:~:text='Sandbox'%20son%20un%20tipo%20de,la%20Ley%202069%20de%202020.

- Ministry of Mineral Resources, Green Technology and Energy Security (2021). National Energy Policy Botswana. Available at:

https://www.bera.co.bw/downloads/National%20Energy%20Policy%20Final%20April%202021.pdf

- Ministry of Mines and Energy Namibia (2022). Namibia Green Hydrogen and Derivatives Strategy. Available at: https://www.ensafrica.com/uploads/newsarticles/0_namibia-gh2-strategy-rev2.pdf
- Ministry of Mines and Energy. (2024). ANEEL's Hydrogen Call attracts interest from 95 electric power companies. Available at: https://www.gov.br/aneel/pt-br/assuntos/noticias/2024/chamada-de-hidrogenio-da-aneel-atrai-interesse-de-95-empresas-de-energia-eletrica
- Ministry of Mines and Energy. (2024). Strategic Call for PDI No. 023/2024: Hydrogen in the Context of the Brazilian Electricity Sector. Available at: https://www.gov.br/aneel/pt-br/assuntos/programa-de-pesquisa-desenvolvimento-e-inovacao/chamadas-de-projetos-de-pdi-estrategicos/chamada-n-o-023-2024-hidrogenio-no-contexto-do-setor-eletrico-brasileiro
- Ministry of New and Renewable Energy of India (2023). National Green Hydrogen Mission 2023. Available at: https://mnre.gov.in/en/national-green-hydrogen-mission/
- Ministry of Power (2021). India begins its journey in the large scale Battery Energy Storage System (BESS) for 1000 Mwhourproject. Available at: https://pib.gov.in/PressReleasePage.aspx?PRID=1763883.
- Ministry of Science, Technology and Innovation of Malaysia (2023). Hydrogen Economy & Technology Roadmap. Available at: https://www.mosti.gov.my/dasar/#dearflip-df_69947/1/

- Mishra et al. (2024). Dual role of 2-aminodiphenylamine with graphene oxide-palladium supported catalyst for direct methanol fuel cell application and removal of Otto fuel II component. Available at: https://www.sciencedirect.com/science/article/pii/S2468023024001743
- Mission Innovation (2018). Clean Energy Materials Innovation Policies and Programs in Mission Innovation Member Countries. Available at: https://mission-innovation.net/wp-content/uploads/2019/01/6.1.21-Materials-IC-Jan-2018-workshop-report-annex.pdf
- Mission Innovation (2019). Off-grid innovation challenge: synthesis report 2019. Available at: https://mission-innovation.net/wp-content/uploads/2019/11/IC2-Synthesis-report-201926920.pdf
- Mission Innovation. (2024). Mission Innovation Hydrogen Valley Platform. Available at: https://h2v.eu/
- Mission Innovations (2021). Country Highlights 6th MI Ministerial. Available at: https://mission-innovation.net/wp-content/uploads/2021/05/MI_2021v0527.pdf
- MNRE. (2023). National Green Hydrogen Mission. Available at: https://mnre.gov.in/national-green-hydrogen-mission/
- MNRE. (2024). Government extends deadline for submission of R&D Proposals under National Green Hydrogen Mission. Available at: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2017558
- Moati, Abdel Wael Eng (2023). Item 6: Prospects of Blue Hydrogen and Ammonia in the Arab Region | UNECE. Available at:

https://unece.org/sed/documents/2023/03/presentations/item-6-prospects-blue-hydrogen-and-ammonia-arab-region-eng-wael.

- Mobility Plaza (2020). Y-TEC launches Hydrogen Development Consortium. https://www.mobilityplaza.org/news/25096#:~:text=H2ar%20Consortium%20is%20an%20initiative,hydrogen%20value%20chain%20in%20Argentina.
- Moradi, Afshari & Baniasadi (2023). Anion exchange membrane water electrolysis: Numerical modeling and electrochemical performance analysis. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0360319923024916?via%3DihubRei
- Morocco World News. (2022). Morocco Establishes Its First Green Hydrogen Production System. Available at: https://www.moroccoworldnews.com/2022/09/351348/morocco-establishes-its-first-green-hydrogen-production-system
- Mukelabai, Wijayantha & Blanchard (2022). Hydrogen for Cooking: A review of cooking technologies, renewable hydrogen systems and techno-economics. Available at: https://www.researchgate.net/publication/366434389_Hydrogen_for_Cooking_A_Review_of_Cooking_Technologies_Renewable_Hydrogen_Systems_and_Techno-Economics
- Müller, Tunn and Kalt (2022). Hydrogen Justice, Environmental Research Letters Vol 17. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/ac991a
- Mutambatsere, E., De Vautibault, M. (2022). Blended finance can catalyze renewable energy investments in low-income countries. Available at:

https://blogs.worldbank.org/ppps/blended-finance-can-catalyzerenewable-energy-investments-low-income-countries

- Najafi & Acaroğlu (2024). Chapter 7 - Current trend of bioenergy of biogas, biomethane, and hydrogen in developed countries. Available at: https://www.sciencedirect.com/science/article/pii/B9780443141126000079
- NamGHA (2024). Namibian Green Hydrogen Association. Available at: https://namgha.org/
- Namport (2022). Namport ready to embrace green hydrogen. Available at: https://www.namport.com.na/news/1086/namport-ready-to-embrace-green-hydrogen/
- Nantong (2020). Rugao hydrogen energy vehicle testing platform unveiled. Available at: https://subsites.chinadaily.com.cn/nantong/2020-09/18/c_538908.htm.
- National Science Foundation of Sri Lanka (2024). Available at: http://www.nsf.ac.lk/
- Navigant (2019). Gas for Climate: Job creation by scaling up renewable gas in Europe. Available at: https://gasforclimate2050.eu/wp-content/uploads/2020/03/Navigant-Gas-for-Climate-Job-creation-by-scaling-up-renewable-gas-in-Europe.pdf
- Nepal Hydrogen Initiative (2021). Nepal Hydrogen Initiative. Available at: https://nhi.ku.edu.np/#:~:text=The%20Nepal%20Hydrogen%20Initiative%20(NHI,the%20environment%2C%20fuel%2C%20energy%2C

- Nivedhitha et al. (2024). Advances in hydrogen storage with metal hydrides: Mechanisms, materials, and challenges. Available at: https://www.sciencedirect.com/science/article/pii/S036031992400778X
- Norgesportalen (2023). Mapping Opportunities in Establishing
- Norgesportalen. (2023). Mapping Opportunities in Establishing . Available at: https://www.norway.no/globalassets/2-world/malaysia/hydrogen-mapping-in-malaysia-report.pdf
- Noticias ASG (2023). Namibia es pionera en la producción de hierro sin emisiones con el proyecto HyIron Oshivela. Available at: https://esgnews.com/es/amp/Namibia-es-pionera-en-la-producci%C3%B3n-de-hierro-con-cero-emisiones-con-el-proyecto-Hyiron-Oshivela/
- Now-Gmbh (2023). Green hydrogen technology for decentralized energy systems in Sub-Saharan Africa (GH2GH). Available at: https://www.now-gmbh.de/en/projectfinder/gh2gh/.
- NTPC (2023). Country's largest power generator, NTPC Ltd commissions India's first green hydrogen blending project. Available at: https://ntpc.co.in/media/press-releases/ntpc-starts-indias-first-green-hydrogen-blending-operation-png-network#:~:text=New%20Delhi%2C%20January%2004%2C%202023,Gujarat%20Gas%20Limited%20(GGL).
- NTPC. (2023). Media. Available at: https://ntpc.co.in/media/press-releases/ntpc-starts-indias-first-green-hydrogen-blending-operation-png-network#:~:text=New%20Delhi%2C%20January%2004%2C%202023,Gujarat%20Gas%20Limited%20(GGL).

- OBAYASHI (2024). Commencement of PoC for Green Hydrogen Production, Transportation and Utilization in New Zealand and the Republic of Fiji. Available at: https://www.obayashi.co.jp/en/news/detail/news20231222_1_en.html
- OCP (2024). OCP & Fortescue to partner in green energy, hydrogen and ammonia in Morocco Available at: https://www.ocpgroup.ma/press-release-article/ocp-fortescue-partner-green-energy-hydrogen-and-ammonia-morocco
- OCPGROUP (2024). OCP & Fortescue to partner in green energy, hydrogen and ammonia in Morocco. Available at: https://www.ocpgroup.ma/press-release-article/ocp-fortescue-partner-green-energy-hydrogen-and-ammonia-morocco
- OECD (2023). Supporting EMDEs in attracting more, better, and safe FDI. Available at: https://www.oecd.org/economy/G7/Supporting-EMDEs-in-attracting-more-better-and-safe-FDI.pdf
- OECD (2024). Chariot & Total Eren - Project Nour in Mauritiania. Available at: https://www.oecd.org/environment/cc/cefim/green-hydrogen/chariottotaleren-projectnourinmauritiania.htm
- OECD. (2023). DAC List of ODA Recipients.
- OECD. (s.f.). Ad Astra - Trucks and buses – Costa Rica.
- Oertzen (2021). Issues, challenges, opportunities to develop green hydrogen in Namibia. Available at: https://www.kas.de/en/web/namibia/single-title/-/content/issues-challenges-and-opportunities-to-develop-green-hydrogen-in-namibia-1

- Offshore Energy (2023). FEED work begins on green hydrogen and ammonia project in Malaysia. Available at: https://www.offshore-energy.biz/feed-work-begins-on-green-hydrogen-and-ammonia-project-in-malaysia/
- Opex (2022). Hevolucion. Available at: https://h2lac.org/noticias/hevolucion-el-proyecto-colombiano-de-movilidad-con-hidrogeno-verde/.
- Osman et al. (2024). Advances in hydrogen storage materials: harnessing innovative technology, from machine learning to computational chemistry, for energy storage solutions. Available at: https://www.sciencedirect.com/science/article/pii/S036031992401053X
- OXPECKERS (2024). Mpumalanga carbon capture pilot project completed. Available at: https://oxpeckers.org/2024/04/mpumalanga-carbon-capture/.
- Ozturk et al. (2024). Experimental investigation of various burner heads in residential gas stoves tested with hydrogen and natural gas blends. Available at: https://www.sciencedirect.com/science/article/pii/S0360319923062031
- PASH Global (2023). Press Release: PASH Global and ERIH Holdings join forces to create a world leader green hydrogen company. Available at: https://www.pashglobal.com/pash-global-and-erih-holdings-join-forces-to-create-a-world-leader-green-hydrogen-company/
- Pashchenko (2024). Ammonia fired gas turbines: Recent advances and future perspectives. Available at: https://www.sciencedirect.com/science/article/pii/S036054422400046X
- Pegu et al. (2024). Cu nanoparticle anchored highly conducting, reusable multifunctional rGO/PANI nanocomposite: A novel material for methanol

sensor and a catalyst for click reaction. Available at: https://www.sciencedirect.com/science/article/pii/S0379677923002382

- Periferia (2023). Y-TEC trabaja en un electrolizador de alta potencia para producir hidrógeno verde. Available at: https://periferia.com.ar/innovacion/y-tec-trabaja-en-un-electrolizador-de-alta-potencia-para-producir-hidrogeno-verde/
- Petroleum Development Authority of Sri Lanka & Greenstat (2023). Sri Lanka National Hydrogen Roadmap. Available at: https://pdasl.gov.lk/wp-content/uploads/2023/08/Sri-Lanka-National-Hydrogen-Roadmap.pdf
- Piedepagina (2024). Delicias Solar: un proyecto de hidrógeno verde estancado en la burocracia. Available at: https://piedepagina.mx/delicias-solar-un-proyecto-de-hidrogeno-verde-estancado-en-el-papeleo/
- Platofrma H2 Argentina (2024). Available at: https://www.plataformah2.org/
- Pradhan, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. (2017). A Systematic Study of Sustainable Development Goal (SDG) Interactions. Earth's Future, 1169-1179.
- Presidency of the Republic. (s.f.). Law 9,991. Available at: https://www.planalto.gov.br/CCIVIL_03/LEIS/L9991.htm#:~:text=LEI%20No%209.991%2C%20DE%2024%20DE%20JULHO%20DE%202000.&text=Disp%C3%B5e%20sobre%20realiza%C3%A7%C3%A3o%20de%20investimentos,el%C3%A9trica%2C%20e%20d%C3%A1%20outras%20provid%C3%AAncias.
- ProNova Energy. (2022). Cavendish joins Mesoamerica and Ad Astra in ProNova Energy, a joint venture to develop green hydrogen projects in Costa Rica. .

- PtX Hub (2024). Jordan is moving beyond green hydrogen. Available at: https://ptx-hub.org/jordan-is-moving-beyond-green-hydrogen/
- PV Europe (2022). German-Namibian cooperation for green hydrogen. Available at: 'https://www.pveurope.eu/markets/international-energy-transition-german-namibian-cooperation-green-hydrogen
- PV magazine (2024). Solatio plans 4 GW of solar for hydrogen production in Brazil. Available at: https://www.pv-magazine.com/2024/06/11/solatio-plans-4-gw-of-solar-for-hydrogen-production-in-brazil/
- PV Magazine. (2024). Green hydrogen hubs: Unfolding India's potential. Available at: https://www.pv-magazine-india.com/2024/06/12/green-hydrogen-hubs-unfolding-indias-potential/#:~:text=as%20hydrogen%20hubs.-,V.O.,India%27s%20first%20green%20hydrogen%20hub.
-
- PV magazine. (2024). Solatio plans 4 GW of solar for hydrogen production in Brazil. Available at: https://www.pv-magazine.com/2024/06/11/solatio-plans-4-gw-of-solar-for-hydrogen-production-in-brazil/
- Rahimi et al. (2023). The effect of hydrogen addition on methane-air flame in a stratified swirl burner. Available at: https://www.sciencedirect.com/science/article/pii/S0360544222032406
- Railwaygazette (2022). Hydrogen-diesel dual-fuel locomotive initiative targets African market. Available at: https://www.railwaygazette.com/traction-and-rolling-stock/hydrogen-diesel-dual-fuel-locomotive-initiative-targets-african-market/62759.article

- Rani et al. (2023). Compton spectroscopy of hydrogen storage material LiAlH4: Experiment and DFT strategies. Available at: https://www.sciencedirect.com/science/article/pii/S2352492823007080
- Reccessary. (2024). Semarak RE secures funding for Malaysia's largest green hydrogen project. Available at: https://www.reccessary.com/en/news/my-market/semarak-re-secures-funding-malaysia-largest-green-hydrogen-project
- Renewable Energy Association of Nigeria (2024). Available at: https://rean.org.ng/
- Renewable watch (2022). BPCL calls bids for building a 5 MW green hydrogen production facility. Available at: https://renewablewatch.in/2022/06/23/bpcl-calls-bids-for-building-a-5-mw-green-hydrogen-production-facility/
- Renewables Now (2023). Flexens to probe feasibility for green H2 production on Cape Verde Hydrogen tanks. Source: US Office of Energy Efficiency & Renewable Energy. Available at: https://renewablesnow.com/news/flexens-to-probe-feasibility-for-green-h2-production-on-cape-verde-824682/
- Renewables now (2024). Chile's Colbun starts green H2 production at gas-fired plant in Peru. Available at: https://renewablesnow.com/news/chiles-colbun-starts-green-h2-production-at-gas-fired-plant-in-peru-846834/.
- Renewables now (2024). Energy Vault gravity storage system of 100 MWh grid connected in China. Available at: https://renewablesnow.com/news/energy-vault-gravity-storage-system-of-100-mwh-grid-connected-in-china-850517/.
- Republic of Türkiye Ministry of Energy and Natural Resources (2023). Türkiye Hydrogen Technology Strategy and Roadmap. Available at:

https://enerji.gov.tr/Media/Dizin/SGB/en/HSP_en/ETKB_Hydrogen_T_Strategies.pdf

- Reuters (2021). Philippines set sights on hydrogen to diversify energy sources. Available at: https://www.reuters.com/article/idUSL4N2K40T8/
- Reuters (2024). World Bank approves $750 million climate change loan to Colombia. Available at: https://www.usnews.com/news/world/articles/2024-04-01/world-bank-approves-750-million-climate-change-loan-to-colombia
- Rheima et al. (2023). Aluminum oxide nano porous: Synthesis, properties, and applications. Available at: https://www.sciencedirect.com/science/article/pii/S2666016423001330
- Riviera (2024). India's first hydrogen fuel cell-powered ferry hits the water. Available at: https://www.rivieramm.com/news-content-hub/news-content-hub/indias-first-hydrogen-fuel-cell-powered-ferry-hits-the-water-79837
- Röd&Partner. (2024). Kenya's guidelines on green hydrogen and its derivatives. Available at: https://www.roedl.com/insights/renewable-energy/2024/july/kenyas-guidelines-green-hydrogen-derivatives
- Rödl and Partner (2023). Brazil- The imminent boom of green hydrogen. Available at: https://www.roedl.com/insights/renewable-energy/2023/june/brazil-boom-of-green-hydrogen
- S&P Global (2024). Vietnam's hydrogen economy takes shape with national strategy, projects. Available at: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/031524-vietnams-hydrogen-economy-takes-shape-with-national-strategy-projects

- SACREEE (2024). Member States. Available at: https://www.sacreee.org/member-states
- SAE (2023). Hydrogen ICE is heating up. Available at: https://www.sae.org/news/2023/12/hydrogen-engines-heating-up
- Samantaray et al. (2021). Graphene supported MgNi alloy nanocomposite as a room temperature hydrogen storage material – Experiments and theoretical insights. Available at: https://www.sciencedirect.com/science/article/pii/S1359645421004201
- Sanderson, Henry (2019). "Hydrogen Power: China Backs Fuel Cell Technology.". Available at: https://www.ft.com/content/27ccfc90-fa49-11e8-af46-2022a0b02a6c
- Sathe, Kumar & Ahuja (2023). Furtherance of the material-based hydrogen storage based on theory and experiments. Available at: https://www.sciencedirect.com/science/article/pii/S0360319922056257
- Scatec (2022). Scatec and partners start commissioning of "Egypt Green", Africa's first integrated green hydrogen plant, during UN Climate summit. Available at: https://scatec.com/2022/11/08/fertiglobe-scatec-orascom-construction-and-the-sovereign-fund-of-egypt-start-commissioning-of-egypt-green-africas-first-integrated-green-hydrogen-plant-during-un-climate/.
- Scatec. (2024). Scatec's Egypt Green Hydrogen Project signed 20-year offtake agreement with Fertiglobe, based on H2Global award. Available at: https://scatec.com/2024/07/11/scatecs-egypt-green-hydrogen-project-signed-20-year-offtake-agreement-with-fertiglobe-based-on-h2global-award/

- SCG Cleanergy (2024). Available at: https://scgcleanergy.com/
- Secretaria de Asuntos Estratégicos Argentina (2023). Estrategia Nacional para el desarrollo de la Economía del hidrógeno. Available at: https://www.argentina.gob.ar/asuntos-estrategicos/estrategia-nacional-para-el-desarrollo-de-la-economia-del-hidrogeno-0
- Secretaría Nacional de Energía de Panamá (2023). Estrategia Nacional de Hidrógeno Verde y Derivados de Panamá. Available at: https://www.gacetaoficial.gob.pa/pdfTemp/29771_B/98196.pdf
- Şefkat & Özel (2022). Experimental and numerical study of energy and thermal management system for a hydrogen fuel cell-battery hybrid electric vehicle. Available at: https://www.sciencedirect.com/science/article/pii/S0360544221020429
- Sharma et al. (2023). Socio-Economic Aspects of Hydrogen Energy. Available at: https://www.sciencedirect.com/science/article/pii/S0040162523002597
- Shell China (2024). China - M4 Electrolyser. Available at: https://www.shell.com/what-we-do/hydrogen.html.
- Ship Technology (2023). China's first hydrogen ship sets sail in Three Gorges area. Available at: https://www.ship-technology.com/news/chinas-hydrogen-ship-three-gorges-area/.
- Siemens (2020). Siemens Energy signs agreement to develop Afghanistan as an energy hub. Available at: https://www.siemens-energy.com/global/en/home/press-releases/siemens-energy-signs-agreement-develop-afghanistan-energy-hub.html

- Singh, Maiya & Murthy (2017). Experiments on solid state hydrogen storage device with a finned tube heat exchanger. Available at: https://www.sciencedirect.com/science/article/pii/S0360319917317949
- Sinopec (2023). Sinopec Xinjiang Kuqa Green Hydrogen Pilot Project Enters Operation, Leading China's Green Hydrogen Development. Available at: http://www.sinopecgroup.com/group/en/Sinopecnews/20230704/news_20230704_299217593563.shtml.
- SLSEnergy (2023). Towards circular batteries. Available at: https://www.slsenergy.io/
- SMH. (2024). Mexican Hydrogen Society. Available at: https://www.google.com/search?q=sociedad+mexicana+del+hidrogeno&rlz=1C1GCEA_enFR1070CL1070&oq=sociedad+mexicana+del+hidrogeno&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIJCAEQABgTGIAEMgoIAhAAGIAEGKIEMgoIAxAAGIAEGKIEMgoIBBAAGIAEGKIEMgoIBRAAGIAEGKIE0gEIMzkwNmowajSoAgCwA
- Solar quarter (2024). AES Brasil Presents Environmental Impact Study for Hydrogen and Ammonia Production Project in Pecém Complex. Available at: https://solarquarter.com/2024/06/07/aes-brasil-presents-environmental-impact-study-for-hydrogen-and-ammonia-production-project-in-pecem-complex/
- Solar Quarter (2024). SeRenE secures RM1.88 billion financing for revolutionary green hydrogen project in Perak, Malaysia. Available at: https://solarquarter.com/2024/02/23/serene-secures-rm1-88-billion-financing-for-revolutionary-green-hydrogen-project-in-perak-malaysia/

- SoluForce. SoluForce joins hydrogen consortium in Argentina (H2ar). Available at: https://www.soluforce.com/about-us/news/soluforce-joins-consortium-for-the-developmen-of-the-hydrogen-economy.html
- Song et al. (2024). Coupled amorphous NiFeP/cystalline Ni3S2 nanosheets enables accelerated reaction kinetics for high current density seawater electrolysis. Available at: https://www.sciencedirect.com/science/article/pii/S0926337324003424
- Sorgulu et al. (2024). Effect of burner head geometry on flame dispersion in gas stoves with hydrogen and natural gas blends. Available at: https://www.sciencedirect.com/science/article/pii/S095758202400096X
- South African Department of Science and Innovation (2021). South Africa Hydrogen Valley Final Report. Available at: https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf
- SP Group. (2019). SP Group Sets Up First Zero-Emission Building Powered by Green Hydrogen in Southeast Asia. Available at: https://www.spgroup.com.sg/wcm/connect/spgrp/c9d8ef18-9a18-4b91-a98b-0e0c0f611b68/%5B20191030%5D+Media+Release+-+SP+Group+Sets+Up+First+Zero-Emission+Building+Powered+By+Green+Hydrogen+In+Southeast+Asia.pdf?MOD=AJPERES&CVID=
- Stamm et al. (2023). Green hydrogen: Implications for international cooperation. With particular reference to South Africa. Available at: https://doi.org/10.23661/idp9.2023.

- Stamm, A., Altenburg, T., Strohmaier, R., Oyan, E., & Thoms, K. (2023). Green hydrogen: Implications for international cooperation. With particular reference to South Africa. Available at: https://doi.org/10.23661/idp9.2023
- State Information Service Egypt. (2024). Gov't announces national low-carbon hydrogen strategy. Available at: https://sis.gov.eg/Story/194224/Gov't-announces-national-low-carbon-hydrogen-strategy?lang=
- Strathmore University. (April de 2024). Strathmore Launches Africa Green Hydrogen Hub. Available at: https://strathmore.edu/news-articles/strathmore-energy-research-centre-launches-africa-green-hydrogen-hub/
- Sun et al. (2023). Ammonia synthesis via chromium-based nitrogen carrier looping. Available at: https://www.sciencedirect.com/science/article/pii/S1385894723053743
- Swansy, A. (2023). Jindal Shadeed Group Plans $3 Billion Green Steel Plant in Oman. December 4, 2022. Bloomberg Markets. Available at: https://www.bloomberg.com/news/articles/2022-12-04/jindal-shadeed-group-plans-3-billiongreen-steel-plant-in-oman#xj4y7vzk
- Ta et al. (2024). An assessment potential of large-scale hydrogen export from Vietnam to Asian countries: Techno-economic analysis, transport options, and energy carriers' comparison. Available at: https://www.sciencedirect.com/science/article/pii/S0360319924012874
- Tarafert (2024). Urea & Green Ammonia. Available at: https://www.tarafertproject.com/projects

- Tata AIG (2023). Hydrogen Cars in India. Available at: https://www.tataaig.com/knowledge-center/car-insurance/hydrogen-cars-in-india.
- The astana times (2022). Kazakhstan and EU to Build Hub for Green Hydrogen Production and Distribution. Available at: https://astanatimes.com/2022/10/kazakhstan-and-eu-to-build-hub-for-green-hydrogen-production-and-distribution/
- The astana times (2022). Kazakhstan Seeks to Develop Green Hydrogen, Accelerates Energy Transition. Available at: https://astanatimes.com/2022/11/kazakhstan-seeks-to-develop-green-hydrogen-accelerates-energy-transition/
- The Green Solutions (2024). TRA VINH GREEN HYDROGEN MANUFACTURING PLANT. Available at: https://thegreensolutions.vn/tra-vinh-green-hydrogen-manufacturing-plant
- The New Indian Express. (2024). Cochin Shipyard Ltd launches India's 1st hydrogen cell ferry. Available at: https://www.newindianexpress.com/states/kerala/2024/Feb/29/cochin-shipyard-ltd-launches-indias-1st-hydrogen-cell-ferry
- The Tico Times (2018). Central America's first hydrogen-fueled bus hits the road in Costa Rica. Available at: https://ticotimes.net/2018/04/18/central-americas-first-hydrogen-fueled-bus-hits-the-road-in-costa-rica.
- The United States Energy Association (2023). Request for Proposals – Bhutan National Green Hydrogen Roadmap Development. Available at: https://usea.org/sites/default/files/Request%20for%20Proposals%20Bhutan%20Hydrogen%20Roadmap%20Development_1.pdf

- Toyota Mobility Foundation (2020). Deploying Hydrogen Systems to Support Costa Rica's Decarbonization Plan. Available at: https://toyotamobilityfoundation.org/en/projects/deploying-hydrogen-systems-to-support-costa-ricas-decarbonization-plan/
- Trading Economics. (2024). Unemployment Rate | World. Available at: https://tradingeconomics.com/country-list/unemployment-rate?continent=world
- Tu et al. (2024). Enhanced stability of bipolar membrane water electrolysis with FeCoNi layered double hydroxides electrocatalyst in a frequently-inverted electrolyte mode. Available at: https://www.sciencedirect.com/science/article/pii/S1383586624009894
- TyT Mexico. (2023). Clúster Energético de NL va por descarbonización con hidrógeno verde. Available at: https://www.tyt.com.mx/nota/cluster-energetico-de-nl-va-por-descarbonizacion-con-hidrogeno-verde
- UDES (2024). De la mano de la UDES, la Isla Galápagos de Ecuador es pionera en la implementación de hidrógeno verde en Latinoamérica. Available at: https://bucaramanga.udes.edu.co/comunicaciones/noticias/de-la-mano-de-la-udes-la-isla-galapagos-de-ecuador-es-pionera-en-la-implementacion-de-hidrogeno-verde-en-latinoamerica.
- UNECE (2023). Sustainable Hydrogen Production Pathways in Eastern Europe, the Caucasus, and Central Asia. Available at: https://doi.org/10.18356/9789210023795
- UNIDO, IRENA & IDOS (2023). Green Hydrogen for Sustainable Industrial Development. A Policy Toolkit for Developing Countries. Available at: https://www.unido.org/sites/default/files/files/2024-

02/Green%20hydrogen%20for%20Sustainable%20Industrial%20Development%20A%20Policy%20Toolkit%20for%20Developing%20Countries.pdf

- UNIDO. (2024). Global Programme for Hydrogen in Industry. Available at: https://www.unido.org/hydrogen
- UNIDO, IRENA & IDOS (2023). Green Hydrogen for Sustainable Industrial Development: Policy toolkit for developing countries. Available at: https://www.unido.org/sites/default/files/files/2024-02/Green%20hydrogen%20for%20Sustainable%20Industrial%20Development%20A%20Policy%20Toolkit%20for%20Developing%20Countries.pdf
- United Nations. (2023). Global Sustainable Development Report. United Nations Global Sustainable Development Report.
- UNU-MERIT (2022). Can developing countries seize emerging windows of opportunity in the green hydrogen economy? Available at: https://www.merit.unu.edu/can-developing-countries-seize-emerging-windows-of-opportunity-in-the-green-hydrogen-economy/
- Valdez-Resendiz et al. (2024). Experimental study of a fuel cell stack performance operating with a power electronics converter with high-frequency current ripple. Available at: https://www.sciencedirect.com/science/article/pii/S0360319924002714
- Vale (2023). Press Release: Vale and Petrobras sign Protocol of Intent to accelerate the development of low-carbon solutions. Available at: https://www.vale.com/w/vale-and-petrobras-sign-protocol-of-intent-to-accelerate-the-development-of-low-carbon-solutions
- Value Chains. Available at: https://www.norway.no/globalassets/2-world/malaysia/hydrogen-mapping-in-malaysia-report.pdf.

- Viceministerio de Minas y Energía (2021). Hacia la ruta del Hidrógeno Verde en Paraguay – Marco Conceptual. Available at: https://www.ssme.gov.py/vmme/pdf/H2/H2%20Marco_Conceptual_DIGITAL.pdf

- Vietnam ASEAN Hydrogen Club (021). Available at: https://vahc.com.vn/en/introduction.html
- Vietnam Investment Review (2024). Chinese corporation proposes $2.4 billion power project in Quang Tri. Available at: https://vir.com.vn/chinese-corporation-proposes-24-billion-power-project-in-quang-tri-109467.html#:~:text=A%20joint%20venture%20between%20China's,investment%20of%20nearly%20%242.4%20billion

- Wang et al. (2024). Hydrogen sorption capacity of diatomaceous earth for geological hydrogen storage. Available at: https://www.sciencedirect.com/science/article/pii/S0360319924008188

- Wang, Dai et al. (2024). Improved performance of fiber-optic hydrogen sensor of porous Pt/WO3 based on ZIF-8. Available at: https://www.sciencedirect.com/science/article/pii/S0360319923029336

- Wang, Han et al. (2024). Highly sensitive fiber grating hydrogen sensor based on hydrogen-doped Pt/WO3. Available at: https://www.sciencedirect.com/science/article/pii/S0925400523019688

- Wang, Huang et al. (2024). Stable lean co-combustion of ammonia/methane with air in a porous burner. Available at: https://www.sciencedirect.com/science/article/pii/S1359431124007609

- Wang, Huo et al. (2024). Superhydrophilic polyphenylene sulfide membrane with enhanced ion transfer for alkaline water electrolysis. Available at: https://www.sciencedirect.com/science/article/pii/S0360319924012588
- Wang, Liu et al. (2023). N-doped carbon sheets supported P-Fe3O4-MoO2 for freshwater and seawater electrolysis. Available at: https://www.sciencedirect.com/science/article/pii/S0021979723016296
- Wang, Liu, Mei et al. (2021). A novel thermally autonomous methanol steam reforming microreactor using SiC honeycomb ceramic as catalyst support for hydrogen production. Available at: https://www.sciencedirect.com/science/article/pii/S0360319921018577
- Wang, Xiang et al. (2024). High-performance monolithic microreactor with a novel pod-shaped NF@Cu/g-C3N4 for enhanced visible light reduction of CO2 to methanol. Available at: https://www.sciencedirect.com/science/article/pii/S0272884224009477
- Wascal (2021). Master Programme in Natural Resources, Biofuel Green Hydrogen Production, Water Resources and Technology, Côte d'Ivoire. Available at: https://wascal.org/master-programme-in-natural-resources-biofuel-green-hydrogen-production-water-resources-and-technology-cote-divoire/
- Wascal (2022). OPTIMIZING SOLAR PV FOR GREEN HYDROGEN PRODUCTION IN WEST AFRICA (PV2H). Available at: https://wascal.org/optimizing-solar-pv-for-green-hydrogen-production-in-west-africa-pv2h/
- Wassha (2022). The future WASSHA wants to realize. Available at: https://wassha.com/en/

- WHEC. (2024). History of WHEC. Available at: WHEC 2024: https://www.wheccancun.org/History-Of-WHEC
- World Bank (1980). "Turkey—IGSAS Fertilizer Project." Project Performance Audit Report No. 3037, World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/540611468915328419/pdf/multi-page.pdf.
- World Bank (1983). "Egypt—Talkha II Fertilizer Project." Project Completion Report No. 4455, World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/542051468023410553/pdf/multi-page.pdf
- World Bank (1986). "Pakistan—Fauji Fertilizer Project." Project Performance Audit Report No. 6214, World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/247001468915251139/pdf/multi0page.pdf
- World Bank (2020). Green Hydrogen in Developing Countries. Available at: https://www.esmap.org/green-hydrogen-in-developing-countries
- World Bank (2022). Press Release: The World Bank supports climate action in Colombia with a US$1 billion Loan. Available at: https://www.worldbank.org/en/news/press-release/2022/12/20/el-banco-mundial-apoya-la-accion-climatica-en-colombia-con-un-prestamo-de-us-1-000-millones
- World Bank (2022). Sufficiency, Sustainability, and Circularity of Critical Materials for Clean Hydrogen. Available at: https://www.esmap.org/Sufficiency_Sustainability_Circularity_of_Critical_Materials_for_Clean_Hydrogen

- World Bank (2022). Sufficiency, Sustainability, and Circularity of Critical Materials for Clean Hydrogen. Available at: https://www.esmap.org/Sufficiency_Sustainability_Circularity_of_Critical_Materials_for_Clean_Hydrogen.
- World Bank (2023). Project Information Document: Expanding Clean Hydrogen in Brazil- Ceará Hydrogen Hub. Available at: https://documents1.worldbank.org/curated/en/099122123142018715/pdf/P18151117d6de30f1a5f8195fd134a22eb.pdf
- World Bank (2024). As Colombia leads on renewables, boosting its clean hydrogen industry is the next step. The World Bank is ready to help. Available at: https://blogs.worldbank.org/en/energy/as-colombia-leads-on-renewables--boosting-its-clean-hydrogen-ind#:~:text=Finally%2C%20socioeconomic%20benefits%20of%20hydrogen,for%20decarbonization%20and%20climate%20resilience
- World Bank (2024). Scaling Hydrogen Financing for Development. Available at: https://www.esmap.org/Hydrogen_Financing_for_Development
- World Bank ESMAP and OECD. (2024). Scaling Hydrogen Financing for Development. World Bank, OECD.
- World Bank. (2022). Data World Bank. Available at: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=KE
- World Bank. (2023). Scaling Hydrogen Financing for Development.
- World Bank. (2023). World Bank Approves $1.5 Billion in Financing to Support India’s Low-Carbon Transition. Available at: https://www.worldbank.org/en/news/press-release/2023/06/29/world-

bank-approves-1-5-billion-in-financing-to-support-india-s-low-carbon-transition

- World Economic forum (2021). 4 technologies that are accelerating the green hydrogen revolution. Available at: https://www.weforum.org/agenda/2021/06/4-technologies-accelerating-green-hydrogen-revolution/
- World Economic Forum (2023). Enabling Measures Roadmap for Low-Carbon Hydrogen Middle East and North Africa. Available at: https://www3.weforum.org/docs/WEF_Enabling_Measures_Roadmap_for_Low_carbon_Hydrogen_in_the_Middle_East_and_North_Africa_2023.pdf
- World Economic Forum (2024). Accelerating the Clean Hydrogen Economy in Latin America. Available at: https://www3.weforum.org/docs/WEF_Accelerating_the_Clean_Hydrogen_Economy_in_Latin_America_2024.pdf
- World Economic Forum (2024). Green Hydrogen: Enabling Measures Roadmap for Adoption in India. Available at: https://www3.weforum.org/docs/WEF_Green_Hydrogen_Enabling_Measures_Roadmap_for_Adoption_in_India_2024.pdf
- World Economic Forum. (2022). Which countries could become the world's hydrogen superpowers?
- World Economic Forum. (2023). Enabling Measures Roadmap for Low-Carbon Hydrogen in MENA . Available at: https://www3.weforum.org/docs/WEF_Enabling_Measures_Roadmap_for_Low_carbon_Hydrogen_in_the_Middle_East_and_North_Africa_2023.pdf

- WWF, IIASA, Boeing (2019). Understanding the sustainable aviation biofuel potential in sub-Saharan Africa: A systems analysis investigation into the current and future potential for sustainable biofuel feedstock production in the sub-Saharan Africa region. Available at: https://pure.iiasa.ac.at/15708/1/Sustainable_Biofuel_Potential_SSAF_SummaryReport_Finalized_V7.1_Pages.pdf

- Yadav et al. (2024). Development and performance evaluation of Sr2CeO4 - SrCe0.85Y0.15O3-δ based electrochemical hydrogen isotopes sensor. Available at: https://www.sciencedirect.com/science/article/pii/S0920379624000437

- Yang et al. (2022). Molybdenum-based nitrogen carrier for ammonia production via a chemical looping route. Available at: https://www.sciencedirect.com/science/article/pii/S0926337322003459

- Y-TEC. (2024). YPF TECNOLOGÍA (Y-TEC). Available at: https://y-tec.com.ar/#/

- Yuan et al. (2024). Novel MOF-303 integrated polymer membrane for efficient separation of azeotropic methanol-MTBE mixtures- Available at: https://www.sciencedirect.com/science/article/pii/S1383586624003629

- Yutopía (2023). Siete proyectos piloto constan en la Hoja de Ruta del Hidrógeno Verde. Available at: https://youtopiaecuador.com/cuidado-del-ambiente/hidrogeno-verde-proyectos-hoja-ruta-ecuador/#:~:text=Proyecto%20Islas%20Gal%C3%A1pagos,el%20funcionamiento%20de%20un%20electrolizador.

- Zeng et al. (2024). Enhanced stability and electrochemical investigations of Ni/ZSM-5 catalyst layer on nickel-based anodes for ammonia-fed solid oxide

fuel cells. Available at:
https://www.sciencedirect.com/science/article/pii/S0378775323013150

- Zhang et al. (2024). Green and efficient electrolysis of seawater using carbon nanotube-based hybrid films. Available at: https://www.sciencedirect.com/science/article/pii/S2211285524001046
- Zhang, He et al. (2023). Chromium doping enabled improvement in alkaline seawater oxidation over cobalt carbonate hydroxide nanowire array. Available at: https://doi.org/10.1039/d3cc02667a
- Zhang, Sun et al. (2022). Proposal of a novel modular photo-thermo-reactor system for cascaded hydrogen production from methanol steam reforming. Available at: https://www.sciencedirect.com/science/article/pii/S0196890422001868
- Zhu, et al. (2021). Improvement of hollow cylinders on the conversion of coal mine methane to hydrogen in packed bed burner. Available at: https://www.sciencedirect.com/science/article/pii/S0360319921026173

ANNEX 2. DESCRIPTIONS OF TECHNOLOGIES

The following annex describes clean hydrogen technologies across various segments of the value chain, their global TRLs[25] and examples from developing countries. After each segment of the value chain, case studies are also presented.

Table 0-1. Clean hydrogen value chain: production technologies.

Technology & Description	Examples from developing countries	Current TRL
Production Method: Electrolysis		
Alkaline Electrolysers Alkaline electrolysers utilise potassium hydroxide and electrical energy to split water into hydrogen and oxygen. They operate at low pressure due to the risk of hydrogen permeating the diaphragms within the cells. To prevent the mixing of gases, thick diaphragms are used, which, although effective, result in higher electrical resistance and reduced efficiency. However, new zero-gap approaches are being developed to overcome these technical challenges and enhance performance.	- Y-TEC Alkaline electrolyser prototype, Argentina	9
PEM Electrolysers PEM electrolysis is a more recent technology that utilises a polymer electrolyte to simplify the electrolysis process, enabling pressure balance and allowing it to operate at nearly 30 barg. Due to the high current densities involved, it requires uniform cooling to maintain optimal performance.	-OCP Group's 4MW Pilot for fertilisers production, Morocco -H2Biscus, Malaysia	9
SOEC SOEC operates at high temperatures (500-800°C) with ceramic components and can currently handle 5-10 barg, aiming for 20 barg by 2030. It uses external heat to reduce electricity consumption by helping to vaporize water.	No projects found	7

[25] All TRLs refer to IEA's TRL assessments, that are constantly updated or to an academic research document when the technology wasn't found in IEA's data base. Last update of IEA technologies: 2023. Available at: https://www.ieahydrogen.org/trl-assessments/

Anion Exchange Membrane Electrolyser Anion Exchange Membrane is the latest electrolysis technology in development that uses a solid electrolyte and a non-noble catalyst. It combines the compact size of PEM technologies with the cost-effective catalyst and other materials of the alkaline electrolysis. Recent tests have shown it can operate at pressures up to 35 bar and larger than alkaline technologies' current densities.	-H2Biscus, Malaysia	6
Sea water direct electrolysis path This method is promising as it utilises seawater instead of freshwater, potentially lowering costs. However, it introduces new complexities, such as the production of chlorine byproducts, salt buildup, corrosion, and lower conductivity.	-Direct sea water Floating platform prototype by Dongfang Electric, China - N-doped carbon sheets supported P-Fe3O4-MoO2 for freshwater and seawater electrolysis, Qingdao University of Science and Technology, China	5

Production Method: Non-Electrolytic Water Splitting		
Photo-electrochemical water splitting This process uses photoelectrodes to convert light into electricity, which then splits water into hydrogen and oxygen. It works like a photovoltaic system but operates while submerged in water. The integration of an electrochemical cell setup adds complexity but offers the potential for greater efficiency compared to simple photocatalytic electrolysis.	No projects found	5

Photocatalytic water splitting This process uses light-sensitive catalysts to split water, like thermal decomposition, but with less heat needed. Currently, titanium oxides and non-noble metals such as sodium, bismuth, cobalt, and potassium are being tested.	No projects found	4-5
Radiolysis High-energy radiation ionizes water into H_2O^+ and releases a hydrogen nucleus, also producing hydroxyl radicals (OH) and hydronium ions (H_3O^+). Its main advantage is the extremely fast reaction and production rate.	No projects found	Not Reported
Thermal decomposition This process splits water at high temperatures (500-2000°C) using non-noble metal catalysts. It only requires water as input and produces hydrogen and oxygen.	No projects found	4
Other routes	- Hydrogen production using aluminium-water splitting, Middle East Technical University, Türkiye	

Production Method: SMR with natural gas and CCUS		
Low-carbon hydrogen can be produced through SMR combined with CCUS. CCUS captures CO_2 from exhaust gases, either storing it underground or repurposing it for products such as methanol and fertilisers. Various CO_2 capture methods can be applied to SMR for cleaner hydrogen production or for the creation of fertilisers and e-fuels. These methods include Amine solvent (TRL 9 for coal/TRL 6-7 for cement), Chilled ammonia (TRL 6), Membrane (TRL 6), Cryogenic (TRL 6-7), Enzyme (TRL 8 for coal/TRL 5-6 for other applications), and Chemical looping (TRL 6-7).	-CCU at IOCL's Koyali Refinery, India	SMR Low capture rate TRL9 SMR High capture rate TRL5-6

Source: Hinicio (2024)

Table 0-2. Clean hydrogen value chain: storage technologies.

Technology	Description	Examples from developing world	TRL
Gaseous Storage	Hydrogen is compressed between 200-700 bar at ambient temperature, with a storage capacity of 26m³. At 200 bar, the density of hydrogen is approximately 15.6 kg/m³, while at 700 bar, the density increases to about 39.75 kg/m³.	-SPE GEOTHERMIKA's Clean hydrogen in Trans-Carpathian region, Ukraine - Energía Los Cabos by HDF in México	8-9
Liquid Storage	Hydrogen is cooled down to -252°C or less at ambient pressure with a maximum reported storage capacity of 11.200 m³.	No projects found	7
Salt Caverns; Depleted Gas Fields	In this type of storage, hydrogen is stored in gaseous form in underground salt caverns with a high storage capacity of up to	-Odessa Valley by Hydrogen Ukraine	9-10[26]

[26] Technologies where TRL are higher than 9 means that it is in a further readiness stage of "Market Readiness".

	900,000 m^3. Depleted gas fields follow a similar process, storing hydrogen in empty gas reservoirs at pressures of 110-280 bar, with capacities of up to 18 million m^3.		
Aquifers	An aquifer storage system typically consists of a confining brine-saturated formation layer that hosts the injected gas, wells for injection into and withdrawal from the target formation layer, and pipelines that connect the wells to the surface facilities.	No projects found	3
LOHC	This storage method involves reacting hydrogen with compounds, such as organic substances, through hydrogenation, allowing it to be stored as a liquid in a reversible process. Hydrogenation releases heat (exothermic), while dehydrogenation absorbs heat (endothermic).	Projects found for hydrogen transformation into LOHC, but not specifically for LOHC storage.	5-7
Metal hydrides	This method uses a metal alloy mesh inside a sealed tank to absorb hydrogen through an endothermic reaction. Water baths or thermoelectric cooling cells are used for loading and unloading. Common materials for solid hydrogen storage include magnesium, aluminium, and alloys with lithium, sodium, and boron.	No projects found	4-5
Sorbents	This method stores large amounts of hydrogen at room temperature by adsorption in porous materials. Key materials include activated carbon, nanotubes, and carbon nanofibers due to their high adsorption capacity. However, achieving effective physisorption at room temperature remains challenging.	No projects found	2-3

Source: Hinicio (2024)

Table 0-3. Clean Hydrogen value chain: transport technologies.

Transport Method	Technology	Description	Examples from developing world	TRL
Gaseous form				
Pipelines Stainless steel is used for short distances, but Seamless Steel pipelines made from low-strength steels such as X42, X52, etc., are chosen for their durability and resistance to hydrogen embrittlement. Other options such as polyethylene (HDPE), fibre/reinforced polymers and glass fibre are now being considered for their lower cost and better performance.			- Morocco-Nigeria Gas Pipeline -Inner Mongolia- Beijing Pipeline - Promigas clean H_2 Pilot plant for gas ducts mixed with NG in Pilot Phase, Colombia -Bharat Petroleum Corporation's clean H_2 in gas distribution networks project, India	7
Tube Trailers Steel tubes are used to handle up to 500 bar for hydrogen transport, but common tubes operate at 200 bar. This lower pressure reduces the efficiency of the final quantity transported.			No projects found	11

Liquified form		
Cryogenic Tanks Cryogenic tanks are used for storing hydrogen in its liquid form. Liquid hydrogen requires extremely low temperatures to maintain. The key conditions: hydrogen must be cooled to -253°C (-423°F) to exist as a liquid at atmospheric pressure (1 atm). This temperature is necessary to keep hydrogen in its liquid form. Handling liquid hydrogen requires special equipment due to its cryogenic nature, which can cause frostbite and cryogenic burns upon contact.	No projects found	2-3
Shipping		
Bunkering Maritime transport of hydrogen is still in the experimental and developmental stages, with a few pilot projects exploring various methods. Hydrogen can be transported as a liquid, in the form of ammonia, or through chemical carriers such as methanol. Current efforts include designing specialised ships and infrastructure to safely and efficiently handle hydrogen, but large-scale commercial operations have not yet been established, with high-income countries leading this segment. The focus remains on overcoming challenges related to storage, safety, and cost.	No projects found	2-3

Source: Hinicio (2024)

Table 0-4. Clean hydrogen value chain: transformation technologies

Technology	Description	Examples from developing world	TRL

Haber Bosch for ammonia production		
A mature industrial process where hydrogen is reacted with nitrogen captured from the atmosphere in a catalytic step at high pressures and temperatures to produce ammonia.	- Atlas Agro Fertilizantes ammonia plant, Brazil - Tarafert Urea & Green Ammonia, México - Hydrogen-Pilot Plant / Refuelling Station in Walvis Bay, Namibia - Tra Vinh Clean Hydrogen project, Viet Nam	9

Pressurised catalytic hydrogenation of carbon monoxide and dioxide for methanol production		
This method involves pressurising and catalysing the reaction of carbon monoxide (CO) and carbon dioxide (CO_2). It is commonly used in the chemical and fuel industries for various applications.	- Clean H_2 and methanol demonstrative centre project for industry use in Manabí province, Ecuador	7

Fischer-Tropsch for e-fuels		
These fuels, also known as e-fuels, are primarily produced using the Fischer-Tropsch process, which converts synthetic gas (from H_2 and CO_2) into hydrocarbon chains. CO_2 capture technologies can be applied here. Examples of these fuels include: • Synthetic Kerosene for Aviation: Made by refining syngas into C8-C16 hydrocarbon chains. • Synthetic Methane: Produced by methanising carbon sources (e.g., CO_2 or biogas) with H_2 to create synthetic natural gas (SNG).	- Renewable Falcon, Phase I, Argentina -HySHiFT SAF project, South Africa	7

Source: Hinicio (2024)

Table 0-5. Clean hydrogen value chain: end-use applications.

End-Use Application	Technology	Description	Examples from developing world	TRL
Transport				
Automobiles •FCEV: FCEVs use a fuel cell to power an electric motor, often combined with batteries in hybrid configurations. The fuel cell converts hydrogen and oxygen into electricity and water, while the battery can be recharged by the fuel cell or through regenerative braking, enhancing efficiency. •Innovation in internal combustion engines: Some companies are developing internal combustion engines that run on hydrogen, particularly for off-road vehicles.			- Oruro Clean H_2 Car prototype, Bolivia - Grove Clean H_2 Cars production, Brazil - OPEX Hevolución, Colombia - Toyota's pilot project for hydrogen-based advanced fuel cell electric vehicles, India - HySA's Fuel Cell-Battery Hybrid Powered Golf Cart, South Africa - Hydrogen Fuel Cell Vehicle Project, Türkiye	7
Buses and Trucks Hydrogen buses, tested for over 20 years, offer environmental benefits and are well-suited for public transport due to their high visibility and manageable routes. They use fuel cells, hydrogen storage, electric motors, and energy management systems. While economic challenges persist, their performance under various conditions demonstrates significant potential			- Ad Astra Central America's first hydrogen-fuelled bus and upgrade pilot, Costa Rica	7

	- Anglo American Hydrogen FC Mining Truck, South Africa	
Trains Hydrogen trains use fuel cells to convert hydrogen to electricity to power electric motors. They offer a cleaner alternative to diesel trains, producing only water as a byproduct. Recently, some developed countries have tested hybrid systems combining batteries and hydrogen fuel cells in railway applications for heavy, long-distance transport.	- Hydrogen Fuel Cell Train Project, Türkiye -Hyphen Hydrogen-Diesel Dual Fuel Locomotive Pilot Project Proposal for Namibia - Indian Railways pilot project for conversion of old Diesel locomotives with Hydrogen Fuel Cells, India	7
Aviation • Airplanes: Both, liquid hydrogen combustion and hydrogen fuel cells are promising technologies for reducing aviation emissions. synthetic fuels for aviation are also presented as an alternative for airplanes. • Short-Distance: Drones and Unmanned Aerial Vehicles (UAV):	Projects found in hydrogen transformation for aviation sector.	3-4

Fuel cell-powered drones and UAVs are gaining popularity, especially for surveillance, as they offer longer ranges compared to battery-powered drones.		
Shipping Ships are being considered for hydrogen use to reduce fossil fuel consumption. Options include hydrogen fuel cells with electric drive, hydrogen for combustion engines, and some are exploring ammonia also for combustion engines.	India's First Hydrogen Fuel Cell Ferry, CochinShipyard Limited	6
Electricity Generation and Storage		
Fuel Cells Fuel cells are efficient electrochemical devices that convert hydrogen's chemical energy directly into electricity. High-temperature variants are favoured for sectors needing high power, reliability, and low carbon emissions. Commonly used in the mobility and transport technologies described above.	- A5 Fuel Cell Solution to Provide Green, Off-Grid Power to 800 Telecom Base Stations, Kenya - Clean hydrogen technology for decentralised energy systems in Sub-Saharan Africa, Ghana	7
Gas Turbines Main technologists are developing conventional energy generation turbines adapted for hydrogen or ammonia. In the short term, the viability includes using mixtures of natural gas and hydrogen with minimal modifications to existing plants.	No projects found	6
Iron and Steel Production		
Reduction in Iron process	- Iron ores for hydrogen	7

Reduction of iron oxide (Fe3O4) or magnetite can be done using H_2 for the reaction instead of carbon. In this case, it only produces water besides the pure iron, according to the non-balanced reaction: $Fe_2O_3 + H_2 \rightarrow Fe + H_2O$. This is one of the most promising applications of clean hydrogen to produce reduced carbon iron and steel.	reduction from Brazil to Sweden.	
Steel production Clean Hydrogen in Steel Production can be applied in 2 main processes: Blast Furnace and Basic Oxygen Furnace (BF/BOF): Hydrogen is injected and together with coal converts iron ore into steel, leading to less CO_2 emissions compared to the use of coal alone. Electric Arc Furnace: Uses electricity to make steel from scrap and DRI. Hydrogen can be used as the reducing agent. Hydrogen reduces CO_2 emissions by minimising coal use in BF/BOF and replacing natural gas in DRI pellet production (DRI-H_2). DRI-H_2 can cut steel emissions by up to 87%, making it a key method for green steel production.	- Hyiron's Project Oshivela, Namibia	4-5-6

Cement		
Fuel substitution Hydrogen can replace fossil fuels such as coal and natural gas as a fuel source in cement manufacturing.	-Argos Hydrogen injection project, Honduras - Holcim clean Hydrogen cement project, Mexico	6
Clinker manufacturing Clinker is a crucial component in cement production and contributes significantly to CO_2 emissions due to its energy-intensive process. By using hydrogen as a fuel, the amount of emissions can be reduced.	No projects found	7
Carbon capture Hydrogen can be used to capture and utilise CO_2 from cement production, converting it into raw materials for	Projects specified in hydrogen	Varies

producing other products such as building materials or fuels.	production as CCUS segment.	
Refining		
Hydrogen is used in hydrogenation processes to chemically modify other substances. It is essential for methanol production and hydrocracking, which enhance e-fuels and produce cleaner fuels such as gasoline and diesel.	- Esmeraldas's refinery pilot project of grey hydrogen substitution, Ecuador - Transition Pha Lai 1 coal plant to 100% clean hydrogen, Viet Nam	9
Fertilisers		
Clean hydrogen benefits can be applied to the fertiliser industry by producing clean ammonia through the Haber-Bosch synthesis, as well as other compounds such as nitric acid, urea, and ammonium hydroxide.	Projects listed in Ammonia section	9<
Buildings		
Hydrogen serves as a dual-purpose energy source for both power and heat generation through fuel cells and combustion. New high-temperature fuel cell technologies are emerging for simultaneous heat and power production.	- HySA's 1 kWe HT-PEMFC Combined Heat & Power System, South Africa	6-9

Source: Hinicio (2024)

ANNEX 3. LIST OF PROJECTS MAPPED

The following annex lists all mapped projects that could classify under A2D Facility scope.

Table 0-6. Projects that may classify under A2D Facility

Country	Project Name	Project Category	Main proponent
Argentina	Alkaline electrolyser prototype	H2 Production	Y-TEC
Argentina	Renewable Falcon, Phase I	Fuels	Not reported
Argentina	HyChico	H2 Production	Hychico
Argentina	ENARSA Bahía Blanca	H2 Production	ENARSA
Argentina	Pico Truncado's experimental plant	H2 Production	ENARSA Santa Cruz Municipalidad de Pico Truncado
Bolivia	GH2 and ammonia plant	Ammonia	H2 Bolivia
Bolivia	GH2 Car	Mobility	Oruro department
Brazil	Uberaba Green Fertilizer	Ammonia	Atlas Agro fertilizantes
Brazil	Solatio project	H2 Production	Solatio
Brazil	Project Iracema	Ammonia	Casa dos Ventos
Brazil	AES Brasil Project	Ammonia	AES Brasil
Brazil	Pecém Green Hydrogen Hub	H2 Production	Fortescue
Brazil	Base one	H2 Production	Enegix
Brazil	GH2 Cars production and distribution	Mobility	Grove Hydrogen Automotive Co. Ltd.
Burkina Faso	Optimization of Solar Photovoltaic for the Production of Green Hydrogen in West Africa (PV2H)	H2 Production	Wascal
China (People's Republic of)	Sinopec Xinjiang Kuqa Green	H2 Production	China Petroleum & Chemical Corporation (Sinopec)

	Hydrogen Pilot Project		
China (People's Republic of)	Wind-to-hydrogen pilot project	H2 Production	Shangai government
China (People's Republic of)	Small-scale hydrogen pipeline	H2 Production	China National Petroleum Corporation
China (People's Republic of)	M4 Electrolyser	Mobility	Shell China Zhangjiakou City Transport Construction Investment Holding Group Co. Ltd
China (People's Republic of)	500 Fuel Cell Commercial Trucks in Shanghai	Mobility	Ballard
China (People's Republic of)	Hydrogen fuel cell boat	Mobility	China State Shipbuilding Corporation China Yangtze Power Corporation Jianglong Shipbuilding
China (People's Republic of)	Zhangjiakou Kangbao-Caofeidian pipeline	Transportation	Tangshan Haitai New Energy Technology Haitai Solar China Petroleum Pipeline Engineering Corporation (CNPC)
China (People's Republic of)	Inner Mongolia-Beijing Pipeline	Transportation	Sinopec
Colombia	GH2 Pilot plant for gas ducts mixed with NG in Pilot Phase	Blending	Promigas
Colombia	Hevolucion's ammonia project	Ammonia	Hevolución (Opex)
Colombia	Refinery project	H2 Production	Ecopetrol
Colombia	Mobile laboratory prototype of hydrogen and antural gas mixing	Heat	Ecopetrol

Costa Rica	Nyuti hydrogen-fuelled bus	Mobility	Ad Astra Rocket Company
Costa Rica	Costa Rica Hydrogen Transportation Ecosystem	Mobility	Ad Astra Rocket Company
Costa Rica	1 MW Pilot project to upgrade existing environment	Mobility	ProNova Energy: Ad Astra Rocket Company Mesoamerica Cavendish
Ecuador	Demonstrative project center for H2 Production, ammonia and fertilisers in Guayas	Ammonia	Ecuador Government
Ecuador	Green ammonia in Chimborazo demonstrative project	Ammonia	Ecuador Government
Ecuador	GH2 and methanol demonstrative center project for industry use in Manabí province	Methanol	Ecuador Government
Ecuador	Nepos Energy Electrolyzer	H2 Production	Nepos Energy
Ecuador	Islas Galápagos project	H2 Production	Ecuador Government
Ecuador	Quito's sustainable mobility project	Mobility	Ecuador Government
Ecuador	Esmeraldas's refinery pilot project of grey hydrogen sustitution	Substitution	Ecuador Government
Ecuador	Sushifundi's refinery pilot project of grey	Substitution	Ecuador Government

	hydrogen sustitution		
Egypt	Scatec ASA's Egypt Green Hydrogen project	H2 Production	Egypt Green: Fertiglobe Scatec Orascom Construction Egyptian Electricity Transmission Compan
Fiji	Renewstable® hydrogen power plant	H2 Production	Hydrogen Power Fiji
Ghana	Green hydrogen technology for decentralised energy systems in Sub-Saharan Africa	Fuel Cell	Hochschule Bochum Green Power Brains SFC Energy AG
Honduras	Hydrogen injection project	Cement	Argos Honduras
India	GH2 in gas distribution networks	Blending	Bharat Petroleum Corporation Ltd.
India	hydrogen blending project	Blending	NTPC Gujarat Gas
India	Jorhat Pump Station GH2 Pilot Plant	H2 Production	Oil India Limited
India	green ammonia project	H2 Production	ACME
India	H2 for Heavy Engineering Facility in Hazira	H2 Production	Gujarat Larsen Toubro
India	Gurugram hydrogen project	H2 Production	IISC Bangalore
India	Green Hydrogen Fuel Cell-based Microgrid	Grid	SJVN
India	Green Hydrogen Fuel Cell-based Microgrid	Grid	NHPC Uneecops Technologies

India	Pilot project for hydrogen-based advanced FCEV	Mobility	Toyota Kirloskar Motors
India	Faribad Station hydrogen refuelling station	Mobility	IndianOil Corporation Tata Motors
India	Hydrogen-based Mobility Station Project at Kargil	Mobility	Gensol
India	Pilot Project for Conversion of Old Diesel Locomotives with Hydrogen Fuel Cells	Mobility	Indian Railways GreenH Electrolysis
India	Integrated Hydrogen Refuelling Station at Greater Noida	Mobility	NTPC Jackson
India	Integrated Refuelling Station for Buses in Leh (Ladakh)	Mobility	Indian Oil Corporation NTPC
India	India’s First Hydrogen Fuel Cell Ferry	Mobility	CochinShipyard Limited KPIT Technologies Council of Scientific and Industrial Research Labs
India	RFNBO-compliant green ammonia plant	Ammonia	Greenko AM Green Ammonia
Indonesia	Sumba	H2 Production	HDF Energy
Indonesia	GH2 pilot project from geothermal	H2 Production	Pertamina Geothermal Energy
Iran	Taleghan solar hydrogen energy system	H2 Production	Renewable Energy Organization of Iran (SUNA)
Kazakhstan	30 GW unnamed GH2 project	H2 Production	Svevind Energy Group

Kenya	A5 Fuel Cell Solution to Provide Green, Off-Grid Power to 800 Telecom Base Stations	Fuel Cell	GenCell Energy Adrian Kenya
Malaysia	Hydrogen Plant	H2 Production	SEDC Energy Sumitomo Corporation Eneos
Malaysia	Samalaju Hydrogen Plant	H2 Production	SEDC Energy H2X Global Thales New Energy
Malaysia	Mobile Hydrogen Refueling Station	Mobility	Nanomalaysia
Malaysia	60 MW Plant	H2 Production	Semarak Renewable Energy PowerChina H2biscus Samsung Engineering Lotte Chemical Korea National Oil Corporation SEDC Energy
Malaysia	Repower Retired CCGT	Heat	TNB Petroliam Nasional Bhd
Malaysia	Integrated Hydrogen Production Plant & Refuelling Station	Mobility	SEB Linde
Mauritania	Project Nour	H2 Production	Chariot's green hydrogen Total Eren
Mauritania	AMAN	H2 Production	CWP Global
Mexico	Tarafert Urea & Green Ammonia	Ammonia	Tarafert
Mexico	Marengo I	Ammonia	Campeche Government GIZ Mexico MexCo Hy2Gen
Mexico	Green Hydrogen cement project	Cement	Holcim

Mexico	Nel A-150 electrolyser plant	H2 Production	Instituto Mexicano del Petróleo Nel Hydrogen Electrolyser (Nel ASA) Pemex
Mexico	Delicias Solar	H2 Production	Dhamma Energy
Mexico	Energía Los Cabos	Storage	HDF Energy
Mongolia	Gobi H2	H2 Production	Elixir Energy SB Energy Corp
Morocco	4 MW PEM Pilot Hydrogen and ammonia production in Morocco	H2 Production	Fortescue Energy Fortescue Ltd OCP Group
Morocco	FC SUV project	Mobility	NamX
Morocco	Nigeria-Morocco Gas Pipeline	Transportation	NNPC ONHYM
Namibia	Hydrogen-Pilot Plant / Refueling Station in Walvis Bay	Ammonia	Ohlthaver & List CMB.Tech
Namibia	HYPHEN Tsau Khaeb	H2 Production	Hyphen
Namibia	Daures Green Hydrogen Village	H2 Production	Daures Green Hydrogen University of Namibia University of Stuttgart
Namibia	Project Oshivela	Iron & Steel	Hyiron
Namibia	HyRail Namibia	Mobility	Hyphen Technical: Hyphen Hydrogen Energy Traxtion TransNamib University of Namibia CMB.Tech
Namibia	Namport pilot project	Substitution	Namibian Ports Authority
Nigeria	Morocco-Nigeria Gas Pipeline	Transportation	NNPC ONHYM
Paraguay	Atome Energy's Green Ammonia Project	Ammonia	Atome Energy ANDE

			Casale AECOM
Peru	MMEX	H2 Production	Mmex Resources Corporation
Peru	Green hydrogen production facility in Arequipa	H2 Production	Peruvian government Phelan green Energy
Peru	Green H2 production at gas-fired plant in Peru	H2 Production	Fenix (Colbun)
Philippines	GenCell Fuel Cells in the Philippines	Fuel Cell	GenCell
South Africa	1 kWe HT-PEMFC Combined Heat & Power System	Buildings	HySA South African SME Company University of Western Cape
South Africa	2.5 kW FC Generator	Fuel cell	HySA UWC
South Africa	HySHiFT SAF project	Fuels	HySHiFT Consortium Linde Sasol Enertrag HydRegenEnergy
South Africa	Clean hydrogen for refuelling project	H2 Production	Sakhumnotho Power Keren Energy
South Africa	H2 for Mining Trucks	Mining	Anglo American
South Africa	Fuel Cell-Battery Hybrid Powered Golf Cart	Mobility	HySA UWC
South Africa	South Africa’s first fuel cell factory	Mobility	CHEM Corporation
South Africa	Toyota's hydrogen station in Johannesburg	Mobility	Shell Toyota
South Africa	BMW SUV project	Mobility	BMW, Sasol and Anglo American Platinum
Thailand	Hydrogen blend pilot	Blending	Energy Policy and Planning Office (EPPO) of Thailand

Thailand	Lam Takhong Wind Hydrogen Hybrid Project	H2 Production	EGAT
Türkiye	Hydrogen Fuel Cell Vehicle Project	Mobility	Karsan BMW
Türkiye	Hydrogen Fuel Cell Train Project	Mobility	TÜVASAŞ Alstom
Türkiye	Hydrogen Fuel Cell Bus Project	Mobility	Bozankaya ZF Friedrichshafen
Türkiye	Hydrogen Mobility Project	Mobility	İGDAŞ Air Liquide
Türkiye	Hydrogen Storage and Transportation Project	Storage	Borusan EnBW Enerji Siemens Energy
Ukraine	Danube Hydrogen Valley	H2 Production	Danube Hydrogen Valley
Ukraine	5 MW Pilot Project	H2 Production	DTEK LLC – Public Private Partnership with German and Ukrainian industrial stakeholders
Ukraine	Green Hydrogen production from Hydropower	H2 Production	PJSC “Nizhnodnistrovska HPP”
Ukraine	Odessa Valley	H2 Production	H2U Studies: LLC "Voden from Ukraine" AB5 Consulting
Ukraine	Transcarpatia Valley	H2 Production	H2U Studies: LLC "Voden from Ukraine" AB5 Consulting
Ukraine	Renewable hydrogen production plant in Trans Carpathian region	H2 Production	LLC “SPE GEOTHERMIKA”

Uzbekistan	Pilot Uzbek Green Hydrogen Project	H2 Production	ACWA Power Company Joint Stock Company UzKimyoSanoat
Viet Nam	Tra Vinh Green Hydrogen project	Ammonia	The Green Solutions Econnect Energy
Viet Nam	Thang Long Hydrogen Project	H2 Production	Enterprize Energy Vietnamese Institute of Energy
Viet Nam	Pilot hydrogen supply in Petrolimex petroleum stations for buses	H2 Production	Petrolimex
Viet Nam	Transition Pha Lai 1 coal plant to 100% green hydrogen (2x100 MW)	Substitution	Pha Lai Thermal Power JSC
Zambia	Turnpike Solar-Green Hydrogen Project	H2 Production	Gei Power Others

Source: Hinicio (2024)

ANNEX 4. DELIVERY MECHANISMS

Funding Institutions

Table 0-7. Financing institutions and their respective initiatives focused on clean hydrogen in developing countries.

	Financing Institution	Incentives identified
LAC	IFC	NAMA – Green H2 Costa Rica27
	IDB	Multilateral Investment Fund
	NAFIN Mexico	Sustainable Bond
Asia	Capital Ventures SG	Financing for green hydrogen project in Malaysia
	Asian Development Bank	Japan Special Fund
	Social Alpha India	Techtonic - Innovations in Clean Energy
	OCBC Bank Malaysia	Financing green H2 projects and Asia Pacific Green Hydrogen Conference and Exhibition 2024
	World Bank	Loan to accelerate India's development of low-carbon energy
Africa	Climate Fund Managers (CFM)	SDG One Fund for Namibia
	African Development Bank	Sustainable Energy Fund for Africa (SEFA)
	Development Bank of Southern Africa	Project Preparation Facility for Hyphen
	EBRD	Green Hydrogen Common Infrastructure Development in Jordan
	German Federal Ministry for Economic Cooperation and Development (BMZ)	Promoting a Green Hydrogen Economy in South Africa (H2.SA)
I n	World Bank (WB)	Loan to accelerate India's development of low-carbon energy

[27] The IFC is providing financial assistance for this initiative, while the main applicant, GIZ, is providing technical assistance, with the IDB supporting through complementary studies

	Loan for Ceará State, Brazil, to support a fair and clean energy transition
IFC	Funds for clean hydrogen projects
EU Commission	Global Gateway
	Horizon Europe
	LIFE Climate Change Mitigation and Adaptation
European Hydrogen Bank	Innovation Fund
	European Executive Agency for Climate, Infrastructure and Environment (CINEA)
H2Global Foundation	Auctions for green ammonia and green methanol
EIB	Green Hydrogen Fund
	Global Energy Efficiency and Renewable Energy (GEEREF)
KfW Development Bank	PtX Development Fund
Global Green Growth Institute (GGGI)	GGGI Global Green Hydrogen Program
Climate Imperative Foundation (CIF)	Climate Neutrality Foundation
Federal Ministry for Economic Affairs and Climate Action (BMWK)	International Hydrogen Ramp-up Programme – H2Uppp
UNIDO	A2D Facility
Climate Investment Fund (CIF)	Clean Technology Fund
	Strategic Climate Fund
Green Climate Fund (GCF)	E-Mobility Program for Sustainable Cities in Latin America and the Caribbean
Global Environment Facility (GEF)	GEF Trust Fund

Source: Hinicio (2024)

Delivery Mechanisms identified across developing countries

Table 0-8. Delivery Mechanisms for clean hydrogen in developing countries

Country	Name of the DM	Category	Year	Funding Details	Description
India	National Green Hydrogen Mission	Incentives/ Subsidies	2023	$2.4 Billion	The Government of India introduced the scheme to drive development and deployment of green hydrogen technologies to help the countries achieve its decarbonisation goals. The scheme has allocated funding to promote domestic production of green hydrogen and its derivatives, foster innovation and R&D in green hydrogen technologies, support infrastructure development and pilot projects, introduce skilling initiatives and establish a robust framework of regulations and standards for green hydrogen economy.
India	Strategic Interventions for Green Hydrogen Transition (SIGHT) Programme	Incentives/ Subsidies	2023	$2.1 Billion	Under National Green Hydrogen Mission, the SIGHT programme aims to incentivise the domestic manufacturing of electrolysers and production of green hydrogen and derivatives, to foster a self-reliant green hydrogen ecosystem within India.
India	R&D Scheme under National Green Hydrogen Mission	RD&D Funds	2024	$47.8 Million	The R&D scheme under National Green Hydrogen Mission aims to promote research and innovation in the country to increase the affordability of Green Hydrogen production, storage, transportation and utilisation, and to enhance the efficiency, safety and reliability of the relevant systems and processes; to foster industry-academia-government partnerships to establish

Country	Name of the DM	Category	Year	Funding Details	Description
					an innovation ecosystem; to facilitate scaling up and commercialisation of the technological advancements. The scheme offers financial support covering 100% of the total project cost for academic institutions, universities, and government or non-profit research organisations. For private institutions, research organisations, and industries, the scheme provides funding of up to 80% of the total project cost.
India	Loan from World Bank (Under First & Second-Low Carbon Energy Programmatic Development Policy Operations)	Concessional Loan / Sustainability & Transition Loan	2024	$3 Billion	Under World Bank's Low-Carbon Energy Programmatic Development Policy Operation, the financial support aims to promote the development of vibrant market for green hydrogen, scale up renewable energy and stimulate finance for low-carbon energy investments. The loan will facilitate installation of 1500MW electrolyser capacity per annum, reduction in CO2 emissions by 50MTS per annum and development of carbon markets
India	Funding Support from EIB for Green Hydrogen Projects	Credit Facility	2024	$1.11 Billion	The Credit Facility aims to support the efforts of the Government in commercialising the upcoming green hydrogen technologies, reduce costs through long-term investment in innovation, R&D, green hydrogen hubs and pilot projects

Country	Name of the DM	Category	Year	Funding Details	Description
India	Incentives and subsidy by State Government of Uttar Pradesh	Incentives/ Subsidies	2024	$604 Million	The initiative aims to promote green hydrogen/ammonia market creation by providing fiscal and non-fiscal incentives, encourage research and innovation to improve cost efficiency, pursue infrastructure development, introduce skilling initiatives and create employment opportunities. Key incentives: • 30% Capital Subsidy (First 5 projects to get 40% capital subsidy) • Provision of land @ $180 per acre annually for private developers and $ 0.012 per acre annually for public sector entities • 100% exemption on stamp, electricity duty, intra-state wheeling/transmission/cross-subsidy surcharges for the first 10 years. • Banking facility for Green Hydrogen Projects
India	Funding Support for R&D Laboratories at IIT Madras by Indus Towers	CSR Funding (CAPEX Support)	2024	-	The R&D Laboratories at IIT Madras focusing on Green Hydrogen and Battery Management Systems aims to create a solar-powered hydrogen generation system, utilising fuel cells to power the load.

Country	Name of the DM	Category	Year	Funding Details	Description
India	Funding Support for Hydrogen Valley Innovation Hub at IIT Madras by Hyundai Motor India	CSR Funding (CAPEX Support)	2024	$12 Million	The innovation hub is carrying research on Hydrogen Internal Combustion Engines (H2ICE) for vehicles, and for other applications such as machinery for factories. Overall, the hub has a special focus on localisation of manufacturing, skill development, creation of validation platforms, roadmaps and landscape analysis for green hydrogen ecosystem in the country
India	Funding raised by startup Hygenco through NEEV II Fund	Private Equity	2022	$25.4 Million	Managed by SBICAP Ventures and backed by domestic investors such as SIDBI, SBI Group, SRI Fund and international investors such as UK Government's FCDO, JICA and EIB, NEEV II is a private equity fund aimed at backing companies offering diverse solutions including clean energy, electric vehicles, efficient usage of raw materials and managing water and circular economy projects in India. Hygenco develops and uses green hydrogen and green ammonia production assets, with in-house experts in developing renewable energy, creating gases and project financing.
India	Funding raised by Ossus Biorenewals	Private Equity	2023	$2.4 Million	The cleantech startup has received Pre-Series-A Funding from Gruhas Proptech and Rainwater Climate. The funding is expected to accelerate the deployment of OB Hydracel, a bioreactor for on-site hydrogen gas production

Country	Name of the DM	Category	Year	Funding Details	Description
India	Funding raised by NewTrace	Private Equity	2023	$5.65 Million	The climate-tech startup has raised funding in seed-funding round led by Sequoia Capital India and Aavishkar Capital. The other investors included IKP Knowledge Park, Speciale Invest and Micelio Fund, and e-commerce start-up founder Ashish Goel.
Namibia	SDG One Fund Namibia	Blended Finance	2023	$1 Billion	The SDG One Fund aims to mobilise $1 billion to support the development of clean H2 ecosystem in Namibia. 100 % of the initial funding was extended as grant of $43 million by Invest International. In March 2024, USAID extended a $1 million grant. Recently, the Namibian government secured 24% equity in the Hyphen Green Hydrogen Project and mobilised over $580 million from Invest International and the EIB. At COP27, the EIB and the Namibian government signed a letter of intent for $537 million, part of which will be invested through the SDG Namibia One Fund.
Kenya	Grants from European Union (under Global Gateway Fund)	Grant	2023	$13 Million	As part of a wider $3.8 Billion Global Gateway Fund, European Commission has extended the grant for green hydrogen and its derivatives such as H2-based fertilisers in Kenya.

Country	Name of the DM	Category	Year	Funding Details	Description
Kenya	Grants from Germany	Loan	2023	$64 Million	The loan will support the project in Olkaria, where geothermal energy is to be used to split hydrogen from water molecules, providing fuel for the fertiliser plant, as well as support the development of Hydrogen Diplomacy Office in Nairobi.
South Africa	Funding from KfW Development Bank	Concessional Financing	2021	$223 Million	In partnership with CSIR and Meridian Economics, the funding provided by KfW aims to identify and support promising projects in the South African clean hydrogen market. Preference will be given to the projects in their pre-feasibility stage
South Africa	Funding from KfW Development Bank	-	2023	$25.75 Million	On behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), KfW entered into a contract with South African state-owned promotional bank Industrial Development Corporation (IDC) to start a promotional programme for building a green hydrogen economy. The funding will be utilised to finance reference projects for the large-scale production and use of green hydrogen and its by-products.
South Africa	South Africa H2 Fund (SA-H2 Fund)	-	2023	$1 Billion	Supported by Invest International, Climate Fund Managers, Sanlam Limited of South Africa, Development Bank of Southern Africa and the Industrial Development Corporation of South Africa and other strategic partners, SA-H2 Fund is an innovative blended finance fund with an aim to facilitate and accelerate the

Country	Name of the DM	Category	Year	Funding Details	Description
					development of green hydrogen sector and circular economy in South Africa. The initiative aims to mobilise $1 billion in funding.
South Africa	Grants from European Union	Grants	2024	$71.37 Million	European Commission has extended two grants to the sum of $35.72 million (€32 million) in support of South Africa's green hydrogen agenda. The first grant is expected to leverage private and public sector finance across the hydrogen value chain, covering production, storage, and downstream industries. The second grant aims to assist Transnet, to leverage additional funding for the green transformation of its operational areas, including ports, rail, pipeline, engineering and related facilities.
Indonesia	Private Sector Investment	-	-	$25.2 Billion	The government of Indonesia is expecting to raise private sector investments to develop green hydrogen industry from 2031 to 2060
Indonesia	Investments from Pertamina	Private Finance	-	$11 Billion	Pertamina is a state-owned oil and gas company in Indonesia, and is a key player in green industry
Indonesia	Investments by Augustus Global Germany	Private Finance	2023	$500 Million	Germany based Augustus Global Investment is planning to invest $500 million in Aceh province to build a green hydrogen plant, which is expected to start production by 2026.

Country	Name of the DM	Category	Year	Funding Details	Description
Indonesia	Technical Assistance by U.S. International Development Finance Corporation (DFC)	Technical Assistance	-	-	The DFC has committed to providing technical assistance to Hydrogène De France (HDF) to support the development of a portfolio of green hydrogen projects in Indonesia. These projects aim to create economic opportunities for local communities, reduce emissions, and enhance energy security.
Indonesia	Investments by ACWA Power, Saudi Arab	MoU	2023	$1 Billion	In partnership with the PT and PLN, Indonesia's state-owned electricity provider and PT Pupuk Indonesia, state-owned fertiliser and chemical producer, ACWA Power is aiming to develop green hydrogen facility in the country. The Garuda Hidrogen Hijau (GH2) Project, is expected to start commercial operations in 2026, running on 600MW of solar and wind power, producing 150,000 tons of green ammonia.
Indonesia	Investments by Samsung and Hyundai	Private Finance	2022	$1.2 Billion	Samsung and Hyundai are collaborating with Global Green Growth Institute (GGGI) to produce green hydrogen in the Sarulla Block, North Sumatra. The green hydrogen will be produced from the geothermal energy source, and supplied to the nearby Sei Mangkei Industrial Zone as eco-friendly fuel for steel and cement making factories.

Country	Name of the DM	Category	Year	Funding Details	Description
					Samsung Engineering is responsible to conduct design and validity study, and Hyundai Glovis is overseeing green ammonia shipping.
Malaysia	Singapore Capital Ventures	Private Finance	2024	$425 Million	Semarak Renewable Energy has secured a financing package of RM1.88 billion from Singapore investment firm for the green hydrogen project in Perak.
Malaysia	Investments from PowereChina	-	2024	$425 Million	Chinese state-owned subsidiary PowerChina's subsidiary China Hydropower and Semarak Renewable Energy signed an investment deal for a green hydrogen project in Perak.
Vietnam	Investments by Huadian Group	-	2024	$2.4 Billion	Chinese state-owned Huadian Group, in partnership with the local electricity producer Minh Quang to develop green hydrogen facility in Quang Tri province
Vietnam	Investments by the Green Solutions Group	Project Finance (Debt and Equity), Concessional Finance, Bonds	2023	$327.7 Million	The Green Solutions Group has invested in the Tra Vinh Green Hydrogen project, the country's first green hydrogen plant in the Mekong Delta.

Country	Name of the DM	Category	Year	Funding Details	Description
Argentina	IDB Loan for Sustainable and Resilient Growth	Loan	2023	$350 Million	The loan aims to promote key measures to facilitate energy transition, including approval of Argentina's first medium and long-term "Energy Transition Plan", first Energy Efficiency Bill and the Hydrogen Bill
Argentina	H2RAR Consortium	Industrial Partnership	2020	-	The consortium aims to establish a collaborative business platform that integrates companies across the hydrogen value chain. It further aims to provide partner companies with access to cutting-edge information, foster the development of technical capabilities, and enable the creation of innovative ventures within the sector.
Argentina	Pampas Project	Project Finance	-	$8.4 Billion (Estimated)	Announced at COP26 in 2021, the project aims to harness the wind energy resource of northern Patagonia to produce green hydrogen and derivatives.
Argentina	Partnership between Argentina and European Union	MoU	2023	-	The bilateral partnership aims to collaborate on the development and promotion of renewable energy, energy efficiency, and the use of hydrogen and its derivatives in industrial processes, transportation, and energy storage. Additionally, EU and Argentina will work towards minimising methane leakages in the fossil gas supply chain to the highest level technically feasible.

Country	Name of the DM	Category	Year	Funding Details	Description
Brazil	Private Partnerships and International Partnerships for Pecém Complex in Ceará, and the Port do Açu in Rio de Janeiro	Traditional loans/ Equity/ Concessional Finance	2018 onwa-rds	-	Private investments and international partnerships are supporting the development of the Pecém Complex in Ceará, and the Port do Açu in Rio de Janeiro, catalysing the growth of Brazil's clean hydrogen economy. Port of Rotterdam has invested over $81.4 million in Pecém Complex. the Port do Açu expects $196 million investments for thermal power plants and pipelines. Further, Shell Brazil plans to invest $60-$120 million in R&D at Port do Açu. Through International Partnerships, Brazil aims to mobilise investments worth $39 million from Germany, $15 billion from Australia, $11 billion from France, and $10 billion from the Netherlands and Portugal.
Brazil	Global Gateway Flagship Project on Hydrogen	Concessional Finance	2023	$2.16 Billion (Commitment)	The funding will be utilised to develop green hydrogen facility in Brazil and improve the energy efficiency
Brazil	Partnership between Germany and Brazil	Bilateral Agreement	2023	$3.84 Million	This bilateral agreement aims to select up to ten green hydrogen projects of small and medium enterprises (SMEs), startups and research and technology organisations in both countries.

Country	Name of the DM	Category	Year	Funding Details	Description
Brazil	Financial Assistance by the World Bank	Project Finance	2024	$90 Million	The funding assistance aims to facilitate investment in the green hydrogen value chain through shared infrastructure in the Port and Industrial Complex of Pecém.
Brazil	Vale and Petrobras Partnership	Letter of Intent	2023	-	Vale has signed a protocol of intent with Petrobras to collaborate on the development of low-carbon solutions. This two-year partnership will explore joint decarbonisation opportunities, including the development of sustainable fuels such as hydrogen, green methanol, biobunkers, green ammonia, and renewable diesel, as well as carbon capture and storage technologies.
Brazil	Green Energy Park and State of Piaui (Partnership)	Letter of Intent	2023	-	Green Energy Park, a renewable energy franchise, is partnering with the Brazilian state of Piauí to potentially establish a 5-GW green ammonia production and export facility in Brazil.
Colombia	Investment and Partnerships by Ecopetrol	Project Finance	2022	$2.5 Billion	Ecopetrol has established alliances with six international companies—Siemens, H2B2, Total Eren, EDF, and Empati—to advance its hydrogen strategy, with the goal of producing 1 million tons of green, blue, and white hydrogen.

Country	Name of the DM	Category	Year	Funding Details	Description
Colombia	Investments by Ecopetrol	-	2021	$140 Million	Ecopetrol has commenced a production test using a 50 kW electrolyser powered by PEM technology and 270 solar panels. The company has outlined a substantial investment plan through 2040, aiming to contribute 11% to its emission reduction target through the production of green, blue, and white hydrogen.
Colombia	World Bank Loan for Climate Action	Concessionary Loan	2022	$1 Billion	The loan is intended to support a reform program aimed at promoting low-carbon development by accelerating the transition in the energy and transportation sectors. The program focuses on expanding non-conventional renewable energy capacity and fostering the development of a green hydrogen industry.
Colombia	World Bank Loan	Concessionary Loan	2024	$750 Million	The loan aims to boost the development of solar and offshore wind energy, green hydrogen, and to strengthen electric urban and multimodal transport, thereby enhancing the country's resilience to climate change
Colombia	+H2 Initiative (FENOGE Fund)	Public Loans, Technical Assistance, Grants	2022	$1 Million (Initial Endowment)	FENOGE aims to promote and advance the knowledge and applications of green and blue hydrogen across the entire value chain in Colombia. The programme aims to finance the pre-feasibility and feasibility studies for the 10 winning projects along the supply chain of hydrogen, both green and blue hydrogen.

Country	Name of the DM	Category	Year	Funding Details	Description
Colombia	Partnership with Germany	Bilateral Agreement	2023	$222.3 Million	This aims to advance a bilateral partnership for climate and a just energy transition by focusing on the expansion of renewable energies, environmental and biodiversity protection, and sustainable urban development, with the ultimate goal of supporting the energy transition and becoming an exporter of clean energies, such as green hydrogen and derivatives.
Colombia	Ministry of Mines and Energy of the Republic of Colombia and the EIB Partnership	Letter of Intent	2022	-	At COP 27, the joint declaration of intent between the Ministry of Mines and Energy and the EIB aims to support the just energy transition in Colombia, focusing on green hydrogen and other green technologies.
Colombia	Partnership between Pan-African Soleil Holdings PTE. Ltd. (PASH Global) and ERIH Holdings (ERIH)	Joint Venture	2023	-	The 50-50 joint venture aims to develop and invest in green hydrogen and ammonia projects totaling 5GW of electrolyser capacity
Colombia	JBIC and EPM Alliance	MoU	2024	-	The Japan Bank for International Cooperation and Empresas Públicas de Medellín E.S.P. (EPM), a public utility company wholly owned by the Municipality of Medellín, signed an MoU to

Country	Name of the DM	Category	Year	Funding Details	Description
					promote cooperation in the hydrogen sector, including its derivatives such as ammonia.
Colombia	Partnership between Government of Colombia and Fraunhofer-Gesellschaft	MoU	2023	-	The MoU was signed between the government of Colombia, represented by the Ministry of Energy and the Minister of Commerce, Industry and Tourism, and the Fraunhofer-Gesellschaft for joint research efforts to expand the hydrogen sector in the country, with a focus on the production of green hydrogen, green ammonia, methanol, and green fertilisers.
Costa Rica	IDB Assistance	Technical Assistance	2018	$0.82 Million	Aimed at facilitating the decarbonisation of economy by strengthening of the electric transport system based on hydrogen
Costa Rica	Mitigation Action Facility	Incentive, Commercial Finance, Concessional Funds and Grants,	2024	$27.14 Million	The funding by Mitigation Action Facility aims to facilitate a transformative change towards the application of hydrogen as an energy carrier and chemical input in the country.

Country	Name of the DM	Category	Year	Funding Details	Description
Costa Rica	Partnership with IRENA	-	2021	-	The strategic partnership aims to accelerate the country's decarbonisation goals by enhancing renewable energy project financing, advancing green hydrogen production, and fostering collaboration in key sectors such as transport, heating, and industry, while leveraging IRENA's expertise and global frameworks to support Costa Rica's National Decarbonisation Plan 2018-2050
Costa Rica	Costa Rica Hydrogen Transportation Ecosystem (Ad Astra)	-	2020	$8.8 Million	The project was developed over the past 10 years, with 49% investment from Ad Astra, 35% from government of Costa Rica, 9% from NGOs and 7% from other investments and sponsorships. It is a small-scale pilot project to test the technology. The green hydrogen produced was utilised in "Niyuti" bus- the first hydrogen-based transport unit in Costa Rica.
Costa Rica	Investments by Kadelco	-	2022	$3.3 Billion	The Australian conglomerate aims to install a green hydrogen plant in Costa Rica, generating 50,000 tons of green hydrogen per year.
Costa Rica	Investments by Toyota Mobility Foundation	-	2020 onwards	-	Toyota Mobility Foundation initiated its second project in Costa Rica in partnership with CRUSA, Ad Astra, Purdy Motors and others. The project aims to expand the commercial utilisation of hydrogen for heavy duty trucking and manufacturing.

Country	Name of the DM	Category	Year	Funding Details	Description
Mexico	Investments by Copenhagen Infrastructure Partners and Mexican Authorities (Project Helax Istmo)	-	2023	$10 Billion (Estimated)	The partnership aims to develop green hydrogen and green maritime fuel infrastructure in the Isthmus of Tehuantepec, linking the Pacific Ocean and Gulf of Mexico. The project is expected to be carried out in partnership with the Interoceanic Corridor of the Isthmus of Tehuantepec (CIIT) and Mexican Navy
Mexico	H2Gen's Ammonia Project in Campeche State	-	2023	$1.22 Billion (Estimated)	Aims to establish 200 MW of electrolysers powered by off-grid wind and solar energy, producing 180,000 tonnes of renewable ammonia per year.
Mexico	Mexican-German Energy Partnership	Bilateral Partnership	2022	-	The Energy Partnership, funded by the Federal Ministry for Economic Affairs and Climate Action, BMWK, joins the strategic alliances promoted by the Mexican Hydrogen Association, with the objective of fostering the exchange of information and best practices for the development and use of green hydrogen technology in Mexico.
Mexico	Partnership between H2V2 Mexico and H2B2	Joint Venture	2023		H2V2 Mexico has entered a partnership with the Spanish company H2B2 Electrolysis Technologies to produce renewable green hydrogen. This collaboration aims to position H2V2 Mexico

Country	Name of the DM	Category	Year	Funding Details	Description
	Electrolysis Technologies				as a leading provider of green hydrogen technology solutions tailored to the needs of the industrial energy sector.
Mexico	Partnership between Mexican Hydrogen Association (AMH2) and Fuel Cell and Hydrogen Energy Association (FCHEA)	Partnership	2023	-	The partnership aims to foster collaboration between the AMH2 and the FCHEA in promoting the deployment of hydrogen as an energy vector in Mexico and the US, by facilitating joint commercial projects, advancing technological innovation, and supporting the development of a robust hydrogen industry. This partnership further aims to enhance cross-border cooperation, drive investments, create jobs, and contribute to the energy transition in both countries, leveraging policy frameworks and renewable energy potential.
Egypt	Scatec AS's Egypt Green Hydrogen Project	Off-Take Agreement	2023		The 20-year agreement between Scatec AS and Fertiglobe includes a 100% off-take of the production of green ammonia. Under the agreement, ammonia will be supplied at $1,085 per ton until 2033, starting with up to 19,500 tons in 2027 and potentially increasing to 397,000 tons by 2033.
Egypt	Loan from EIB for Egypt Green Hydrogen S.A.E	Equity Bridge Loan	2022	$80 Million	The loan aims to support the funding of procurement and construction of a 100 MW electrolyser facility together with the related facilities and civil works needed for the project.

Country	Name of the DM	Category	Year	Funding Details	Description
Morocco	Incentives under National Green Hydrogen Strategy	Incentives, Investment Guarantees, Untied Financial Loan Guarantees, ECA	2022	$38.12 Billion-$272 Billion (Estimated)	To develop a local hydrogen market with a capacity of 4 TWh and an export market with a capacity of 10 TWh, contributing to an increase in renewable energy capacity to 6 GW.
Morocco	Investments by Total Energies	-	2023	$10.69 Billion (Planned)	Total Energies aims to invest in green hydrogen and ammonia production project in Guelmim-Oued Noun, in southern Morocco
Morocco	Investments by TAQA Morocco	-	2024	$27 Billion (Planned)	TAQA Morocco has announced plans to invest in a green hydrogen project in Morocco's Dakhla-Oued El-Dahab region.
Türkiye	EU Investments to South Marmara Hydrogen Shore Project	Concessional Finance	2022	$40 Million	The funding aims to support the development of South Marmara Hydrogen Shore, which is further prioritising the production of clean hydrogen as well as liquid and solid derivatives such as ammonia, methanol and boron-hydrogen compounds.
Brazil, Egypt, India, Kenya, Morocco,	PtX Development Fund by KfW Development	Development Fund	2024	$301.8 Million	The main objective of the PtX Development Fund is to promote the production of green hydrogen and its derivatives in developing and emerging economies by providing non-

Country	Name of the DM	Category	Year	Funding Details	Description
South Africa, Georgia	Bank (funded by Federal Ministry for Economic Cooperation and Development)				reimbursable grants to industrial-scale projects. These projects must be close to financial close and aim to contribute to decarbonisation, sustainable economic development, and local growth by driving investment in the green hydrogen value chain.

Source: Hinicio and puREsource (2024)

Key Funding Initiatives for Research & Innovation in Developing Countries

Table 0-9. Funding Initiatives for Research & Innovation focusing on clean hydrogen in developing countries

COUNTRY	FUND	FUNDING DETAILS	OBJECTIVES
INDIA	R&D Funding under National Green Hydrogen Mission	$47 million	The R&D scheme aims at scaling up the R&D effort to promote indigenous technology development fir wide spread deployment of Green Hydrogen technology in an efficient and cost-effective manner across the country. Academic Institutions, Universities, Government/Non-Profit research organisations will be eligible for 100% financial support, while the private institutes and industry would be eligible for 80% of the total project cost.
INDIA	Hyundai Motor India Pvt Ltd Grant for Development of Hydrogen Valley	$12 Million	Automotive giant Hyundai has extended funding for the development of the Hydrogen Valley Innovation Hub at IIT Madras. In collaboration with Hyundai and Guidance Tamil Nadu, the state's investment promotion agency, IIT Madras is establishing this innovation hub, which will focus on research

COUNTRY	FUND	FUNDING DETAILS	OBJECTIVES
	Innovation Hub at IIT Madras		related to hydrogen internal combustion engines (H2ICE) for vehicles and other applications.
INDIA	Funding support by Indus Towers for Research Laboratories at IIT Madras	-	In partnership with the telecom infrastructure company Indus Towers, IIT Madras is setting up Research & Development Laboratories focused on "Green Hydrogen & Battery Management System" at the campus of the institute.
INDIA	Clean Energy International Incubation Centre (Social Alpha's Energy Lab)	-	The first international innovator in India under Mission Innovation, this energy lab is a joint initiative of Tata Trusts and the Government of India supported by Department of Biotechnology, BIRAC, Tata Power. The CEIIC has been set up to promote innovations in the energy space, as a public-private partnership with a cost-sharing model between the Government of India and Tata Trusts (43:57).
INDONESIA	Research Grants by DIPI (Indonesian Science Fund)	-	The DIPI is actively promoting research and innovation in Indonesia by providing research grants across several key areas, including clean hydrogen, though the focus on hydrogen remains limited. One notable recent outcome is a paper titled "Intensified Nano-Catalyst Design for Hydrogen Synthesis". Additionally, the National Research and Innovation Agency (BRIN) is actively involved in advancing

COUNTRY	FUND	FUNDING DETAILS	OBJECTIVES
			research and innovation for development of clean hydrogen industry.
MALAYSIA	Funding by Government of Malaysia (Ministry of Science, Technology and Innovation, MOSTI)	$9.7 Million	Since the Eighth Malaysia Plan (2001-2005), the government has prioritised hydrogen fuel cells as a key area for research and development. From 1997 to 2013, the Ministry of Science, Technology, and Innovation allocated approximately $10 million in funding to support hydrogen fuel cell research initiatives. University of Technology Malaysia (UTM) and National University of Malaysia (UKM) have been appointed as research partners with the ministry. This partnership has produced prototypes such as solar-hydrogen eco-house, hydrogen-based boiler, vehicle, and conversion kits.
MALAYSIA	Partnership between PETRONAS Gas and New Energy and ENEOS Corporation	MoU	The joint partnership will see both the parties to undertake a technical-commercial joint-study of a hydrogen supply chain which includes hydrogen production and its transportation in methylcyclohexane (MCH) form.

COUNTRY	FUND	FUNDING DETAILS	OBJECTIVES
SOUTH AFRICA	South African Research Chairs Initiative (SARChI)	$0.13 Million for Tier-1 Chairs $0.083 Million for Tier-2 Chairs	The primary objective of the DSI/NRF-Sasol Research Chair in Green Hydrogen is to enhance South Africa's research and innovation capacity in green hydrogen, develop new technologies, train skilled researchers, and support the country's green hydrogen strategy to drive decarbonisation and economic growth
SOUTH AFRICA	HySA Catalysis (National Hydrogen Catalysis Competence Centre)	-	Established by Department of Science and Innovation, HySA is hosted by the University of Cape Town and South African national mineral research organisation-Mintek. It is one of the three Centres of Competence forming part of the National Hydrogen and Fuel Cells Technologies Flagship project.
SOUTH AFRICA	HyPlat	-	Commercial arm of HySA Catalysis, HyPlat is a specialist fuel cell technology company, hosted by University of Cape Town and Mintek.
COLOMBIA	Partnership between Government of Colombia and Fraunhofer-Gesellschaft	MoU	The MoU was signed between the government of Colombia, represented by the Ministry of Energy and the Minister of Commerce, Industry and Tourism, and the Fraunhofer-Gesellschaft for joint research efforts to expand the hydrogen sector in the country, with a focus on the production of green hydrogen, green ammonia, methanol, and green fertilisers.

COUNTRY	FUND	FUNDING DETAILS	OBJECTIVES
BRAZIL	Rehidro Tax Regime	Incentives	The Special Incentive Regime for Low-Carbon Hydrogen Production (Rehidro) aims to provide benefits of the Special Incentive Regime for Infrastructure Projects (REIDI) to the hydrogen companies. To qualify for the incentives, the companies must show qualification to produce low-carbon hydrogen, minimum percentage of local content used in the production process and minimum investments in research, development and innovation.
BRAZIL	Photovoltaic Laboratory at the Federal University of Santa Catarina (UFSC)	$2.9 Million	The project is part of H2Brazil and is supported by the government in the context of the hydrogen ramp-up and development of PNH2 (Agora Industry, Agora Energiewende and Instituto E+ Transição Energética, 2024).
BRAZIL	Hydrogen and Advanced Fuels Laboratory	$0.735 Million	As part of Brazil-Germany cooperation through H2Brasil Project, together with SENAI Institute for Innovation in Renewable Energies (ISI-ER), Brazil's first Hydrogen and Advanced Fuels Laboratory (H2CA) is established with the goal of producing SAF and supporting the development of Brazil's hydrogen economy through scientific research, innovation, and international collaboration.
ARGENTINA	Y-Tec Alkaline Electrolyser Prototype	-	Y-Tec has developed a prototype which is in testing stage and aims to build the first high-power (1MW) alkaline electrolyser. This project is supported by the Argentine Sectoral Fund (FONARSEC) of the National Agency for the Promotion of

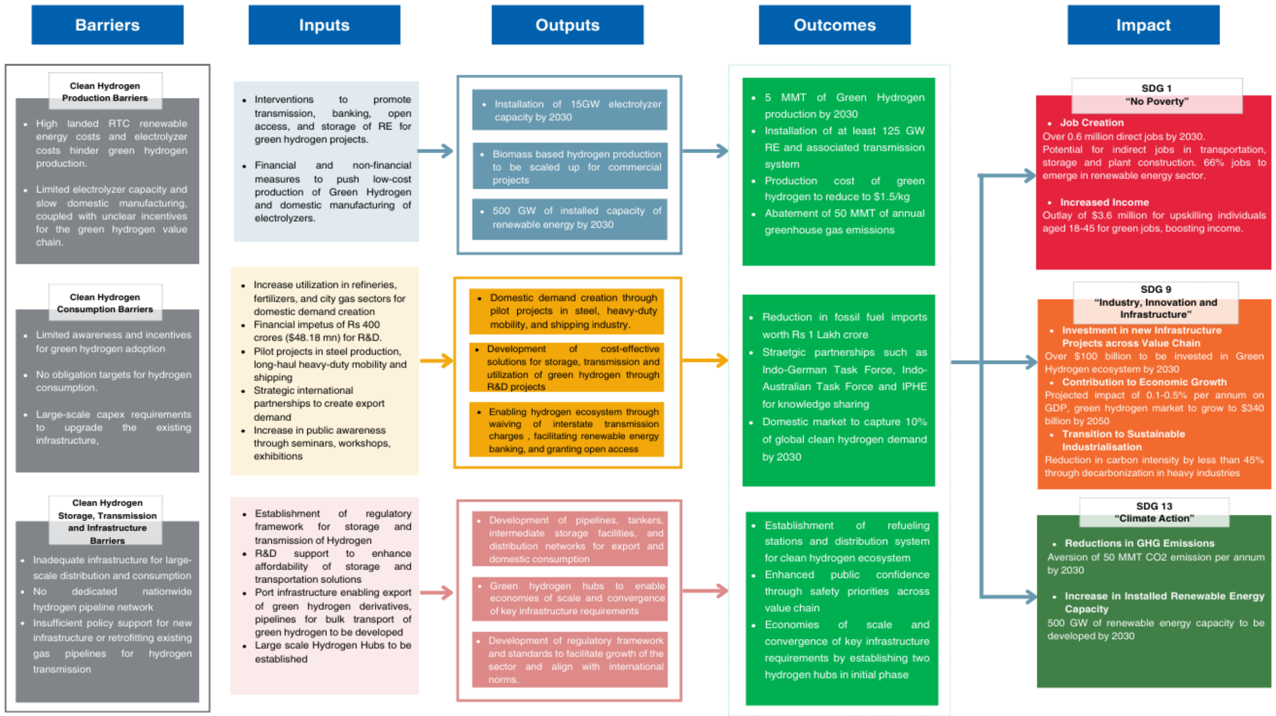
COUNTRY	FUND	FUNDING DETAILS	OBJECTIVES
			Research, Technological Development and Innovation, in collaboration with the Ministry of Science, Technology and Productive Innovation (MINCyT) and the Federal Council for Science and Technology (COFECyT).
COSTA RICA	Joint Study for Hydrogen Fuel Cells in Sailing Cargo Ships by Ad Astra and SAILCARGO INC	-	Under “Hydrogen for Sea” campaign, SAILCARGO INC and Ad Astra Servicios Energetico y Ambientales (AASEA) are jointly working to promote the development and demonstration of hydrogen fuel system in zero-emission cargo ships.

Source: Hinicio and puREsourc (2024)

ANNEX 5: COUNTRY LEVEL ANALYSIS FOR SDG ASSESSMENT BASED ON THE PROPOSED THEORY OF CHANGE[28]

- **India**

Figure 0-1. Theory of Change across clean hydrogen value chain in India



[28] The following case studies from India and Namibia are examples of the country-level assessments performed to measure the impact of developing the clean hydrogen value chain on the SDGs.

Table 0-10. Summary of Theory of Change for clean hydrogen ecosystem illustrating impact on SDGs in India

Theory of Change in Clean Hydrogen Value Chain: India					
Barriers Identified		**Proposed Inputs**	**Outputs**	**Estimated Outcomes**	**Impact on SDGs**
Production Barriers	• High cost of production. The current production cost of green hydrogen in $4-5/kg. Renewable energy electricity accounts for 50-70% of this cost and needs optimisation.[29] • Limited capacity of electrolysers. [30] • Lack of green incentives to promote clean hydrogen production. • Early-stage infrastructure and technological maturity poses risk leading to high capex requirements.	• Policy interventions to promote renewable energy transmission, connectivity, banking, open access, and storage for green hydrogen projects. • Financial measures up to $2.1 billion to increase low-cost production of Green Hydrogen and domestic manufacturing of electrolysers under Strategic Interventions for Green Hydrogen Transition (SIGHT). • Establishment of regulatory framework for green hydrogen ecosystem	• Installation of 15GW electrolyser capacity and 500 GW renewable energy capacity by 2030 • Scaling up of biomass-based hydrogen production for commercial projects • Enabling hydrogen ecosystem through waiving of interstate transmission charges for GH2 production, facilitating renewable energy banking, and granting open access • Framework of regulations and standards to be established, facilitating growth of the sector and enabling harmonisation and engagement with international norms.	• 5 MMT of Green Hydrogen production by 2030 • Installation of at least 125 GW RE and associated transmission system • Production cost of green hydrogen to reduce to $1.5/kg • Abatement of 50 MMT of annual greenhouse gas emissions • Reduction in carbon intensity by 45%, 50% of electrical energy capacity from RE sources by 2030	**SDG 1 "No Poverty"** • Green hydrogen industry w drive the country's progres in alleviating poverty by create 0.6 million jobs in th economy by 2030. • The green hydrogen ecosystem will create both high and low-skilled jobs. 66% of Green Hydrogen job to come from renewable energy sector, electrolyser manufacturing and plant construction to generate 4 and 11% of the jobs. Green Hydrogen production and storage facilities will gener 11% and 2% jobs, respectively.[31] • Long term plans include expanding grid to provide access to energy in remote and rural areas, reducing energy poverty. **SDG 9 "Industry, Innovation an Infrastructure"** • Transition to clean hydroge will drive green and
Consumption Barriers	• Lack of public and industrial awareness about application of hydrogen and its derivatives. • Lack of regulatory framework mandating the integrating of green hydrogen across industry. • Currently, green hydrogen is twice as expensive as grey	• Policy support to increase green hydrogen utilisation in refineries, fertilisers and city gas sectors to stimulate demand creation. • Initiate green transition in hard to abate sectors such as steel production, long-haul heavy-duty mobility and shipping through pilot projects, boosting domestic demand	• Pilot projects in steel, heavy-duty mobility, and shipping industry to initiate green transition in hard to abate sectors and boost demand • Establishment of two plants each for production of green hydrogen-based urea and green hydrogen-based DAP to boost domestic production of fertiliser	• Increase in production of Green Steel • Reduction in fossil fuel imports worth Rs 1 Lakh crore • Enhanced public confidence through safety priorities across value chain • Strategic interventions to enable the domestic market to capture 10% of global	

[29] https://www.weforum.org/publications/green-hydrogen-enabling-measures-roadmap-for-adoption-in-india/
[30] https://mopng.gov.in/files/article/articlefiles/2023Q2.pdf
[31] https://sscgj.in/wp-content/uploads/2023/05/Skills-Lanscape-for-Green-Jobs-Report.pdf

Theory of Change in Clean Hydrogen Value Chain: India

Barriers Identified		Proposed Inputs	Outputs	Estimated Outcomes	Impact on SDGs
	hydrogen. Availability of cheaper alternatives hinders the wider adoption. • Limited demand for green hydrogen, uncertainty regarding potential off-take agreements. • R&D to support the utilisation of green hydrogen in road transport and power sector in early stages, limiting the domestic demand creation.	• Knowledge creation through seminars, workshops, exhibitions for stakeholders and general public. • Strategic international partnerships to create export demand for hydrogen and its derivatives.	• International trade partnerships to create export markets for green hydrogen, stimulating demand.	clean hydrogen demand by 2030 • By 2034-35, complete substitution of import of ammonia-based fertilisers with domestic production, reducing annual import value of over $6 billion	sustainable industrialisatio Wider adoption in steel industry, heavy-duty vehicl city gas distributions and fertiliser industry will accelerate significant decarbonisation efforts. • ~$96 million to be invested pilot projects and green infrastructure to promote clean hydrogen ecosystem • Financial impetus of $48.18 million to increase R&D projects to innovation in th green hydrogen industry, **SDG 13 "Climate Action"** • Production target of 5 MMT green hydrogen by 2030 wi avert 50 MMT CO2 emission • Reduction in emission will also be driven by increase the installed capacity of renewable energy. By 2030, 500 GW of renewable energ capacity will be installed.
Transmission and Storage Barriers	• Lack of infrastructure and limited technological maturity to develop cost and energy efficient solutions for storage and transmission of green hydrogen • Lack of regulatory framework to standardise the storage and transmission of green hydrogen. • Geographical constraints due to lack of nationwide interconnected pipelines. Insufficient policy and R&D support for new infrastructure or retrofitting the existing pipelines for green hydrogen usage.	• Policy and technical support to enhance cost and energy efficiency of storage and transportation systems of green hydrogen and to enhance the efficiency, safety and reliability of the relevant systems and processes • Policy support and financial impetus of $48.18 million for R&D projects. • Port infrastructure enabling export of green hydrogen derivatives, pipelines for bulk transport of green hydrogen will be developed • Large scale Hydrogen Hubs will be established	• Development of cost-effective solutions for storage, transmission and utilisation of green hydrogen through R&D projects • Development of pipelines, tankers, intermediate storage facilities, and last-leg distribution networks for export and domestic consumption of green hydrogen • Establishment of green hydrogen hubs enabling economies of scale and convergence of key infrastructure requirements	• Establishment of refuelling stations and adequate distribution system for clean hydrogen ecosystem • Strategic partnerships such as Indo-German Task Force, Indo-Australian Task Force and IPHE for knowledge and technology sharing • Economies of scale through establishing two hydrogen hubs in initial phase	

- **Namibia**

Figure 0-2. Theory of Change for clean hydrogen ecosystem in Namibia

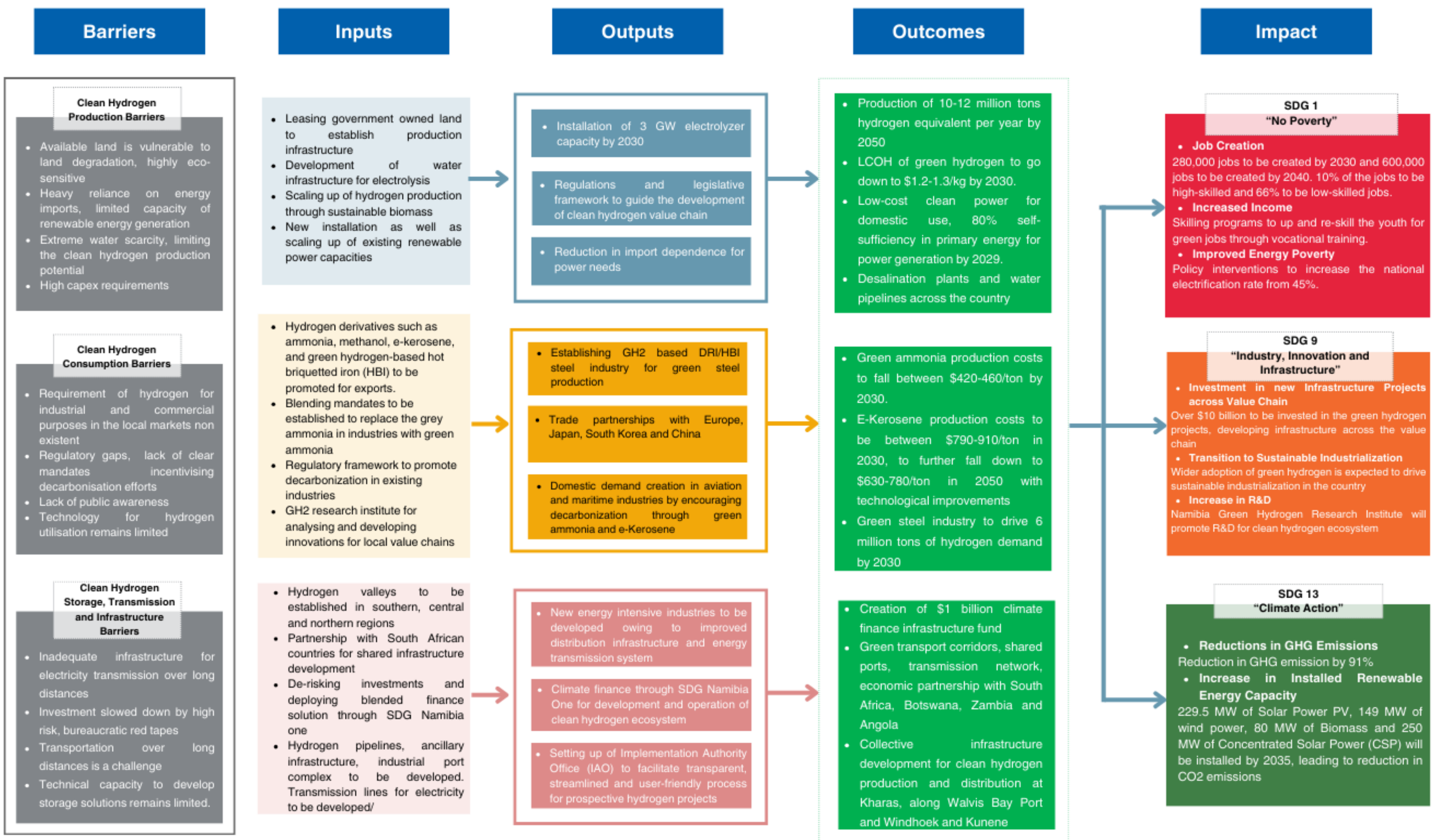


Table 0-11. Summary of Theory of Change for clean hydrogen ecosystem illustrating impact on SDGs in Namibia

Theory of Change in Clean Hydrogen Value Chain: Namibia					
	Barriers Identified	**Proposed Inputs**	**Outputs**	**Estimated Outcomes**	**Impact on SDGs**
Production Barriers	• Developing clean hydrogen infrastructure in Namibia is challenging due to the arid climate, which causes ecological sensitivity and land degradation.[32] • High costs of production stem from heavy reliance on energy imports and limited renewable energy capacity. Water scarcity further restricts hydrogen production through electrolysis. • High upfront capital costs due to early-stage infrastructure and limited technological maturity.	• Leasing of government owned land in alignment of sound environmental regulations for infrastructure development. • Desalinations plants will be set up along the coastal areas in addition to the water transmission pipelines • Deployment of the $1 billion SDG Namibia One fund to provide blended climate finance, mitigating the investment risks and addressing high capex requirements. • New electricity transmission system will be developed and existing power generation capacities will be scaled up.	• Installation of 3 GW electrolyser capacity supported by installation of 5 GW wind and solar capacity.[33] • Power generation capacities to be scaled to meet the energy needs at an affordable rate and reduced emissions. • Establishment of new Implementation Authority Office to enable enhanced transparency, streamlined and user-friendly process for all stakeholders in the prospective hydrogen projects. • Financing of development, construction and operation of the green hydrogen ecosystem at reduced risk through SDG Namibia One fund.	• Production target of 10-12 million tons of hydrogen equivalent to be achieved by 2050. • Reduction in the LCOH to $1.2-1.3/kg by 2050. • Reduction in GHG emissions by 91% by 2030 • Development of production and distribution infrastructure for renewable energy to enable 80% self-sufficiency in power generation by 2029. • Desalination plants and water pipelines will be established for Green Hydrogen production.	**SDG 1: "No Poverty"** • Clean hydrogen industry is expected to create 280,000 jobs by 2030 and 600,000 jobs by 2040. Skill development and training programs will assess the skill gap and train the labour force for the upcoming green jobs, leading to reduction in unemployment and improved incomes. • The national electrification rate will be improved beyond 45% which will further reduce energy poverty and improve quality of life. **SDG 9: "Industry, Innovation and Infrastructure"** • Three green hydrogen valleys will be established to develop green infrastructure for clean hydrogen industry • Namibia Green Hydrogen Research Institute will promote research, development and innovation to enhance technical maturity for clean hydrogen industry
Consumption Barriers	• Domestic demand of hydrogen for commercial or industrial purposes is limited or non-existent. • Lack of regulatory framework and safety standards for clean hydrogen value chain. Lack of incentives for	• Policy interventions will boost demand in both domestic and export markets. • Production of hydrogen derivatives such as ammonia, methanol, e-kerosene, and green hydrogen-based hot briquetted iron (HBI) for exports.	• Development of regulatory and legislative framework to guide the development of clean hydrogen ecosystem. • Policy interventions to drive decarbonisation in the aviation and maritime industry creating domestic demand for Green Ammonia and E-Kerosene.	• E-Kerosene production costs to be between $790-910/ton in 2030, to further fall down to $630-780/ton in 2050 with technological improvements • Green ammonia production costs to fall	

[32] Namibia Land Degradation Neutrality National Report 2015.pdf (gov.na)
[33] https://www.fdiintelligence.com/content/news/explainer-how-green-hydrogen-put-namibia-on-the-map-83146

Theory of Change in Clean Hydrogen Value Chain: Namibia					
	Barriers Identified	**Proposed Inputs**	**Outputs**	**Estimated Outcomes**	**Impact on SDGs**
	domestic industries to adopt clean hydrogen. • Lack of general awareness about the environmental and economic benefits of clean hydrogen transition. • Wider domestic adoption of clean hydrogen remains constrained due to limited technological maturity.	• Pilot projects and incentives to drive decarbonisation in aviation and maritime industry through E-Kerosene and Green Ammonia • Essential mandates to promote blending of clean hydrogen in domestic industries • Pursuit of international trade partnerships to facilitate the creation of export market.	• Trade partnerships with Europe, Japan, South Korea and China[34] to create export markets • Promotion of green hydrogen based DRI/HBI steel industry to encourage production of green steel. • Development of energy infrastructure and increased investments will attract new energy-intensive industries, such as Aluminium and Glass Production, expanding domestic market	between $420-460/ton by 2030. • Green steel to achieve carbon price competitiveness in the range of $50-100/ton of CO2. • Production of green steel to account for 6 million tons of domestic hydrogen demand in 2030. • Green hydrogen industry to contribute $4.1 billion to GDP by 2030.	• Adoption of green hydrogen across industrial sector will facilitate sustainable industrialisation. **SDG 13: "Climate Action"** • Namibia plans to reduce the GHG emissions by 91% • Shift to renewable energy will further reduce the import dependence and lead to lower CO2 emissions.
Transmission and Storage Barriers	• Lack of infrastructure, technology readiness and policy regulations for storage and transmission of GH2. • Geographical constraints due to lack of nationwide interconnected pipelines. • Insufficient policy and technical support for development of new infrastructure or retrofitting the existing for green hydrogen ecosystem.	• Development of Common Use Infrastructure (CUI) for the first large-scale hydrogen projects. • Namibia Green Hydrogen Research Institute will be set up to aid in localising the value chain, develop innovations in the clean hydrogen value chain and foster partnerships between university-industry-government. • Establishment of three green hydrogen valleys at Kharas in Southern region, Walvis Bay port and Windhoek in Central region and Kunene in the northern region • Partnership with other African countries to develop shared infrastructure.	• Infrastructure development for cost and energy efficient storage and transmission of clean hydrogen through the international partnerships and policy interventions. • Increase in R&D through establishment of research institutions and upskilling programs to skill the population in alignment with the Namibian Training Authority for green jobs. Tailored immigration policies will attract talent. • Policy initiatives to enhance access to energy in remote areas. Development of transmission system and	• Domestic labour market to create 280,000 jobs by 2030 and 600,000 jobs by 2040, driving clean hydrogen ecosystem. 10% of direct jobs to be higher-skilled and 66% to be lower-skilled. • Economic partnerships with South Africa, Angola, Botswana and Zambia to establish integrated green ecosystem, through development of green corridors, shared ports, pipelines and transmission networks. • Collective infrastructure development for clean	

[34] https://newclimate.org/sites/default/files/2023-11/The%20landscape%20of%20green%20hydrogen%20in%20Namibia_nov2023.pdf

Theory of Change in Clean Hydrogen Value Chain: Namibia				
Barriers Identified	**Proposed Inputs**	**Outputs**	**Estimated Outcomes**	**Impact on SDGs**
	• Hydrogen pipelines, ancillary infrastructure, distribution corridor will be developed.	establishment of Rural Electrification Fund will aid in the initiative	hydrogen production and distribution at Kharas, along Walvis Bay Port and Windhoek and Kunene. • Development of hydrogen pipelines and refuelling stations	

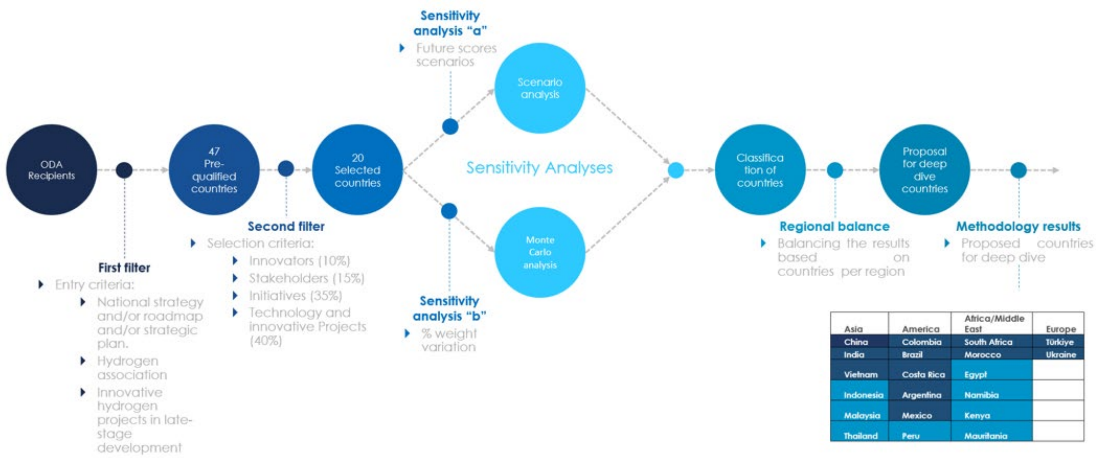
ANNEX 6: METHODOLOGY FOR DEEP-DIVES

Proposed countries for the deep-dives

The methodology used by Hinicio to preselect the 20 countries (then truncated to 16) is described in this annex. It is included in this report to demonstrate the process followed to UNIDO and UK DESNZ.

A flow diagram of the followed methodology is presented in the figure:

Figure 0-3. Countries selection methodology flow diagram.



Source: Hinicio (2024)

Description and application of the methodology – Scorecards

After organising information innovators, pilot projects, stakeholders, delivery mechanisms and initiatives on all the developing countries included, they were listed in an Excel spreadsheet to create a fair and objective ranking. Then, Hinicio established preselection criteria based on the existence of either public or private support and interest to create a clean hydrogen ecosystem that can foster innovation and technological development. The entry criteria served as a preliminary filter that was applied to those countries that presented at least one of the following categories:

(i) Has a national strategy and/or roadmap and/or strategic plan; and/or
(ii) Has a renewable hydrogen association; and/or

(iii) Shows evidence of innovative hydrogen projects in advanced stages of development in the territory.

It should be noted that the existence of either one of these criteria was enough for a country to be considered for the next selection phases.

Once the countries that meet the criteria had been filtered, from a total of 141 countries, **only 47 met the criteria**, as 94 countries did not meet any of the three criteria.

Table 0-12. Countries matching any of the three criteria

Country	Evidence of a national strategy and/or roadmap	Evidence of clean hydrogen association	Evidence of pilot innovation projects
Afghanistan	1	0	0
Algeria	1	0	1
Angola	0	1	0
Argentina	1	1	1
Bangladesh	0	0	1
Bhutan	1	0	0
Bolivia	1	1	1
Brazil	1	1	1
Burkina Faso	0	0	1
Cabo Verde	0	1	0
China (People's Republic of)	1	1	1
Colombia	1	1	1
Costa Rica	1	1	1
Ecuador	1	1	1
Egypt	1	1	1
Fiji	0	0	1
Georgia	0	1	0
Ghana	0	1	0
Guinea-Bissau	0	1	0
India	1	1	1
Indonesia	1	1	1
Iran	0	0	1
Kazakhstan	0	0	1

Kenya	1	1	1
Malaysia	1	1	1
Mauritania	1	1	1
Mexico	0	1	1
Mongolia	0	1	1
Morocco	1	1	1
Namibia	1	1	1
Nepal	0	1	0
Nigeria	0	0	1
Panama	1	1	0
Papua New Guinea	0	1	0
Paraguay	1	1	1
Peru	1	1	1
Philippines	0	0	1
Sao Tome and Principe	0	1	0
South Africa	1	1	1
Sri Lanka	1	1	1
Thailand	0	1	1
Türkiye	1	1	1
Turkmenistan	1	0	0
Ukraine	1	1	1
Uzbekistan	1	0	1
Viet Nam	1	1	1
Zambia	0	1	1

Source: Hinicio (2024)

For the next phase, four criteria categories were established: Innovators, Stakeholders, Initiatives (including delivery mechanisms), and Technology & Projects. These categories were assigned a relevance percentage of 10%, 15%, 35%, and 40%, respectively. Distributed into subcategories with scores ranging from 1-5 for those countries that present these criteria.

To establish the 4 main categories, we considered the objectives of the market assessment landscapes, including delivery mechanisms and projects. We then established sub-categories for each section, ensuring that each sub-category held a weight of at least 5% and no more than 15%. Among all the sub-categories, innovative technologies and projects carried the most weight, given the scope of the market assessment and the importance of having a substantial number of projects that can be applied to the facility, as well as the level of development of these projects. Next in importance were initiatives, due to the positive financial and supportive environment of a country that fosters the development of such innovative projects. The stakeholders category followed with a lower percentage, and lastly, innovators was deemed the least relevant due to its correlation with the innovative projects section.

The categories with their respective weights (in percentages) and scores are presented below:

1) **Innovators (10%)**
    - 5: Evidence of =>7 innovators
    - 4: Evidence of 3-6 innovators
    - 3: Evidence of <3 innovators
    - 0: No evidence

2) **Stakeholders (15%)**
    - Existence of clean hydrogen association (10%)
        - 5: Existence of clean hydrogen association
        - 0: No evidence
    - Existence of an authority in charge of H2 (5%)
        - 5: Existence of a public authority or department leading clean hydrogen and/or renewable energies
        - 0: No evidence

3) **Initiatives (35%)**
    - National Strategy/Roadmap (5%)
        - 5: Country has strategy/roadmap
        - 0: Country does not have strategy/roadmap
    - Evidence of innovation and R&D hydrogen programs (5%)
        - 5: Evidence of programs for H2 value chain
        - 0: No evidence
    - Evidence of hydrogen hubs, valleys or clusters for the develop of hydrogen environment (5%)
        - 5: Evidence of operational hydrogen Hubs
        - 3: Announcement of future hydrogen Hubs
        - 0: No development of hubs
    - Financial support of national or international private funding (10%)
        - 5: Evidence of private support
        - 0: No support
    - Public funding for innovation in hydrogen (10%)

- 5: Evidence of public support
- 0: No support

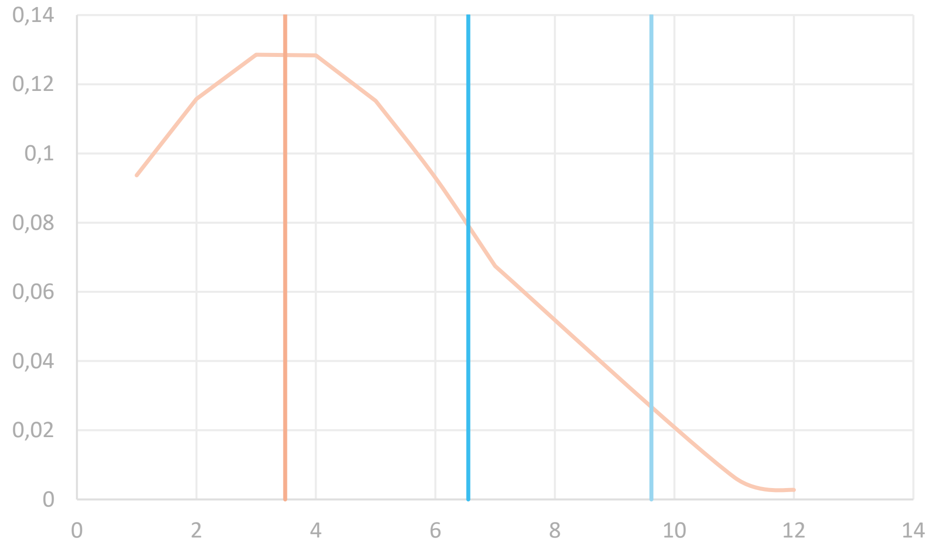
4) Technology and innovative Projects (40%)

- High quantity of laboratory pilot scale technology research (10%)
  - 5: Countries with 13+ Research
  - 3: Countries with 5-13 Research
  - 2: Countries with -5 Research
  - 0: No research found
- High quantity of potential lighthouse projects (15%)
  - 5: Countries with 10< Projects
  - 4: Countries with 7-9 Projects
  - 3: Countries with 3-6 Projects
  - 2: Countries with <3 Projects
  - 0: No pilot projects announced
- High Project Readiness Level (15%)
  - 5: Projects with PRL3-4 (TRL5-7) (Prototype Field validation and operational)
  - 3: Projects with PRL2 (TRL 4-5) (Laboratory validation or Planning phase)
  - 0: Lower than PRL2 (<TRL 4)

In terms of the criterion “High quantity of potential lighthouse projects”, the score assigned was calculated based on a standard deviation analysis to determine the ranges which should be considered. Hence, once the scores for each country and subcategory were assigned, the ranges were calculated based on the Standard Deviation[35], resulting as in the table below.

[35] The deviation from the mean is the difference between each value of the statistical variable and the arithmetic mean. The mean deviation is the arithmetic mean of the absolute values of the deviations from the mean.

Figure 0-4. Normal distribution curve of projects number in mapped countries.



Source: Hinicio (2024)

The X axis represents the number of mapped projects while the Y axis represents the normal distribution of data. The vertical lines indicate the range to be considered for the scores, being:

- 5 points: Countries over 10 projects (Over average + 2 deviations)
- 4 points: Countries between 7 and 9 projects (Between 1 and 2 deviations)
- 3 points: Countries between 3 and 6 projects (Between average and 1 deviation)
- 2 points: Countries with less than 3 projects (Below average)
- 0 points: No projects

The same methodology of standard deviation was applied to "High quantity of laboratory pilot scale technology research", obtaining the following scoring distribution:

- 5 points: Countries over 13 research (Over average + 1 deviation)
- 3 points: Countries between 5 and 13 research (Between average and 1 deviation)
- 2 points: Countries with less than 5 projects (Below average)
- 0 points: No research

It is relevant to mention that a country that passes the first filter criteria, referring to the existence of projects, did not necessarily receive points in either research or projects. That depends on the number that the country has.

Using the above methodology, a list of the 20 highest scored countries is presented[36]:

Table 0-13. List of 20 countries with the highest scores

Ranking	Country	Score
1	China (People's Republic of)	5,00
2	India	4,70
3	South Africa	4,40
4	Colombia	4,00
4	Morocco	4,00
6	Brazil	3,90
6	Viet Nam	3,90
8	Costa Rica	3,75
9	Türkiye	3,70
9	Ukraine	3,70
11	Argentina	3,55
11	Mexico	3,55
13	Egypt	3,45
14	Indonesia	3,40
15	Peru	3,35
16	Kenya	3,30
16	Malaysia	3,30
16	Namibia	3,30
19	Mauritania	3,20
20	Thailand	3,15

Source: Hinicio (2024)

Sensitivity Analyses

[36] The scores obtained by the countries in this list was obtained based on initial number of projects, research, and development stage. The number and readiness of some projects changed as public information was updated and interviews were conducted in the months leading up to the final report's submission. As a result, small variations in the final score may have occurred. Therefore, a variability analysis section is provided below to anticipate these minor changes in the score.

In the third phase, two different sensitivity analyses were performed to understand if the selected countries could keep their spots on the list. A Montecarlo analysis and a scenario analysis.

ANNEX 7. INTERVIEWS, SURVEYS AND WORKSHOPS

List of interviews conducted

Table 0-14. List of interviews conducted and date of the interview

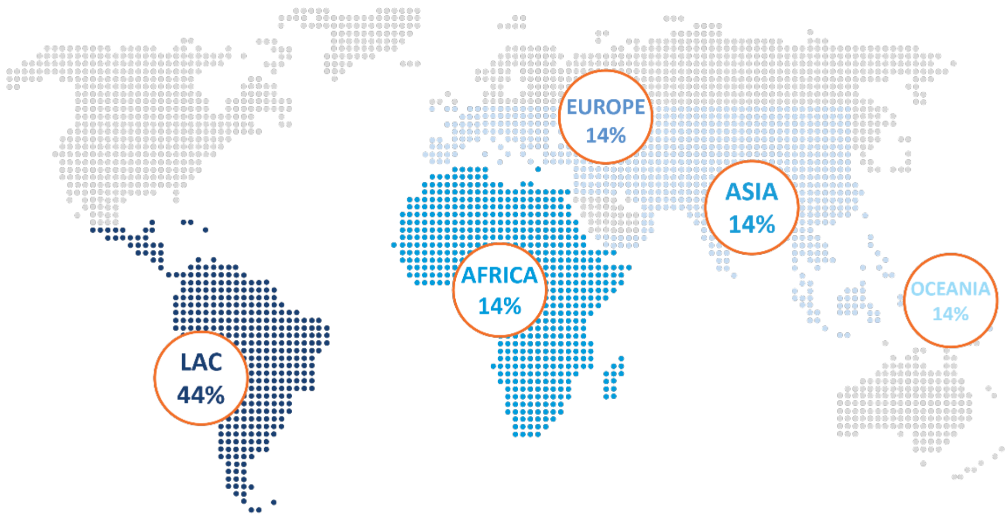
#	Interview	Date of interview
1	ACE ASEAN Region	3rd July 2024
2	African Development Bank	13th May 2024
3	Cavendish	28th June 2024
4	CCEE Brazil	4th July 2024
5	Daures	8th July 2024
6	GIZ México	13th May 2024
7	Economic Research Institute for ASEAN and East Asia (ERIA)	7th June 2024
8	Ecopetrol	27th June 2024
9	FENOGE Colombia	17th July 2024
10	GIZ Kenya	3rd July 2024
11	H2 Colombia	16th July 2024
12	H2 Egipt	1st July 2024
13	H2 Turkiye	1st July 2024
14	HDF	25th June 2024
15	Hydrogen Ukraine (Association)	26th June 2024
16	H2U	26th July 2024
17	IAHE	13th May 2024
18	IEA	22nd May 2024
19	IDB	17th May 2024
20	International PtX Hub	6th June 2024
21	JETP	9th July 2024
22	LAC Clean Hydrogen Association	17th July 2024
23	Minae Costa Rica	3rd July 2024
24	NamGHA	25th July 2024
25	Nanomalaysia	23rd July 2024
26	OPEX	31st July 2024
27	Sowitec Kenya	15th July 2024
28	Talus Kenya	8th July 2024
29	UBA	10th July 2024
30	Umagine India	22nd July 2024
31	United Nations Development Programme	6th June 2024
32	World Bank	23rd May 2024
33	Y-TEC	17th July 2024

Source: Hinicio (2024).

Surveys and Workshops

Workshops sessions and focus group discussions were organised providing a platform to explore the challenges encountered by developers and researchers working on clean hydrogen technologies. They were conducted with participants from Eastern Europe, MENA, Africa, Latin America, and Asia. The collected data was then analysed to generate statistical insights, offering direct perspectives from those actively engaged in the clean hydrogen sector. Figure presents the diversity of participants in the information gathering activities.

Figure 0-5. Distribution of participation in conducted activities



Source: Hinicio (2024).

These represents the securement of public funds and an off taker. As shown in the figure, only half of the developers have secured an off taker for their projects, while almost 60% have received public funding, primarily in the form of grants.

Vienna International Centre
Wagramerstr. 5, P.O. Box 300,
A-1400 Vienna, Austria

+43 1 26026-0

http://a2dfacility.unido.org

A2DFacility@unido.org

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION