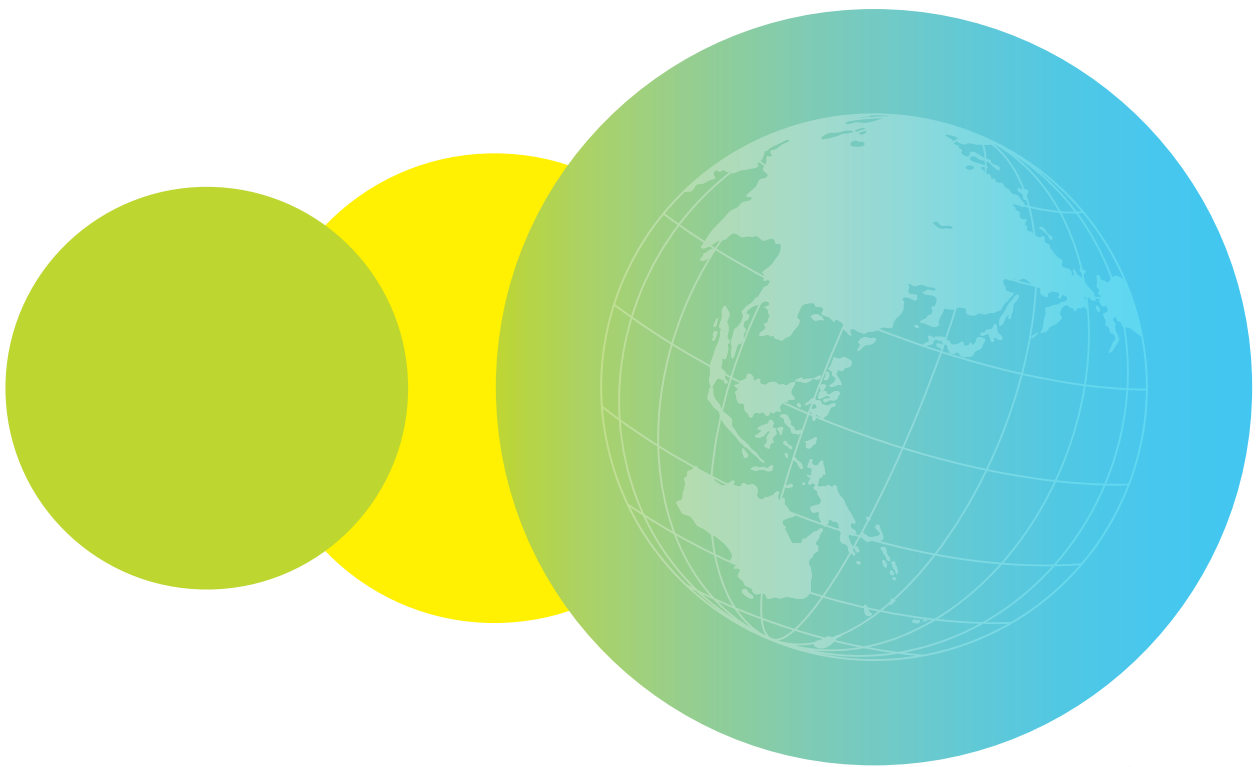


# Green Hydrogen Technologies for Systems Transformation:

Building a compilation of national strategies,  
plans and projects

2023





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## Foreword



I am pleased to introduce Green Hydrogen Technologies for Systems Transformation: Building a compilation of national strategies, plans and projects, from developing and developed countries, leveraging research, production, storage and export of green hydrogen as part of their national net-zero ambitions and commitments.

Curated by the UN Climate Technology Centre & Network (CTCN), this compilation intends to distil what has been learned to date and equip countries with the knowledge and capacity to understand and assess available system transformation options, including opportunities and challenges, to reach net zero emission targets.

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) identifies hydrogen as one of the most promising alternative fuels of multiple energy supply options available to reduce emissions over the next decade. Hydrogen produced from electrolysis ('Green Hydrogen') has the great potential to transform systems of heavy industry, residential and commercial buildings, and transport. However, as the report shows, the effectiveness of

hydrogen will depend on how quickly and how far technology improves.

This report offers a snapshot of the current implementation and future developments of green hydrogen projects, providing examples of green hydrogen technology research, development, and deployment efforts and the impact on increasing renewable energy infrastructure and transformation at the national level. It can be a resource for developing countries, showcasing how green hydrogen technologies can assist national systems' transformation of energy industry, mobility, agriculture, buildings, and business.

This compilation of national examples not only sheds light on the technological advancements and successful national strategies in the realm of green hydrogen, but also underscores the significance of regional collaboration. The journey toward systems transformation requires a collective effort, as nations grapple with shared challenges and shared opportunities. By showcasing a range of national and regional perspectives, we are building a bridge between global imperatives and localized solutions, while facilitating the exchange of best practices and lessons learned.

We must acknowledge that any innovation in climate technology, as a solution to increasing the endogenous capacities of countries on environmentally sound technologies, will and must require continuous investment and effort both at the national and global levels.

As part of CTCN's Programme of Work 2023-2027, this document is a testament to our commitment to fostering innovation, knowledge sharing, and capacity building. By showcasing the experiences of countries and regions that are at the forefront of green hydrogen deployment, we aim to inspire a global dialogue that accelerates the adoption of cutting-edge climate technologies and the replication of successful approaches.

We hope that the cases collected in this document will inform and influence action on system-changing solutions that exploit synergies of research, development and dissemination (RD&D) collaboration globally.

Rajiv Garg, Director a.i. of the CTCN

A handwritten signature in black ink, appearing to read 'Rajiv Garg', with a horizontal line underneath it.

We are pleased to publish Green Hydrogen Technologies for Systems Transformation: Building a compilation of national strategies, plans and projects.

Carbon neutral and green growth are pursuing all over the world, hydrogen is regarded as an environmentally-friendly energy source. Hydrogen technology has significant advantages as a next-generation energy source with a value chain in production, storage, transportation, and utilization.

In particular, among hydrogen energy, green hydrogen produces hydrogen and oxygen by using electrical energy to water obtained from renewable energy such as solar or wind power and it's called 'ultimate eco-friendly hydrogen'. This is because there is no emission of carbon dioxide during the production process.

In 2022, the Republic of Korea (ROK) established a hydrogen technology future strategy with the goal of leading the global hydrogen market by securing excellent technology in the hydrogen field, and the ROK announced hydrogen as one of the 12 national strategic technologies.

Jeollanamdo is a local government located in the South-Western part of ROK. As a region with the highest renewable energy potential in ROK, a full-cycle hydrogen hub capable of producing, importing, exporting, storing and utilizing hydrogen will be established in the Yeosu and Gwangyang Bay areas by 2030. We also plan to create a green hydrogen energy island in connection with the Shinan 8.2GW large-scale offshore wind power complex. Jeollanamdo is actively working to develop Jeollanamdo into a global hydrogen industry mecca.

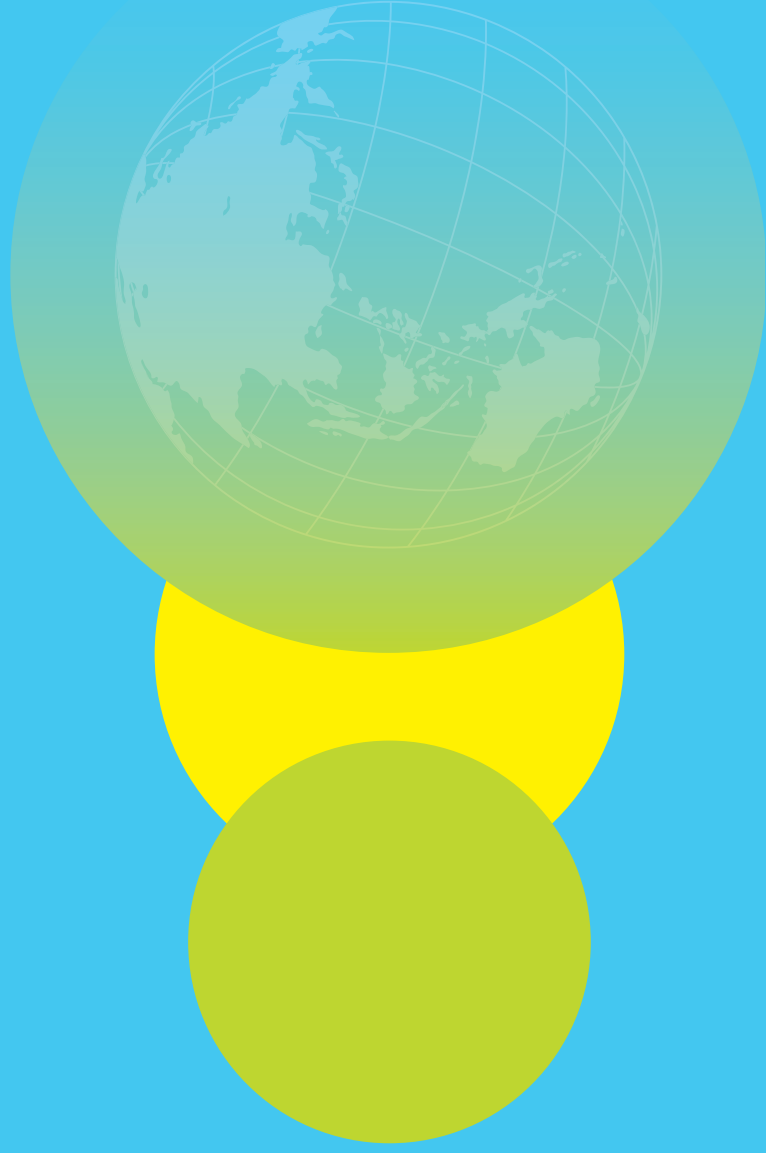
Green Energy Institute, we, as a leading Network member of the CTCN for green hydrogen, will do our best to respond to the global climate crisis and support green hydrogen technology establishment in keeping pace with the rapidly changing hydrogen market. We hope this report provides an avenue for you to build strong partnerships with ROK and GEI to expand green hydrogen's impact globally.



**Dongsik Joo, President of the Green Energy Institute**

A handwritten signature in Korean calligraphy, consisting of three characters: '주동식' (Joo Dong-sik).

# Green Hydrogen Technologies for Systems Transformation



## About the CTCN

CTCN is the operational arm of the UNFCCC Technology Mechanism, hosted by the UN Environment Programme (UNEP). Since 2013, CTCN has been promoting the accelerated transfer of environmentally sound technologies for low carbon and climate resilient development at the request of developing countries. CTCN delivers technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries by harnessing the expertise of a global network of technology companies and institutions.

More information on CTCN's work in global can be found at: [www.ctc-n.org](http://www.ctc-n.org)

# Introduction

**Figure 1** World's status of Green Hydrogen Technology in LT-LEDS



“We are approaching a decisive moment for international efforts to tackle the climate crisis – a great challenge of our times. The number of countries that have pledged to reach net-zero emissions by mid-century or soon after continues to grow, but so do global greenhouse gas emissions. This gap between rhetoric and action needs to close if we are to have a fighting chance of reaching net zero by 2050 and limiting the rise in global temperatures to 1.5°C.”

## Fatih Birol

Executive Director, International Energy Agency

Net Zero by 2020: A Roadmap for the Global Economy, 2021

By 2050, the global temperature rise must be limited to 1.5°C. To achieve this, equal opportunities must be given to all countries to set out cost-effective and economically productive pathways that result in a clean, dynamic and resilient energy economy dominated by renewables like solar and wind instead of fossil fuels.

Most of the global reductions in CO<sub>2</sub> emissions between now and 2030 in the net zero pathway come from technologies which are readily available. However, going forward to 2050, almost half the reductions will come from technologies that are currently only at the demonstration or prototype phase. This demands that governments quickly increase and reprioritize their spending on research and development (R&D), as well as on demonstrating and deploying clean energy technologies—putting them at the core of energy and climate policy. Climate change and the energy transition have made R&D in clean energy a priority as countries aim to reach net-zero or to be 100 per cent carbon-free

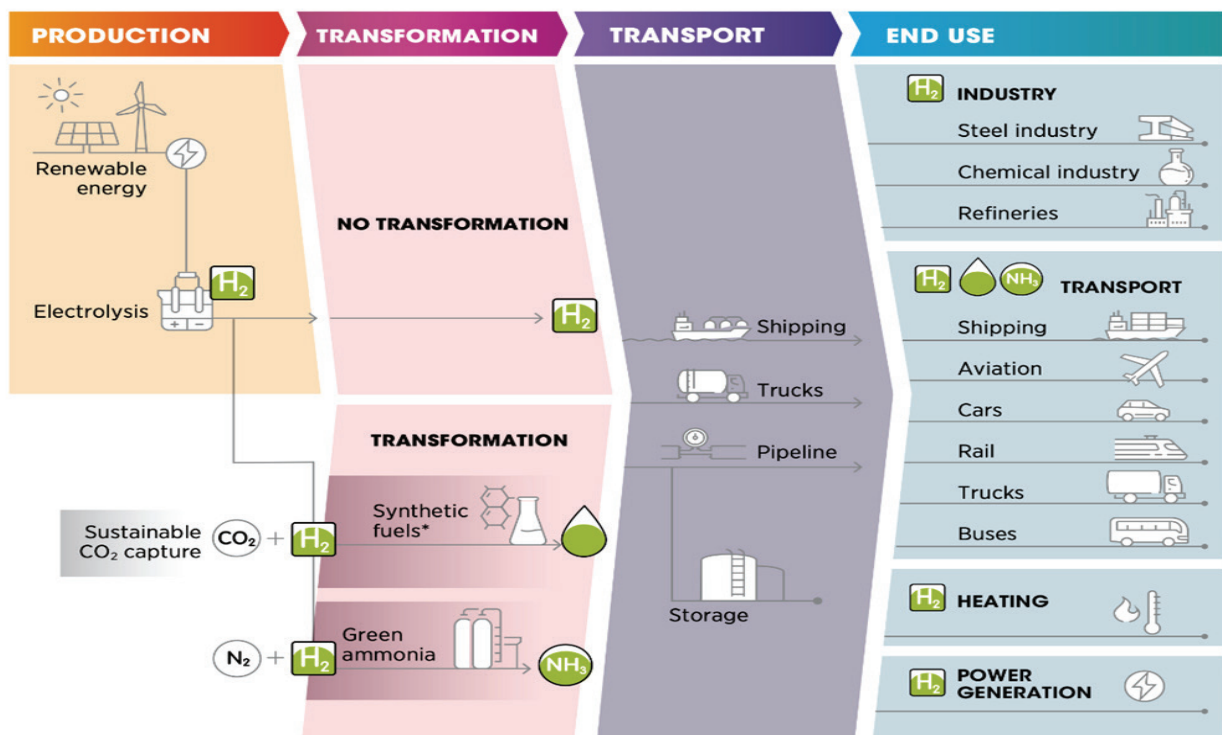


(CF100) by 2050. Green hydrogen has been categorically singled out as a possible source of energy in the not-too-distant future.

But what do we mean when we talk of hydrogen energy? Well, green hydrogen refers to hydrogen, as an energy carrier, produced using renewable energy sources. The best-established technology for producing green hydrogen is water electrolysis, a process that separates water into hydrogen and oxygen, using electricity generated from renewable sources (IRENA, 2020).

Green hydrogen is environmentally friendly, with minimal carbon emissions due to its use of renewable energy sources. It enhances energy supply diversity and supports new industries for economic sustainability. Key commercialization challenges encompass high system costs (capital, operational, maintenance, running), supply chain development, integration with other energy vectors, need for legal and administrative adherence, certification mechanisms, current low-user acceptance, and after-sales service development for hydrogen technology (Bhagavathy & Thakur, 2021).

**Figure 2** Green hydrogen production, conversion and end uses across the energy system (IRENA, 2020)



As a service to help establish and build the endogenous capacity of climate technology in developing countries, CTCN along with the Green Energy Institute (GEI) put together this compilation of case studies on green hydrogen applications from the Asia-Pacific, Latin America and Caribbean, Africa, and Middle East regions. These case studies showcase green hydrogen technologies can assist transformation of developing countries' energy industry, mobility, and buildings.

- **Grey hydrogen** is produced by mixing fossil gas with steam, resulting in large quantities of  $CO_2$ .
- **Blue hydrogen** is created by mixing fossil gas with steam and capturing and storing the resulting carbon emissions.
- **Green hydrogen** is produced by using electricity from renewables such as solar and wind power.

# Green Hydrogen Technology Application

## Asia and the Pacific region

The Asia- and the Pacific region emits about half of the world's total greenhouse gases, but the region lags behind when it comes to the transition to low-carbon. The retrospective analysis of 62 National Determined Contributions (NDCs) submitted by Asian and Pacific countries found that only 10 countries<sup>1)</sup> had a brief plan on hydrogen technologies in energy systems and sustainable mobility sectoral transformation. In contrast, more developed countries (i.e. Australia, and Germany), following the establishment of national economic and regulatory policy instruments for green hydrogen technology, have not only implemented their first commercial-scale examples but have also developed multiple socio-behavioural change projects. So, in developing countries, it is the design and implementation of public policy instruments that support innovation of green hydrogen for system transformations that will be most vital.

The following sections summarize the national

plans and key strategies of three countries which are pioneering green hydrogen technology development and dissemination in the Asia-Pacific region. Understanding the specific measures and actions on green hydrogen technology deployed by each country shows how nations can navigate innovative technologies to foster the transformation of national energy systems.



<sup>1)</sup> Australia, Bhutan, China, Jordan, Qatar, Republic of Korea, Saudi Arabia, Thailand, United Arab Emirates, Viet Nam

# Australia

## National plans

Australia is pursuing the world's largest hydrogen production and export strategy based on its abundant hydrogen resources. With the goal of mass production of eco-friendly hydrogen using carbon capture technology, Australia has set itself the goal of lowering hydrogen production costs to AUD \$1.39 per kilogram by 2030 and has already invested about AUD \$350 million in the development of Carbon Capture, Utilization and Storage technology (Australia's National Hydrogen Strategy–DCCEEW, 2023). Australia is creating a hydrogen production and supply strategy based on the hydrogen energy strategy prepared by central and local governments and which takes into consideration any regional conditions.

## Key strategies

The most important factor in Australia's hydrogen production strategy is the supply of green hydrogen produced by electrochemical water decomposition using electricity generated from renewable energy. Though the production of green hydrogen using renewable energy does not emit CO<sub>2</sub>, challenges for scaling up remain, mainly due to high production costs and difficulties in the expansion of infrastructure for stable renewable energy supply. There are also issues in some regions with access to renewable energy facilities, and advanced water electrolysis technology. In addition, Australia can produce blue hydrogen by combining it with Carbon Capture and Storage that can store CO<sub>2</sub> by extracting gas from abundant fossil fuels such as natural gas, coal, and oil. Australia is also focusing policy support on technology development related to steam methane reforming, coal gasification, and CCS to produce hydrogen. Australia is actively seeking for bilateral cooperation between countries to establish supply chains to achieve 75 per cent of its total hydrogen production by 2050 and to become one of the three largest exporters of renewable electricity resources to Asia.

## Projects

- The largest electrolyser operating in Australia is the 1.25 MW hydrogen plant located in Adelaide's innovation district of Tonsley Park in South Australia. This will soon be joined by a new facility, the Yuri project (currently under construction in the Pilbara region of Western Australia), which will include a 10 MW electrolyser to produce renewable hydrogen, powered by solar energy. Once completed, Yuri will be one of the world's largest hydrogen plants.

Figure 3 The Yuri Renewable Hydrogen Facility (2023)



- With around 30 GW worth of projects in the pipeline, Australia has huge potential when it comes to green hydrogen production capacity. To ensure oversight and meet the country's potential, the Australian Government is also continuously monitoring legislation around hydrogen. Currently, all green hydrogen produced in Australia is transported to a hub before being used or exported overseas (Growing Australia's hydrogen industry-DCCEEW, 2023).
- The Hydrogen Energy Supply Chain (HESC) project, which transports hydrogen produced using lignite to Japan, is currently under development. In 2020, an MOU was signed with local steel producers, the Australian Federal Science and Industry Research Organization (CSIRO) and Hyundai Motor Company Korea, to promote technology development to transport hydrogen that has been produced using liquid ammonia (Gillespie, 2022).
- "Australia's Hydrogen Export Opportunity report" released by the Australian Renewable Energy Agency (Australian Renewable Energy Agency, 2018), reports that Korea, China, Japan, and Singapore have been selected as Australia's major hydrogen importers, having taken a strategic approach from a mid-to long-term perspective on hydrogen production and storage and transportation.

# Japan

## National plans

As part of Japan's strategy to use overseas resources for low-cost hydrogen procurement and supply, and to strengthen its green hydrogen production capacity, a "Hydrogen Fuel Cell Strategy Roadmap" was released in 2014. This sets out step-by-step tasks and milestones for realizing the hydrogen economy by 2040.

The second stage of the strategy will focus on hydrogen power generation and Japan creating a large-scale hydrogen supply system infrastructure (KEEI, 2018). Japan is also committed to establishing a stable global supply network through strategic cooperation with countries such as Australia, which can supply hydrogen in large quantities.

## Key strategies

After the announcement of the roadmap in 2014, Japan renewed its "Hydrogen Fuel Cell Strategy Roadmap" in 2019 to include major technology developments, updated hydrogen unit prices, and specific action plans, reflecting changes in the industrial and policy environment. The new roadmap also featured a detailed action plan on technology development for hydrogen production and included government support for water electrolysis technology to increase hydrogen supply from 2 million tons per year to 3 million tons per year by 2030 (Ministry of Economy, Trade and Industry, 2019).

## Projects

- Japan is focusing on reducing liquid hydrogen costs through investments in technology development at the government level. Reducing liquid hydrogen costs is expected to play the biggest role in establishing Japan's global hydrogen value chain. The Hydrogen Energy Supply Chain Research Association (HySTRA), which consists of Japan's J Power, Kawasaki Heavy Industries, Iwatani, and Shell Japan, has established a liquid hydrogen supply chain that can transport, and store hydrogen extracted and liquefied from Victoria, Australia. The Advanced Hydrogen Energy Chain Technology Development Association (AHEAD), which consists of four large Japanese companies (i.e. Chiyoda Chemical Engineering & Construction, Mitsubishi Group, Mitsui Group, and Nippon Yusen), is also seeking to establish a supply chain that transports hydrogen extracted from gas from the Brunei liquefied natural gas (LNG) plant in liquid hydrogen.
- Japan also signed an MOU with Saudi Aramco in July 2019 to investigate the feasibility of the production of decarbonized ammonia and began joint research on hydrogen production and import and export with Rosatom Overseas in Russia (Rosatom, 2019). As such, Japanese private companies are playing a key role in Japan's global hydrogen supply along with support at the government level.

**Figure 4** Hydrogen Energy Supply Chain project (2023)



# Republic of Korea

## National plans

In March 2023, the government of the Republic of Korea (ROK) announced its revised (NDC goal, including an increase in the proportion of hydrogen used for power from 7.6 per cent to 8.4 per cent (Ministry of Environment, 2021). This clearly shows RO's ambition to be a clean hydrogen leading country by establishing an integrated hydrogen economy ecosystem.

## Key strategies

The ROK enacted the world's first hydrogen law in 2020 to support the hydrogen industry. Building on this, projects are underway to fast-track the hydrogen industry through the creation of six hydrogen cities, the designation of hydrogen-specialized complexes, and the construction of a hub terminal for storage and processing of overseas green hydrogen.

## Projects

- The Republic of Korea is in the process of shifting from grey hydrogen and blue hydrogen to support green hydrogen produced by using electricity from renewables.
- In 2022, a project was launched to demonstrate all four existing water electrolysis technologies: alkaline electrolysis cell, proton exchange membrane electrolysis, solid oxide electrolysis cell and anion exchange membrane electrolysis (12.5 MW-level). The hydrogen produced, around 1,176 tons a year, is used to fuel city garbage carriers, buses, and intercity buses via on-site hydrogen refuelling stations linked to the production complex.
- The Energy Island project, makes use of offshore wind power to produce green hydrogen on nearby islands. This technology is also being promoted for the second time after Denmark (Park, 2022). Green hydrogen produced on the Energy Island will be supplied to nearby industrial complexes to help convert hydrogen energy in the industrial sector.
- As of 2021, 77 per cent of the world's energy came from fossil fuels such as coal, oil and gas. These fuels are converted to electricity in thermal plants and this energy is supplied to homes and industries. There are plans to ensure that powerplants can switch to more renewable energy sources by mixing ammonia and hydrogen to reduce fossil fuel. The Government of ROK is working on a plan to commercialize power generation that uses 20 per cent ammonia and 30 per cent hydrogen by 2035, in line with overseas green hydrogen and green ammonia import plans (Ministry of Trade, industry and Energy, 2021). In addition, there are plans to speed up the commercialization of hydrogen and ammonia power generation for coal and LNG power plants.
- Since 2017, the Ministry of Trade, Industry and Energy has been gradually expanding its green hydrogen production demonstration project from an output of 260 KW to 30 MW (Ministry of Trade, Industry and Energy, 2022).

**Figure 5** 12.5MW Jeju green hydrogen production facility demonstration project  
(Ministry of Trade, Industry and Energy, 2022)





# Green Hydrogen Technology Application

## Latin America and Caribbean Region

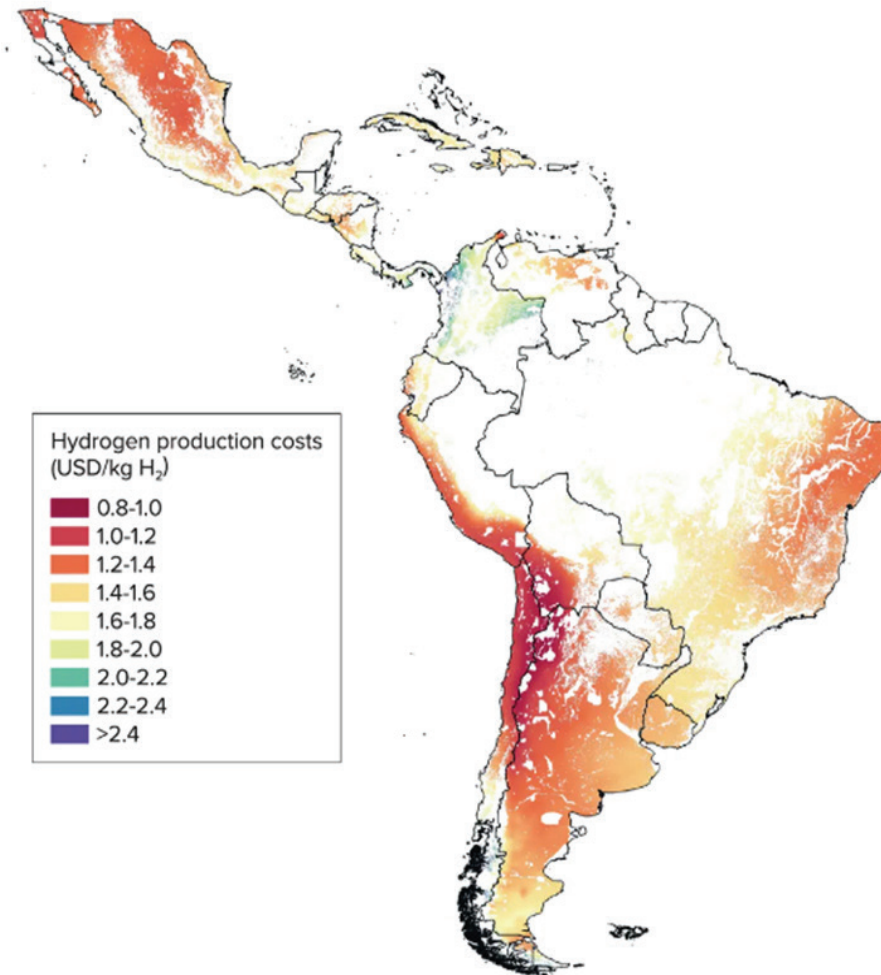
The momentum for low-carbon hydrogen is growing in Latin America, with many countries currently developing long-term hydrogen strategies and a project pipeline that includes more than 25 initiatives, including several gigawatt-scale projects to export power beyond the region. Today, no international market exists for “pure” green hydrogen. However, Latin America, one of the regions with the most renewable energy potential to help produce green hydrogen and achieve a future with net-zero emissions, may play a prominent role in developing such a green market. The International Energy Agency (IEA) recently produced a report on the potential of low-carbon hydrogen in Latin America, stating that Argentina, Brazil, Chile, Colombia, Costa Rica, El Salvador, Panama, Paraguay, Trinidad and Tobago, and Uruguay are preparing national hydrogen strategies (2021).

The report also listed some low-carbon projects under development in the region. Low-carbon hydrogen deployment depends on many technologies that are still under development, and considerable cost reductions will be needed to enable such technology to reduce global emissions in the future.

Indeed, the next decade will be crucial for implementing low-carbon hydrogen in Latin America, but a great deal needs to be done today to develop and demonstrate emerging technologies and prepare the ground for their future scaling up/expansion.



Figure 6 Project cost of production with renewable energy by 2050 (IEA, 2021)



## Brazil

The share of renewable energy in Brazil has been increasing in recent years from 46.1 per cent in 2019 to 48.4 per cent in 2020. At the same time the production costs for renewable energy have been falling. These lower production costs, in combination with advantageous geological and climatic conditions, make Brazil a promising country for the production of green hydrogen.

### National plans

The northeastern state of Ceará is characterized by very strong winds and sunny days for most of the year. In 2022, the number of home solar power generators more than doubled compared to 2019, with over 10,000 micro and mini solar generators installed. This represents 130.8 percent more than the 4,300 registered in 2019 (Brazilian Electricity Regulatory Agency, 2023). Of the country's 653 wind farms, 82 percent are found in the Northeast, and Ceará is the third-largest producer of wind power, behind Rio Grande do Norte and Bahia. In the more windy months, these farms produce enough electricity to power the whole region, which is home to over 50 million people.

### Key strategies

The state of Ceará has announced a significant investment in the seaport of Pecém, primarily intended to enhance the infrastructure for green hydrogen production and is designing a hub with the capacity to produce at least 500,000 tons of green hydrogen annually. Named the Ceará Green Hydrogen Hub, the space installed in the Pecém Industrial and Port Complex (CIPP) was launched in 2023 in partnership with the Federal University of Ceará and the Federation of Industries of Ceará (Sousa, 2022). Ceará is now seeking new investments to expand business opportunities and create jobs in the state. So far, 18 MOUs have been signed with national and foreign companies to implement projects in the hub.

### Projects

The goal of the Green Hydrogen Hub Partnership is to establish Brazil as a global producer, exporter, and distributor. The nation produces some of the most cost-efficient renewable energy in the world, and Bloomberg forecasts that it will be among the few countries able to provide green hydrogen at a highly competitive price, targeting US\$ 0.55 per kilo by 2050. But Brazil needs to speed up its adoption of laws and standards if it is to become a key exporter of green hydrogen and its derivatives in the global race toward energy transition (Biogradlija&Biogradlija, 2023).

- Ceará's state government is working on a plan to build a green hydrogen plant on 500 hectares of commercial land at the Port of Pecém, northwest of state capital Fortaleza (The Brazilian Report, 2021).
- The state intends to become a global supplier of this type of fuel, contributing to reduced emissions and expanding business opportunities and job creation in Ceará.

**Figure 7** Green Hydrogen Ceara Strategy-from Policy to Practice (CEARA, 2023)



## Chile

Chile has advantageous natural conditions for renewable energy production. The country's longitudinal length and terrain which extends from latitude 17 degrees south to 56 degrees means there is a wide range of climates and environments. The northern Atacama Desert experiences the most intense levels of sunlight on Earth, and at the southernmost point, the world's most powerful and constant winds blow. Thanks to these unique characteristics, Chile's future potential for renewable energy generation is approximately 70 times larger than its current capacity (centralized 587GW, solar 879GW, wind 295GW and hybrid 15GW). These advantages will allow Chile to secure favourable opportunities for the development of new industries related to renewable energy worldwide and contribute positively to sustainable development.

In November 2020, Chile presented its National Green Hydrogen Strategy. There is a target of reaching 5GW of renewable energy capacity dedicated to electrolysis by 2025. With this, Chile aims at being a producer of the world's cheapest green hydrogen by 2030, and to be one of the top three exporters of the fuel by 2040.

### National plans

- The Chilean Ministry of Economy has announced the aim for green hydrogen to “generate an industry that promotes a new development model focused on the generation of local value” (Moore, 2023). The Ministry also recognized that the strengthening of green hydrogen production will help reduce emissions and promote more sustainable growth.
- Chile has a strong regulatory framework and incentives for the development of these projects, including storage facilities and flexible technologies that contribute to the stability of the energy grid.
- Public-private partnerships have been key in accelerating Chile's energy transition, especially when it comes to the country's green hydrogen market. Green hydrogen sits at the heart of Chile's energy transition. Chile's National Green Hydrogen Strategy calls for incorporating green hydrogen into the country's mining and commodity sectors, as well as other carbon-reliant local supply chains.

### Key strategies

Chilean green hydrogen could be among the most affordable in the world due to its favourable renewable energy environment. The country benefits from consistently strong winds in mountainous region of Patagonia and some of the world's highest levels of solar radiation in the Atacama Desert. This predictable supply of wind and solar energy has led the Chilean government to estimate that 13 per cent of the world's green hydrogen will be produced within its borders (Conley, 2023).

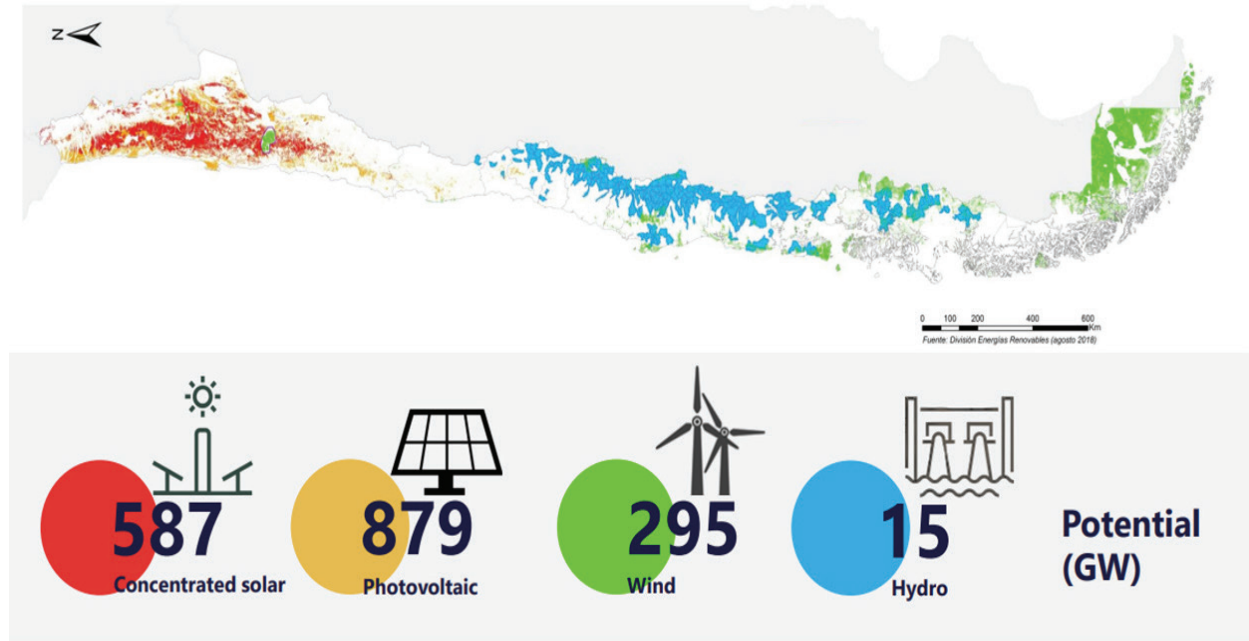
### Projects

Chile's government has already pledged US\$50 million in funding to six projects aimed at advancing the national green hydrogen industry. In April 2023, the Chilean Development Office signed additional funding agreements with GNL Quintero, CAP and Air Liquide for their green hydrogen initiatives (Conley, 2023).

Officials estimate that by 2050, 27 per cent of Chilean green hydrogen production will be consumed

locally and the balance exported. Currently, some 50 projects have been announced, with the bulk of the multi-billion-dollar outlay planned for the regions of Magallanes and Antofagasta, home to world-class wind and solar resources, respectively.

Figure 8 Chile investment in the Energy Sector (Ministerio de Energia, 2020)



# Green Hydrogen Technology Application

## Africa Region

African countries are at the starting line of the race to develop green hydrogen. Over 55 per cent of African countries (30 of 53) have presented green hydrogen as a climate technology solution in their NDCs. To unlock the world's first zero-carbon industrial opportunities, submitted NDCs are heavily focused on establishing green hydrogen production infrastructure, enabling renewable energy sources to be converted into transportable and value-added products. In conjunction with solar and wind energy resources, recently approved large-scale green hydrogen projects call for partnership-generating networking opportunities with the private and public sectors to strengthen the green hydrogen business ecosystem. Taking a system stakeholder engagement standpoint, opportunities to enhance the mobilization of internal and external resources at each national level and the ability to identify potential partners are essential to strengthen endogenous capacity for green hydrogen technology innovation in the Africa region.

Africa is blessed with abundant renewable energy potential from solar and wind sources.

In the region, solar energy has a capacity factor of 28 per cent to 36 per cent, while wind energy boasts a capacity factor ranging from 26 per cent to 51 per cent (Green Hydrogen Organisation, 2022). Comparatively, the global average for solar capacity factors ranges from 10 per cent to 21 per cent, while wind capacity factors vary from 23 per cent to 44 per cent. This means that Africa is in a favourable position to utilize clean and sustainable energy sources.

Nonetheless, even though Africa is well-placed to take advantage of its abundant energy sources,



there remain underlying concerns. There are several instances in the North African region that illustrate how energy colonialism practices are being reproduced even in transitions to renewable energy. This phenomenon is sometimes referred to as 'green colonialism' or 'green grabbing' (Hamouchene, 2023).

A just and sustainable energy transition is crucial to prevent this 'energy colonialism'. Thea Riofrancos, associate professor of political science at Providence College and an expert in resource extraction, renewable energy, climate change, and social movements said, "As we push for a rapid transition, we need think more critically about investment, regulation and ownership, so that energy is less extractive, companies are held accountable and communities' benefit through co-ownership or community ownership" (Lakha, 2022).

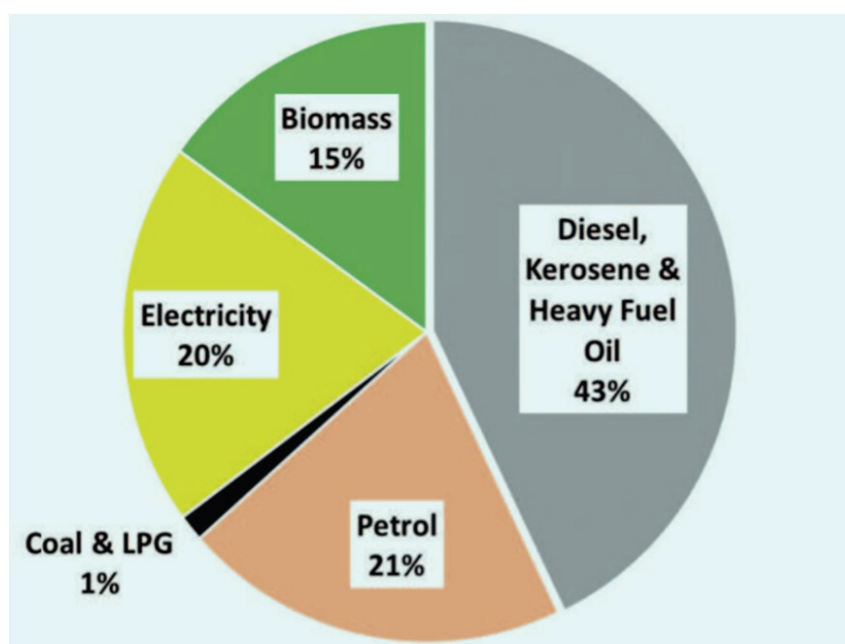
The initiatives focused on green hydrogen production in Africa are expected to play a significant role in addressing local electricity challenges and promoting economic growth, all while minimizing adverse environmental impacts. Global cooperation is essential to ensure that clean energy benefits everyone.



## Namibia

Namibia's energy mix is predominantly composed of liquid fossil fuels, and the country currently has limited domestic power generation. Namibia intends to make use of its renewable energy capabilities, particularly focusing on the utilization of green hydrogen production. Collaborating with Germany, Namibia has plans for an ambitious US\$9.4 billion project to expand renewable energy generation and electrolysis capacity by 2030, targeting an annual production of 300,000 tons of green hydrogen (Von Oertzen, 2021). Despite challenges in infrastructure, water resources, and regulations, Namibia is dedicated to harnessing renewable energy, the potential of the green hydrogen industry sector appears optimistic.

**Figure 9** Composition of Namibia's total energy use by energy type (Von Oertzen, 2020)



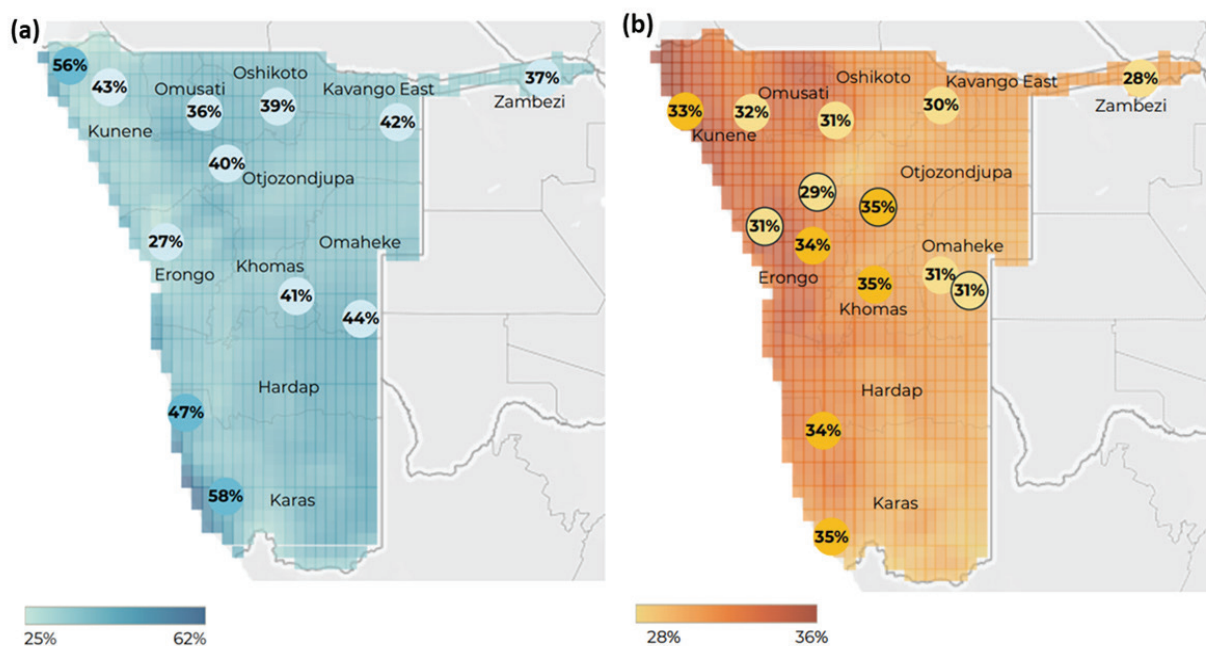
### National plans

As of 2020, Namibia ranks 141st in global emission contributions, and it has set a goal to reduce greenhouse gas emissions by 91 per cent by 2030 (Ministry of Mines and Energy Namibia, 2022). The country seeks to establish a large-scale green fuels sector, targeting 10-12 million tons of hydrogen equivalent production by 2050. The hydrogen sector could contribute US\$6 billion to GDP by 2030, with potential for 80,000 jobs by 2030 and up to 600,000 jobs by 2040. Namibia's action plan includes enhancing delivery infrastructure, enacting regulatory legislation, and offering investor support (Ministry of Mines and Energy Namibia, 2022). This strategy will be developed through collaboration with partners, involving financial mobilization, regional cooperation, and global outreach efforts. The aim is to ensure shared prosperity for Namibians, involving socioeconomic development, inclusive citizen engagement, and environmental safeguards.

## Key strategies

Namibia possesses world-class renewable energy resources. Located in the southwestern region of Africa, Namibia receives intense sunlight for approximately 300 days a year. The summer season runs from October to April and temperatures can reach as high as 40 degrees Celsius. The southern parts of the country experience solar radiation levels surpassing 3,000 kWh/m<sup>2</sup>/year. Additionally, Namibia boasts long coastlines stretching 1,572 km, which provide highly favourable wind conditions (Hanns Seidel Foundation Namibia, 2015). Namibia has the potential to produce hydrogen and its derivatives cost-effectively. The country's goal is to export hydrogen products like ammonia, methanol, synthetic kerosene, and hot-briquetted iron, which entail relatively lower transportation expenses (Green Hydrogen Organisation, 2022). Namibia is in a good position to supply products to Europe, China, Japan, ROK, and other global regions.

**Figure 10** The regional (a) Photovoltaic Solar capacity factor and (b) onshore wind capacity factor in Namibia (Ministry of Mines and Energy Namibia, 2022)



## Projects

In November 2021, the Namibian Government announced its first mega project for developing green hydrogen production facilities (Atchison, 2021). They selected Hyphen Hydrogen Energy from Germany as their priority negotiation partner. The chosen site for the project, TsauKhaeb National Park, is rich in onshore wind and solar resources and is conveniently located near the sea, facilitating both land and maritime transportation and exports. This ambitious project, estimated to cost US\$9.4 billion, aims to expand renewable energy generation capacity to 5 GW and electrolysis capacity to 3 GW by 2030. The goal is to produce 300,000 tons of green hydrogen annually. The initial stage aims to produce 2 GW of renewable energy capacity by 2026 for green hydrogen production, with an approximate projected cost of US\$4.4 billion.

## South Africa

About 85 per cent of the electricity in South Africa is produced using coal-fired power stations (International Trade Administration, 2023). As of 2021, the South Africa was the largest emitter of greenhouse gases on the African continent. In world rankings, South Africa is the world's 14th largest emitter of greenhouse gas (European Commission, 2022). To address this issue, the South African government is actively promoting the robust development of renewable energy as a means to decrease carbon emissions and mitigate electricity shortages. The South African Government's Integrated Resource Plan (IRP) aims to add a total of 29,500 MW to the electricity capacity by 2030, primarily focusing on the addition of renewable energy sources, notably 14,400 MW from wind power and 6,000 MW from solar energy (International Trade Administration, 2023).

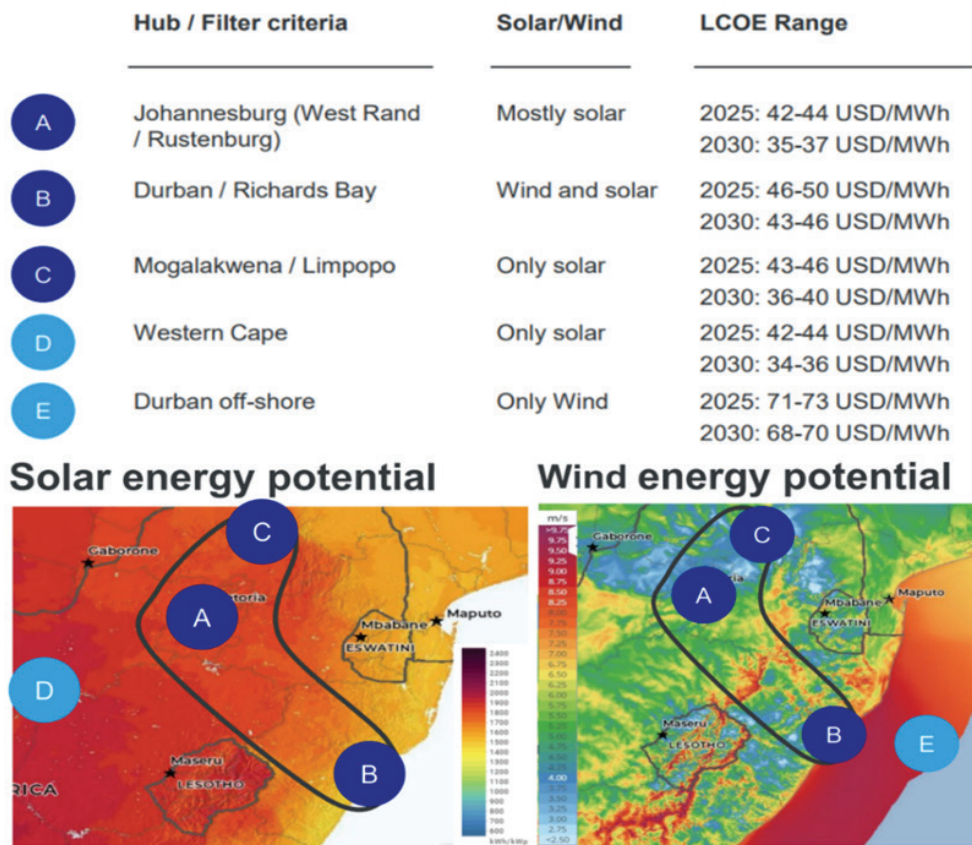
### National plans

- In 2007, South Africa initiated a long term (2008–2022) hydrogen research programme by introducing the "Hydrogen South Africa" (HySA) programme, led by the Department of Science and Technology (GIZ, 2016). Its objectives included developing the value chain of hydrogen and fuel-cell technology, creating cost-competitive hydrogen production solutions through renewable energy, and cultivating human resources.
- In 2021, the Department of Science and Innovation (DSI) released the South African Hydrogen Society Roadmap (HSRM). This strategic plan aims to establish a market for green hydrogen and green ammonia exports, to create hubs for hydrogen product manufacturing, to build a domestic hydrogen supply chain, and produce 500,000 tons of green hydrogen by 2030, and generate 15 GW of hydrogen-based power capacity by 2040 (Department of Science and Innovation, 2021).
- Additional goals include building: a) small-scale electrolysis facilities of up to 1MW by 2025, b) 10 GW electrolysis facilities in the Southern Province by 2030, and c) 1.7 GW electrolysis facilities in the Hydrogen Valley by 2030.

### Key strategies

In 2021, a collaborative feasibility study with South Africa's Department of Science and Innovation (DSI), the South African National Development Institute (SANEDI), ENGIE, and Bambili Energy identified three hubs: Johannesburg, Durban (including Richards Bay), and Limpopo province centered on the Mogalakwena PGM mine. These hubs are anticipated to play a significant role in transforming South Africa into a centre for producing green hydrogen, utilizing its abundant renewable energy sources (Department of Science and Innovation, 2021).

**Figure 11** Renewable energy potential and regional levelized cost of electricity for green hydrogen hubs in the South Africa (Department of Science and Innovation, 2021)



### Projects

Hive Hydrogen’s Coega Green Ammonia project in South Africa is set to produce 950,000 tons of green ammonia annually. Additionally, Hive Hydrogen has secured commitments from battery and solar panel manufacturers to establish plants in Coega. Discussions on bringing ring electrolyser manufacturers to set up in Nelson Mandela Bay are also ongoing (Hive Energy, 2022).

In addition, an EU€15 million subsidy from Germany is helping fund the HySHIFT renewable hydrogen project. This project involves Linde, Sasol, Enertrag, and Hydregen and aims to create sustainable aviation fuel (E-Kerosene) using green hydrogen. The consortium’s goal is to produce 50,000 tons a day of PtL Kerosene for greener flights. Also in the pipeline is a plan to build a 200 MW electrolyser and produce 450 MW of renewable electricity annually (Green Building Africa, 2022).

## Morocco

Morocco established its national energy strategy in 2010 and formed the National Hydrogen Commission in 2019, leading to the establishment of the National Green Hydrogen Roadmap in 2021 (RES4Africa and PwC, 2022). According to IRENA (2022), Morocco aims to achieve green hydrogen production costs of approximately US\$0.7-US\$1.4 per kilogram by 2050. Morocco is expected to benefit from green hydrogen production, enabling opportunities such as green ammonia production, Resolving the intermittency issue of renewable energy supply and stabilizing the grid, and hydrogen export via gas pipelines connected to Europe.

### National plans

Morocco is actively advancing renewable energy to reduce import reliance and transition from fossil fuels. Their goal is to produce 52 per cent renewable energy by 2030, increasing solar capacity from 844MW to 3,351 MW. The Green Hydrogen Roadmap (2020–2050) outlines short, medium, and long-term goals (RES4Africa & PwC, 2022). The priorities for each period are as follows:

- In the short term, green hydrogen exports and the utilization of phosphates for national industries, along with the exploration of natural hydrogen deposits.
- In the medium term, the focus is on hydrogen project development and the use of green hydrogen as an energy storage solution.
- In the long term, the goal is to achieve higher levels of hydrogen exports and ammonia production.

The roadmap is built on technology development, industrial clusters, and market strategies. It has been divided into eight action plans targeting cost reduction, research, local content, industry, markets, storage, exports, and financing to develop national green hydrogen by 2050.

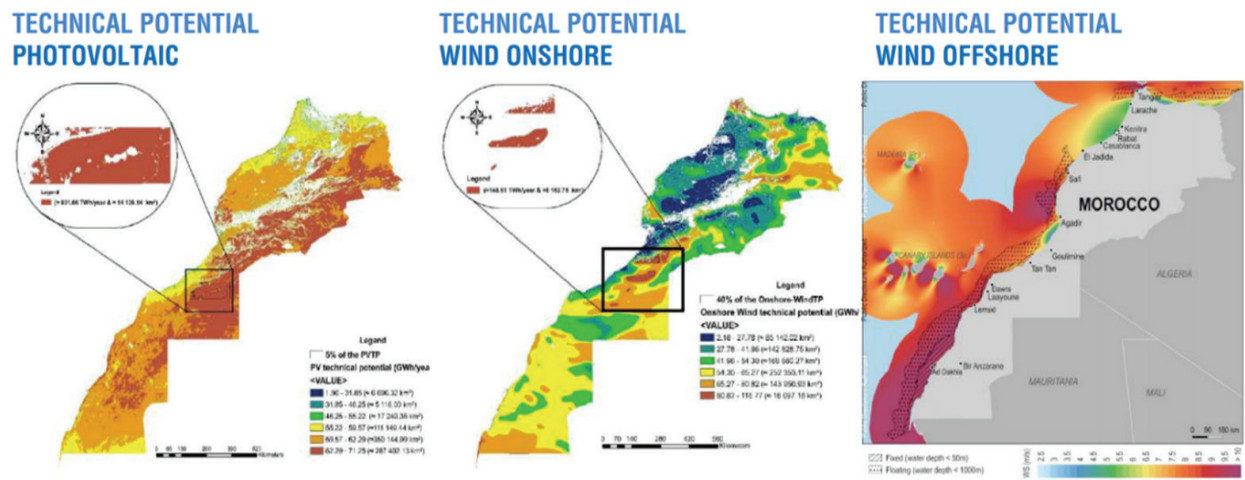
### Key strategies

Morocco boasts favourable conditions for solar and wind energy development and the nation has great potential for green hydrogen production. The country's energy strategy aims at deriving 52 per cent of its installed electricity production capacity from renewable sources by 2030, equivalent to 7,300 MW (Ministère de l'énergie des Mines et de l'Environnement, 2009). Abundant sunlight, strong wind resources, and offshore potential contribute to Morocco's substantial capacity. Utilizing just 5 per cent of this potential would result in 1,000 GW of solar power and 325 GW of wind power. Morocco ranked 6th in the 2020 Climate Change Performance Index and 7th in 2021. In 2020, solar power contributed 4 per cent (1,520 GWh), wind power 12 per cent (4,520 GWh), and hydroelectric power 3.4 per cent (1,290 GWh) to its electricity mix (RES4Africa and PwC, 2022).

Moreover, repurposing existing gas pipelines could lower hydrogen transportation costs. The pipelines used for natural gas transportation between North Africa and Europe could be used to export hydrogen produced in Africa to Europe. Intracontinental pipelines like the West African Gas Pipeline and the planned Nigeria-Morocco pipeline could also facilitate hydrogen transportation (RES4Africa and PwC, 2022).

Due to its substantial green hydrogen potential, Morocco has established various agreements with European nations. With its renewable energy capabilities, large-scale projects, and infrastructure development experience, Morocco is well-positioned in the hydrogen market. Collaborative efforts with Europe focus on supply chain development and joint research. Germany, Portugal, and Chile have shown strong interest in importing green hydrogen from Morocco for decarbonization (RES4Africa and PwC, 2022).

Figure 12 Photovoltaic and wind technical potential in Morocco (IRESEN, 2020)



	Photovoltaic (PV)	Wind Onshore	Wind Offshore
Technical Potential (TWh)	49 000	11 500	2 250
Technical Potential (GW)	20 000	6 000	500
5% of the Tech. Pot. (GW)	1 000	300	25

## Projects

The “Power-to-X” project represents Morocco’s first large-scale industrial green hydrogen initiative, aiming to produce green hydrogen through electrolysis, utilizing renewable energy sources. Proposed by Moroccan Agency for Sustainable Energy, the project is set to be completed by 2025 (Clifford Chance, 2021).

The largest green hydrogen project in Morocco at present is the Hevo Ammonia project, which involves an anticipated investment of over EU €50 million. This initiative is a collaboration between Fusion Fuel, an Irish-based green hydrogen technology company, and Consolidated Contractors Company, a Middle Eastern construction firm. Expected to be completed by 2026, the project will boast a 600 MW electrolysis capacity, producing an estimated 183,000 tons of green ammonia annually, leading to a reduction of around 280,000 tons of carbon emissions per year (Fusion Fuel, 2021). Fusion Fuel will provide the technology for producing 31,000 tons of green hydrogen annually for the project.

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# Green Hydrogen Technology Application

## Middle East Region

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Between 2009 and 2016, electricity consumption in the Middle East increased significantly due to economic growth and population growth caused by the implementation of energy-intensive industrialization programmes and the development boom. As energy consumption continued to increase, the issue of energy supply stability came to the fore (Farzaneh, 2020).

Moreover, since 2014, the continuous decline in international oil prices and declining profitability of oil production have resulted in a decrease in investment in the oil sector. Recently, as the world faced a decline in crude oil demand and falling oil prices due to COVID-19, interest in developing alternative energy resources is increasing along with the need to reduce our dependence on crude oil exports (Trading Economics, 2023).

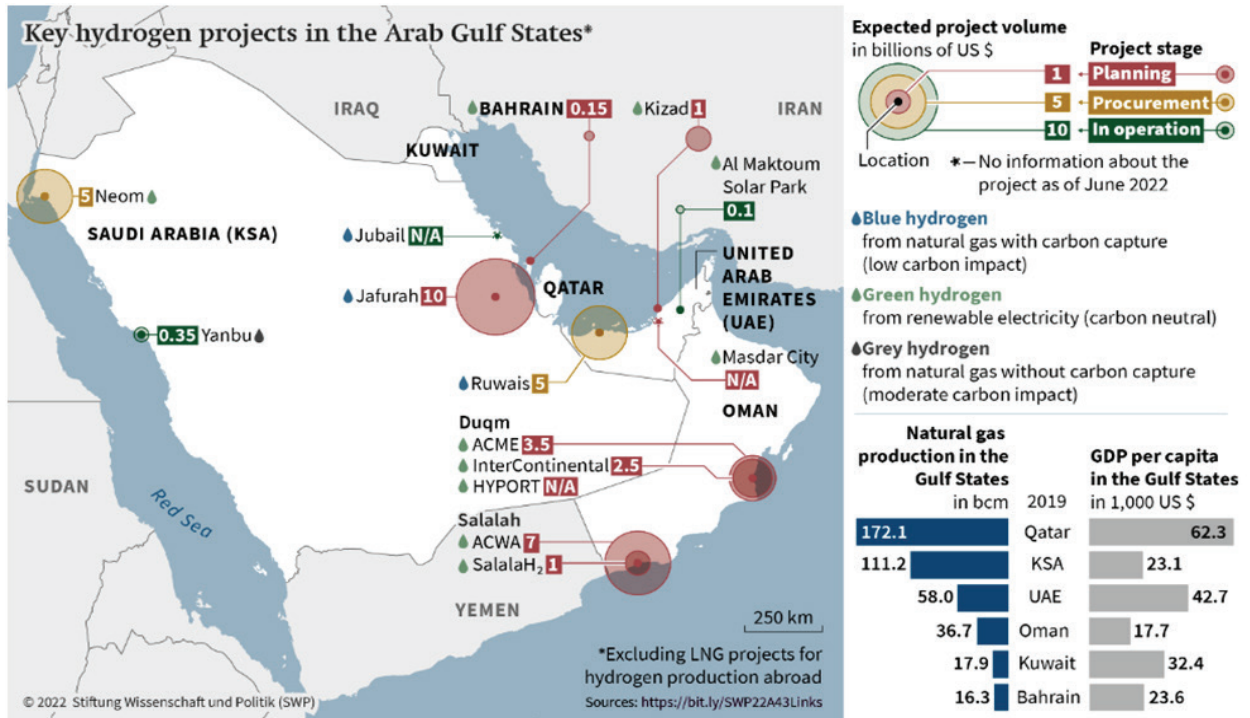
As the unit cost of renewable energy has steadily declined by technological development, Middle Eastern countries have implemented state-led solar and wind energy development projects to increase the share of renewable energy in power generation as an alternative energy source.

In the Middle East, as most countries are located in hot desert regions and have high potential for eco-friendly low-carbon hydrogen production, state-led hydrogen projects are being implemented.

Major hydrogen projects in the Middle East are being promoted in three countries: Saudi Arabia, the United Arab Emirates (UAE), and Oman. Representative examples include Saudi Arabia's NEOM Green Ammonia, Oman's Hyport Duqm Green Hydrogen Project, and UAE's Abu Dhabi Hydrogen Alliance (Clifford Chance, 2021).

These projects aim to reduce the Middle East's economic dependence on oil, diversify resource exports through renewable energy, and engage in the global hydrogen market.

Figure 13 SWP Comment 44: The Hydrogen Ambitions of the Gulf States (Ansari, 2022)





## United Arab Emirates (UAE)

The UAE is most actively promotes renewable energy development in Middle East, and has achieved significant development of the renewable energy market by the government's full support, increased investor interest, and falling solar power generation cost.

### National plans

The UAE has laid the foundation for expanding renewable energy in various ways including through the construction of Masdar City (2008–2030), by hosting the IRENA secretariat, making the UAE Energy Strategy 2050 announcement (2015), creating of the Ministry of Climate Change and Environment (2016) and announcing a national integrated energy model in 2021. As part of the UAE Energy Strategy 2050, the UAE government plans to invest US\$ 163 billion in phases to achieve 50 per cent clean energy share and reduce carbon emissions by 70 per cent by 2050 and created a US\$ 27.7 billion Dubai Green Fund (UAE Government, 2023).

### Key strategies

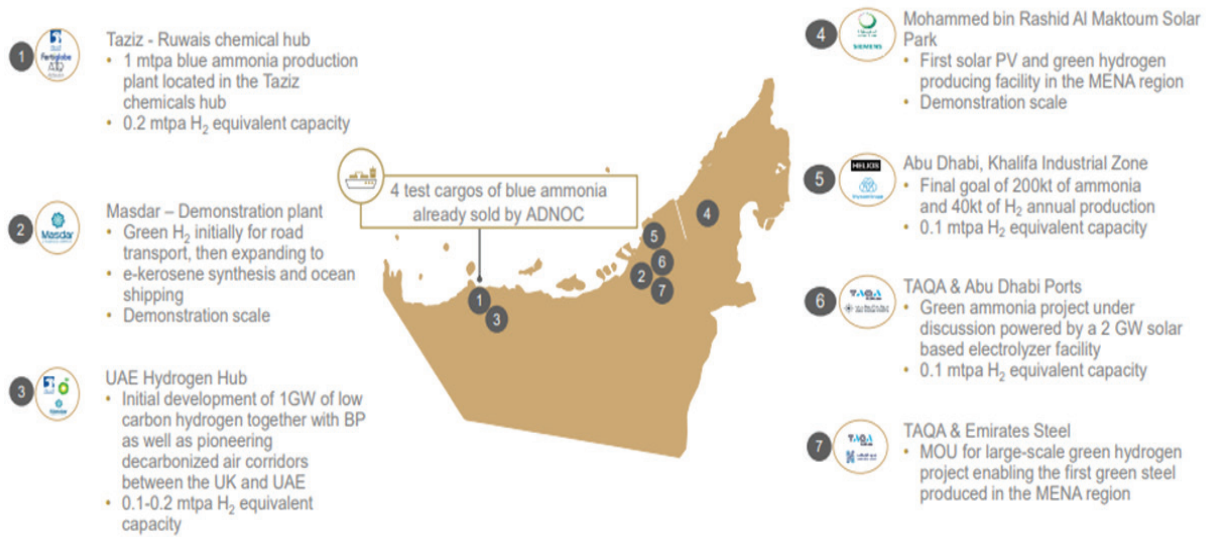
The Government of UAE is making massive investments in the development and research of green hydrogen energy solutions for energy sustainability and working with the private sector to launch a joint initiative. In 2021, Mubadala, ADNOC, and ADQ signed a hydrogen alliance with the aim of strengthening the production capacity of green and blue hydrogen in the UAE and are pursuing projects related to road map development to expand investment in the hydrogen economy and accelerate hydrogen energy use in major areas (Mubadala, 2021).

### Projects

- Currently, the UAE's first green hydrogen plant and the Middle East's most advanced solar power generation green hydrogen production facility is under construction at Mohammed bin Rashid Al Maktoum Solar Park.
- A production facility capable of producing 200,000 tons of green ammonia will be built in the Khalifa Industrial Zone Abu Dhabi by 2025.
- In accordance with the national hydrogen strategy to produce 1.4 million tons of hydrogen per year by 2031 by developing 7 hydrogen projects, including the above 2 projects, low-carbon hydrogen development is progressing smoothly (UAE Government, 2023).
- In addition, in relation to hydrogen and carbon capture, the Korea-UAE Joint Research Agreement, Japan-UAE MOU, Total-ADNOC Strategic Framework Agreement, and ENI-ADNOC MOU have been signed.

Figure 14 UAE Hydrogen Leadership Roadmap (UAE Government, 2023)

## The UAE is well on its way to champion the development of low carbon hydrogen projects



## Oman

Oman is striving for economic diversification, including energy transition, while still relying on oil and gas imports. As the third participant in the Gulf Cooperation Council (GCC) carbon neutrality movement, Oman has set goals for greenhouse gas reduction and is actively developing renewable energy sources.

### National plans

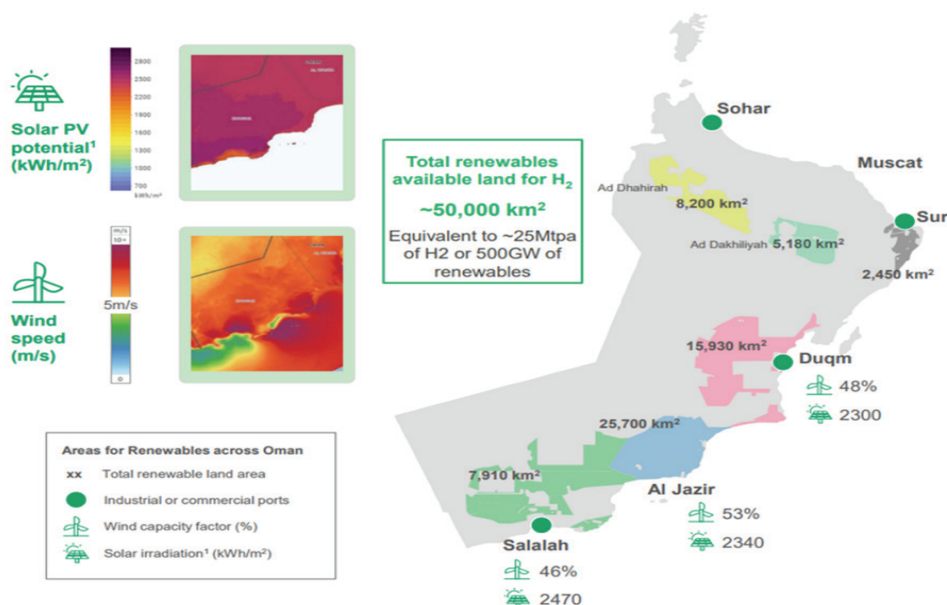
The Omani Government initiated renewable energy development goals through policies like Intended Nationally Determined Contribution (INDC) in 2015, with subsequent initiatives such as FDP, Oman Vision 2040, and NDC. As per the July 2021 NDC, Oman aims for a 4 per cent reduction (conditional 7 per cent) in emissions by 2030 (Sultanate of Oman, 2021). To achieve these goals, Oman aims to transition its economy from fossil fuels to renewable energy, reducing natural gas's share in energy production from 97 per cent to 70 per cent by 2030. They are currently developing multiple renewable energy projects, including solar and wind, to increase the renewable energy generation share to 20 per cent by 2030 and 39 per cent by 2040 (Sultanate of Oman, 2019).

### Key strategies

The Omani government aims to transform its economy into one based on the hydrogen industry by the year 2040. They plan to invest around US\$140 billion in low-carbon energy ventures and target an annual hydrogen production of 1 million tons by 2030, with a long-term plan to achieve 8.5 million tons per year by 2050 to fulfill their carbon neutrality goal (Global Energy Future, 2022).

Oman aims to establish green hydrogen initiatives in the Duqm, Dhofar, and Al-Jazir regions by 2030. The regions are part of Oman's Green Hydrogen Development Zones. The objective is to increase green hydrogen production and electrolysis-based power capacity to achieve electrolysis capacity of 90–100 GW and renewable energy capacity of 175–185 GW by 2050 (Oman's Ministry of Energy and Minerals, 2022).

Figure 15 Oman's Green Hydrogen Development Zones (2022)



### Projects

- Hybrid Hydrogen Project by Japan's Sumitomo and Oman's Ara Petroleum: The project aims to produce hydrogen from gas by-products at Ara Petroleum's refinery. The feasibility study is underway, and if successful, it could annually produce 300–400 tons of hydrogen from flare gas.
- PDO Block 6 Green Hydrogen Project: Petroleum Development Oman (PDO) is collaborating with the Brussels-based consulting firm Hinicio for a feasibility study on a green hydrogen pilot project within PDO Block 6. This project aims to explore low-carbon or zero-carbon alternative fuels to reduce greenhouse gas emissions and decrease dependence on natural gas.
- Sohar Green Hydrogen Hub Project: The project aims to produce green hydrogen using low-carbon solar energy, with the goal of transforming Sohar Port and Freezone into a national hub. The project is managed by Sohar Industrial Port Company, a joint venture between Rotterdam Port and Oman.
- ACME SEZAD Green Ammonia Plant Project: Indian ACME Group is partnering with Norway's Scatec ASA and OPAZ to invest in a US\$3.5 billion green hydrogen and ammonia plant in SEZAD. The facility, powered by 3 GWp of solar and 0.5 GWp of wind, plans to produce 1.2 million tons of green ammonia and has received certification from TUV Rheinland.
- DEME & OQ Green Hydrogen Plant Project: In 2020, Belgium-based DEME International NV (DEME) and Oman's OQ announced a joint project for the development of a green hydrogen plant in collaboration with the Special Economic Zone at Duqm (SEZAD) in Oman. Duqm boasts geographical advantages such as abundant renewable energy sources (solar and wind), extensive land availability, and access to port infrastructure. In the first phase of hydrogen plant construction, the electrolysis capacity is expected to be around 250–500 MW, with plans to subsequently expand to a final capacity of 1 GW.
- Green Energy Oman Project: In May 2021, InterContinental Energy headquartered in Hong Kong, along with OQ and Enertech, a subsidiary of the Kuwait Investment Authority's sovereign wealth fund, formed an international consortium with the aim of constructing a green hydrogen plant. They plan to develop a 25 GW solar and wind power generation complex in Oman's Al-Wusta Governorate, utilizing electrolysis powered by renewable energy sources in the Arabian Sea to produce green hydrogen and green ammonia.

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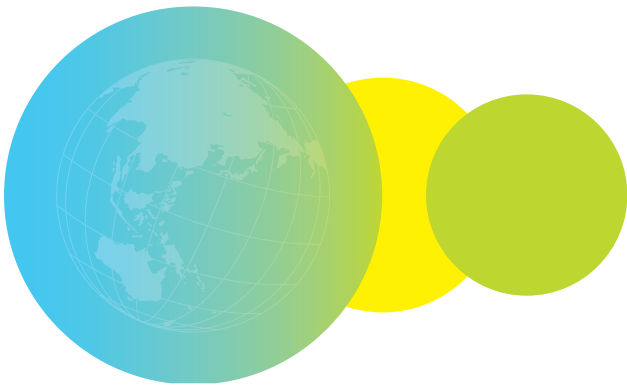
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# Green Hydrogen Technologies for Systems Transformation:

Building a compilation of national strategies, plans and projects

**2023**