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Winds, Waters, and Watts: How Colombia's Ports Can Fuel a Green Hydrogen Economy

Synthesis Report

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Enabling Infrastructure Investment

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Acknowledgments

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Acronyms

CAPEX	Capital Expenditure
CO_2	Carbon dioxide
CONPES	Consejo Nacional de Política Económica y Social
CORFO	Corporación de Fomento de la Producción
DIMAR	La Dirección General Marítima
DNP	Departamento Nacional de Planeación
eq	equivalent
ESMAP	Energy Sector Management Assistance Program
EU	European Union
GHG	Greenhouse Gas
GW	GigaWatt
H_2	Hydrogen
H_2O	Water
IEA	International Energy Agency
IMO	International Maritime Organization
IRR	Internal Rate of Return
kt	kilotons
kW	kiloWatt
LCOA	Levelized Cost of Ammonia
LCOH	Levelized Cost of Hydrogen
LCOM	Levelized Cost of Methanol
LF	Load Factor
m^3	meters cubed

MeOH	Methanol
MW	MegaWatt
N_2	Nitrogen
NH_3	Ammonia
NPV	Net Present Value
OPEX	Operational Expenditure
POFPA	Plan de Ordenamiento Físico Portuario y Ambiental
PPP	Public-Private Partnership
t	tons
US$	United States Dollar
WACC	Weighted Average Cost of Capital

Executive Summary

Background

The World Bank tackles the decarbonization of international maritime transport from two intertwined angles. On a global level, it supports the International Maritime Organization (IMO) policymaking process through targeted analytics and advisory. On a country level, the World Bank assists its member countries in identifying business and development opportunities. Colombia has been identified as one of the countries with the highest potential to become a future supplier of green hydrogen-based shipping fuels to the global fleet of vessels.

As part of this engagement with the Government of Colombia, the World Bank supported the development of pre-feasibility studies in four port locations: Cartagena, Barranquilla, Puerto Brisa, and Puerto Bolívar. The objective was to understand the opportunities, challenges, and requirements of developing green shipping fuel[1] value chains in Colombia. By making the findings available to public and private stakeholders alike, the studies serve as one of many building blocks for seizing this unique growth opportunity for Colombia. From December 2023 to November 2024, two in-person stakeholder workshops with more than 100 Colombian and international experts, various roundtables, and technical interactions at green hydrogen-related events, significantly benefited this work. A list of the main stakeholders involved can be found in Annex 1.

This report presents the key findings and conclusions of the World Bank engagement, showcasing Colombia's opportunity to become an important global supplier of green hydrogen-based fuels for shipping and other sectors.

This analysis evaluated Colombia's emerging green hydrogen economy from a maritime transport perspective. With shipping and ports at the center, the analysis explored the potential for producing, storing, supplying, and exporting green hydrogen-based fuels in the ports of Colombia, thereby highlighting its efforts at sustainability. Figure E1 illustrates a two-stage approach that aims to answer three key questions:

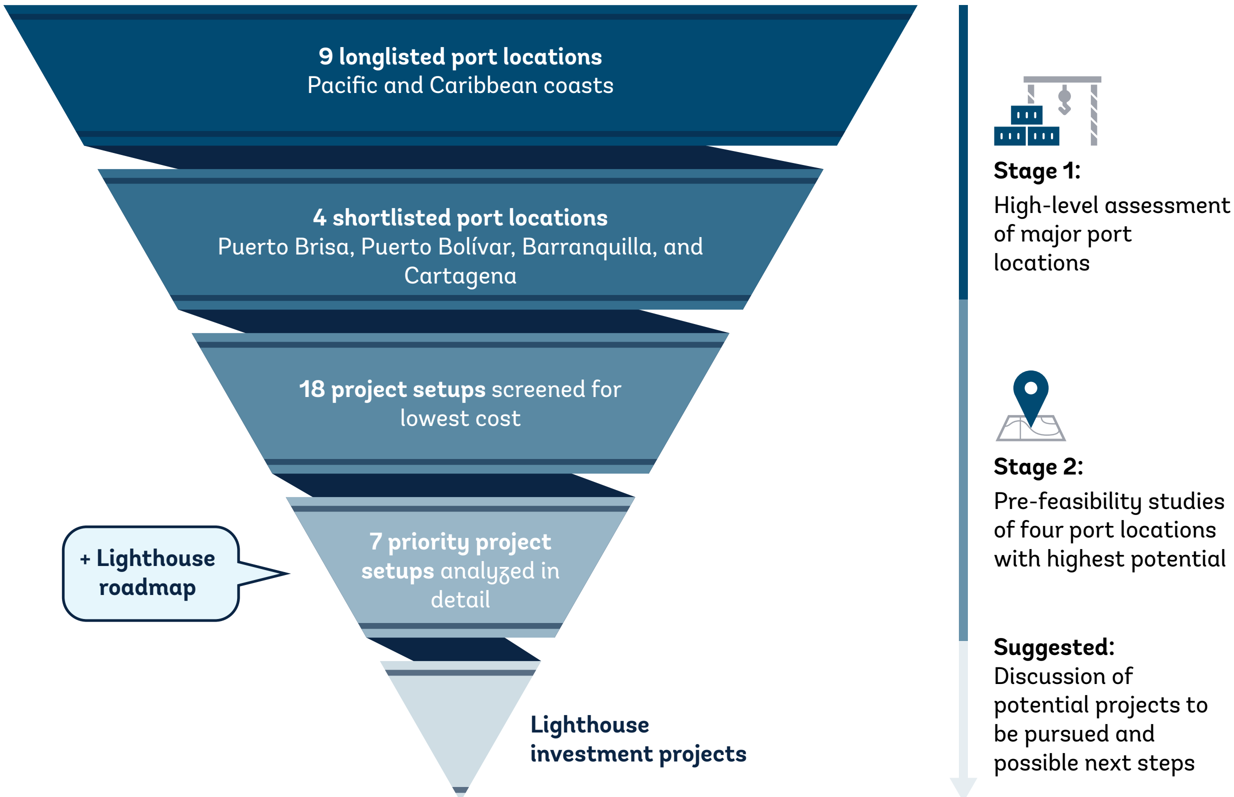
i. Which Colombian port locations are best suited to become part of future value chains for green hydrogen-based fuels?

ii. What would the technical and financial feasibility of potential lighthouse investment projects at these port locations look like?

iii. What actions should the public and/or private sector take to develop these potential lighthouse investment projects?

1 A green shipping fuel refers to shipping fuels that achieve minimal to no net greenhouse gas emissions (GHG)—particularly carbon dioxide (CO_2)—across their entire lifecycle, from production to combustion. This definition includes both the direct GHG emissions from fuel combustion as well as the indirect emissions from its production, processing, and distribution.

Figure E1. Overview of the two-stage approach under the completed analysis



Source: World Bank.

The main findings and conclusions can be summarized in five key messages:

1. The decarbonization of maritime transport will depend on green hydrogen-based fuels, and the global green hydrogen economy will depend on maritime transport.

As international shipping decarbonizes in accordance with the climate commitments made by the International Maritime Organization, ships will use a new generation of fuels—the so-called zero-carbon bunker[2] fuels. These new fuels will likely be biofuels or green hydrogen-based (H_2) fuels produced by wind and solar power, namely green ammonia (NH_3) and green methanol (MeOH). Green hydrogen-based fuels are much more scalable. Other varied global industries such as chemicals, fertilizers, iron and steel, aviation and trucking will also need green hydrogen and its derivatives to decarbonize. In this scenario, ships and ports will be key. They will be needed to link low-cost production centers with abundant renewable energy resources (e.g., in Latin America) and energy-constrained high-demand consumption centers (e.g., in Europe or East Asia), to enable the global trade of green hydrogen-based fuels.

[2] Bunkering is the technical term for supplying (any type of) fuel to be used by ships. This fuel is often called bunker fuel. The term bunkering still comes from the days of steamships whose coal was stored in bunkers.

2. Based on a two-stage analysis, seven key investment opportunities for lighthouse green H_2 projects were identified along the Caribbean Coast of Colombia.

Four port locations were shortlisted for further analysis after a high-level assessment of all major port locations across the country. This was based on evaluation criteria like energy resources, infrastructure, safety, environmental and social considerations, among others. The shortlisted ports were: Puerto Bolívar, Puerto Brisa (both in La Guajira), Port of Barranquilla (Atlántico), and Cartagena (Bolívar, to be precise, Puerto Bahía which is located next to Cartagena). Across these high-potential port locations, 18 project setups were designed. This was further whittled down to seven priority project setups—targeting a start of commercial operation in 2032. Detailed pre-feasibility studies for the production, storage, supply and export of green ammonia (NH_3) and green methanol (MeOH) were conducted for Cartagena, Barranquilla, Puerto Brisa, and Puerto Bolívar (with only green ammonia being assessed in the two latter ports). The relatively small number of green methanol priority project setups compared to its ammonia counterpart is explained by the crucial need for reliable and sustainable biomass supply for methanol projects.

3. The largest business opportunities for commercializing green hydrogen-based fuels from these potential projects are primarily in exports, followed by bunkering demand.

The demand analysis revealed that the export market will likely account for the largest market potential to sell green hydrogen-based fuels "made in Colombia". This demand of up to 12,000 kilotons (kt) of H_2 equivalent (eq) in 2030 and 59,000 kt H_2eq in 2050, relates primarily to exports to the European Union, Japan and South Korea, as well as Panama, which plans to establish itself as a green fuel distribution hub. At a much smaller scale, demand from international ships calling at these four port locations, comes in at second place. They could account for 30.7 kt H_2eq in 2030 and 675 kt H_2eq in 2050. Lastly, local industry situated at these locations may demand green hydrogen and its derivatives in the order of 7.0 kt H_2eq in 2030 and 188.4 kt H_2eq in 2050.

4. The financial viability of the priority projects remains highly dependent on the future market prices for green hydrogen-based fuels, which, in turn, are determined by international policy decisions.

Assuming a yearly output of approximately 50 kt H_2eq, the seven priority projects were estimated at CAPEX ranging from US$ 1.6 billion (Puerto Bolívar NH_3) to US$ 2.7 billion (Cartagena NH_3). In the base scenario, almost all priority projects were deemed to be financially viable—with an estimated internal rate of return between 14 percent and 24 percent. This base scenario assumed average green premium fuel prices. These are prices that future (European) off-takers are likely willing to pay on average for green ammonia or green hydrogen. However, the sensitivity analysis also revealed that with lower green premium prices, or even market prices for the products' gray competitors, all projects would become financially unviable and would initially need public support. Ultimately, future prices for green hydrogen-based fuels will heavily depend on climate policy decisions made by the European Union, Japan, South Korea, and the International Maritime Organization. While it may be more difficult with national or regional policies, the Government of Colombia can strategically influence international policy at the IMO.

5. Following recommendations from the lighthouse roadmap, the public and private sectors alike can maximize the contribution of Colombian ports to form a national green hydrogen economy.

The analysis developed a strategic lighthouse roadmap based on six axes of action: (1) Governance, (2) Regulation, (3) Value Chain, (4) Market, (5) Social and Environmental, (6) Financial and Economic. The lighthouse roadmap puts special emphasis on the creation of an enabling environment for developing green hydrogen-based value chains in Colombia, providing implementable recommendations to both the public and private sector to address key challenges and gaps. For instance, the creation of a new governance mechanism for green hydrogen value chains in Colombia, the introduction of new a regulatory environment, and the strategic management of social and environmental issues (especially regarding local indigenous communities). Other recommendations included exploring financing options such as the establishment of a public investment fund (in line with the Chilean CORFO[3] model), collaboration with the 10 GW Clean Hydrogen Initiative, or working with the World Bank's new Fondo de Transición Energética.

[3] CORFO (Corporación de Fomento de la Producción) is Chile's economic development agency. Together with the World Bank and other development finance institutions, CORFO established a blended finance fund for Chilean green hydrogen projects in 2023.

01

Context

- Maritime transport and the green hydrogen economy depend on each other.
- Ships are likely to become major consumers of green hydrogen-based fuels such as green ammonia or green methanol as maritime transport reduces its greenhouse gas emissions.
- Likewise, shipping and ports will be indispensable in linking low-cost production centers and high-demand consumption centers for green hydrogen and its derivatives around the world.
- As facilitators of the green hydrogen economy, ports will be expected to supply green hydrogen-based fuels to ships, provide these fuels to local industry, and help export them to international markets.

1.1. Maritime transport to decarbonize through green hydrogen-based fuels

Maritime transport is crucial for global trade and the economic growth of countries. For instance, Colombia, with its extensive coastline of over 3,200 km along the Caribbean and Pacific, holds substantial economic promise due to its strategic geographic maritime position, facilitating access to major markets in Asia, North America, and Europe. The Caribbean ports alone handle around 95 percent of the country's exports (over 90 million tons) and 64-70 percent of the imports (DIAN, 2020; Supertransporte, 2023).

While being a key enabler for the global economy, international maritime transport also contributes significantly to climate change. Greenhouse gas (GHG) emissions from ships account for about 2.9 percent of global GHG emissions, or approximately 1.1 billion tons carbon dioxide equivalent (tCO_2eq) per year (IMO, 2020). If shipping was a country, it would be among the top 10 GHG emitters, worldwide. In 2023, the International Maritime Organization (IMO) set ambitious decarbonization targets for international shipping. These include, for instance, the goal to fully decarbonize international vessels by or around 2050, and to ensure that zero or near-zero GHG emission technologies, fuels, and/or energy sources represent at least 5-10 percent international shipping's energy mix by 2030.

Decarbonizing shipping will require a massive energy transition away from fossil fuels—predominantly oil with a little bit of natural gas— to green shipping fuels. Next to biofuels, these future green shipping fuels refer, amongst others, to green hydrogen-based (H_2) fuels. They include green ammonia (NH_3) and green methanol (MeOH), which are derived from green hydrogen[4]. If all green fuels required by shipping in 2030 were based on hydrogen, this would imply a need for an estimated 5 to 10 million tons of green hydrogen (IMO, 2023 and World Bank calculations). For comparison, today's global demand for (almost exclusively gray[5]) hydrogen is estimated at around 100 million tons per year (IEA, 2024).

With stringent policies in place, green hydrogen-based fuels are deemed most promising to decarbonize the shipping industry at scale. They are likely to be preferred over biofuels, which often raise sustainability concerns and face cross-sectoral demand from other sectors such as aviation. In deep-sea shipping, they are also likely to be used over electrification, as electrification has its technical limits due to the high requirements—both in terms of power levels and storage space—by ocean-going vessels (World Bank, 2021). With the IMO's goal of achieving full decarbonization, international shipping could create a significant and stable demand for green hydrogen-based fuels worldwide.

Alongside shipping, other economic sectors will be in need of green hydrogen-based fuels to decarbonize. So far, (gray) hydrogen has been used mainly in refineries and chemicals, specifically in fertilizer production. In a decarbonizing global economy, fertilizer production based on green ammonia will take on increased importance. In addition, large-scale demand for green hydrogen is likely to come from heavy industries (to replace coke with green hydrogen) and from transport sectors like aviation (to replace fossil kerosene with synthetic kerosene) or possibly even trucking (to replace diesel with green hydrogen).

[4] Green hydrogen is hydrogen produced by the electrolysis of water, using renewable electricity or biomass. In other contexts, it may also be called renewable hydrogen.

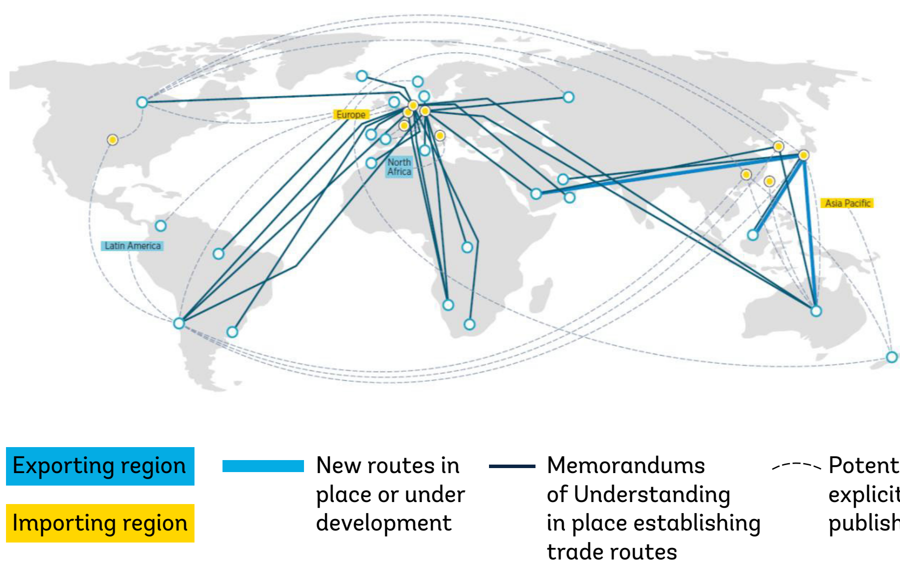
[5] In this context, gray hydrogen is considered as hydrogen produced by fossil fuels, in most cases natural gas.

1.2. Trading green hydrogen and derivatives by sea

Many developing countries, including Colombia, are touted to be able to produce green hydrogen at the most competitive cost worldwide. In general, renewable electricity generation accounts for the lion's share, i.e., around 80 percent of total investment needs for green hydrogen production (ESMAP et al., 2023), followed by electrolyzers. Consequently, developing countries with abundant renewable energy resources, particularly wind and solar, are estimated to have the lowest levelized cost of green hydrogen (IEA, 2023). Future low-cost production centers of green hydrogen are likely to be found in Latin America, Northern and Southern Africa, the Middle East, and Oceania. Parts of Colombia are among the world's top locations for low-cost green hydrogen production.

Economically, it will be very beneficial to link these countries that are able to produce green hydrogen at low cost with those willing to offer higher prices. In contrast to the low-cost production centers in many developing countries, high-demand consumption centers of green hydrogen-based fuels are expected to emerge in Europe (mostly Central Europe and Eastern Europe) and East Asia (mostly Japan and South Korea) (IRENA, 2022). For optimal mutual benefit, it will make sense to connect these low-cost production centers with the high-demand consumption centers in a cost-effective manner, thereby facilitating the export, import, and trade of green hydrogen-based fuels around the world. As illustrated in Figure 1.1, in most cases, this global trade will happen by sea.

Figure 1.1. Predictions for low-cost production centers and high-demand consumption centers of future green hydrogen



Source: IRENA (2022).
MoU stands for memorandum of understanding.

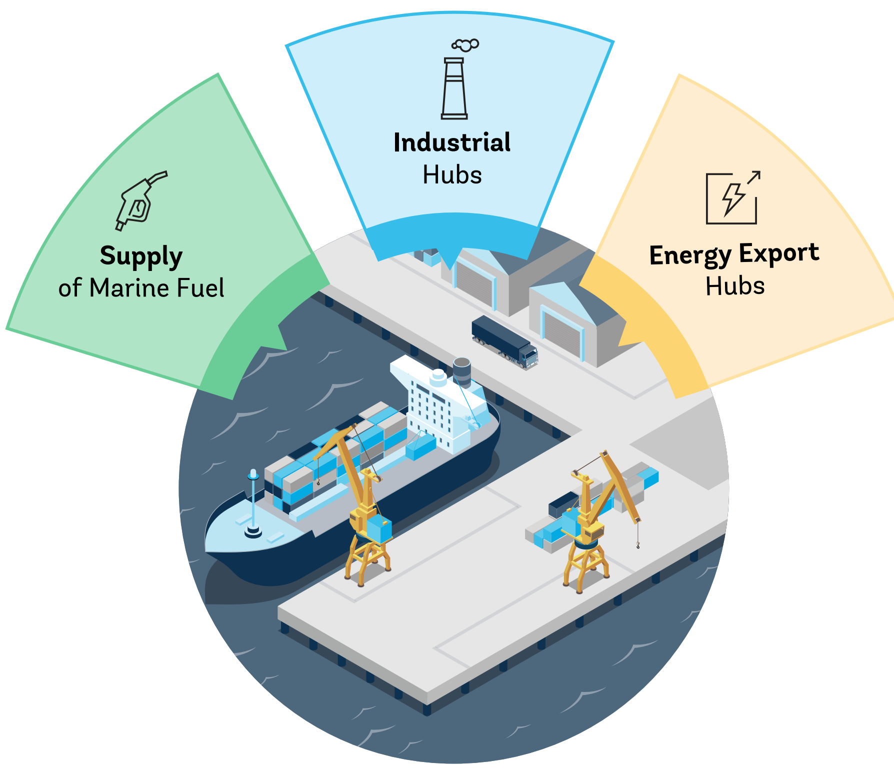
Thus, ships will play an important role not only as consumers of green hydrogen-based fuels, but also as their global distributors, thereby contributing to the wider decarbonization of the global economy. Where pipelines may be technically impossible or financially unviable, maritime transport through shipping and ports will serve as the only realistic solution to facilitate the global trade of green hydrogen-based fuels. This positions ships as essential distributors and ports as pivotal import and export hubs for green hydrogen, its derivatives, and its technical components.

1.3. Ports as enablers of the green hydrogen economy

Ports will play a crucial enabling role in most countries, leading to the emergence of green hydrogen economies. They are expected to fulfill key functions in building green hydrogen value chains locally, nationally, and internationally in a cost-effective manner. In many cases, ports will be the only means of enabling the large-scale supply of and demand for green hydrogen and its derivatives.

On the green hydrogen demand side, ports are expected to play a triple role, catering to shipping, local industry, and export demand. Figure 1.2 illustrates this point. First, ports will continue assuming their traditional role as bunkering hubs for maritime transport by providing shipping fuels to vessels. While this fuel has been mostly oil for many decades, shipping's decarbonization commitments will soon require more and more vessels to refuel with green hydrogen-based fuels like green ammonia or green methanol. Second, ports are often strategically located in or next to major industrial zones. In many cases, these zones host important industrial activities such as chemicals, fertilizers, iron and steel, aviation, or trucking. These will be in need of the same green hydrogen-based fuels, too, in order to comply with their own climate commitments. Here, ports can serve as strategic aggregators of local demand. Third, and likely most important, ports will be vital to facilitate the sea-borne export of green hydrogen and its derivatives to foreign markets at a large scale.

Figure 1.2. The triple role of ports in the green hydrogen value chain



Source: World Bank.

On the hydrogen supply side, ports are often the only viable transport gateways through which large-scale technical components can be imported. In terms of building a green hydrogen value chain, this is particularly true for technical energy components like wind blades, wind turbines, solar panels, or electrolyzers. In many cases, these components need to be manufactured abroad and imported by sea. They then often need to be transported to remote locations along the coast. These locations have excellent renewable energy conditions, but suffer from inadequate land-based transport infrastructure.

Colombia has the potential to become a key player in the international hydrogen market. According to the Inter-American Development Bank (Gischler, et al., 2023), by 2030, Colombia's average levelized cost of hydrogen (LCOH) is expected to be around US$ 3 per kg H_2. This is lower than that of Costa Rica, Panama, South Africa and Trinidad and Tobago (US$ 3-6 per kg H_2). It is, however, higher than average LCOH levels in Argentina, Brazil, Chile, Namibia and Uruguay (US$ 1.5-3 per kg H_2).

These national averages mask regional variations. The International Energy Agency (IEA, 2024) highlights that Colombia's Caribbean coast, particularly its northernmost areas, are likely to achieve LCOH levels comparable to the best areas in Southern Argentina and Chile, and even slightly better than the Arab Gulf countries. Other non-Caribbean regions of Colombia maintain acceptable LCOH levels, with the Pacific coast appearing less competitive when the renewable energy focus is set solar and wind power, and not on bioenergy.

From a policy perspective, the Government of Colombia has already made significant strides in developing its national green hydrogen economy. Recognizing its abundant renewable energy potential, its favorable geographic location, and its existing and planned energy and transport infrastructure, the Government of Colombia has developed key public policies and strategies from a maritime perspective. These include, amongst others, the Green Hydrogen Roadmap (Ministerio de Minas y Energía, 2022), the Offshore Wind Roadmap, or Consejo Nacional de Política Económica y Social (CONPES) 4118 of 2023 on sustainable development in ports. These initiatives have started building a robust framework for action, fostering a conducive investment climate as well as the development of sustainable infrastructure projects.

02

Pre-Feasibility Assessment

- The analysis was divided into two stages. Stage 1 involved a high-level assessment of nine major port locations in Colombia. Stage 2 zoomed in on four selected ports (Cartagena, Barranquilla, Puerto Brisa, and Puerto Bolívar) deemed to have the highest potential for producing, storing, supplying, and exporting green hydrogen-based fuels.

- The demand analysis in Colombia concluded that by far, the largest market potential can be expected in exporting green hydrogen or its derivatives to markets such as the European Union, Japan, or South Korea. This potential is likely followed by bunkering demand from ships, and eventually, local industry.

- The analysis focused on developing value chains for green ammonia and/or green methanol with a production capacity of approximately 50,000 tons per year of green hydrogen at each shortlisted port location.

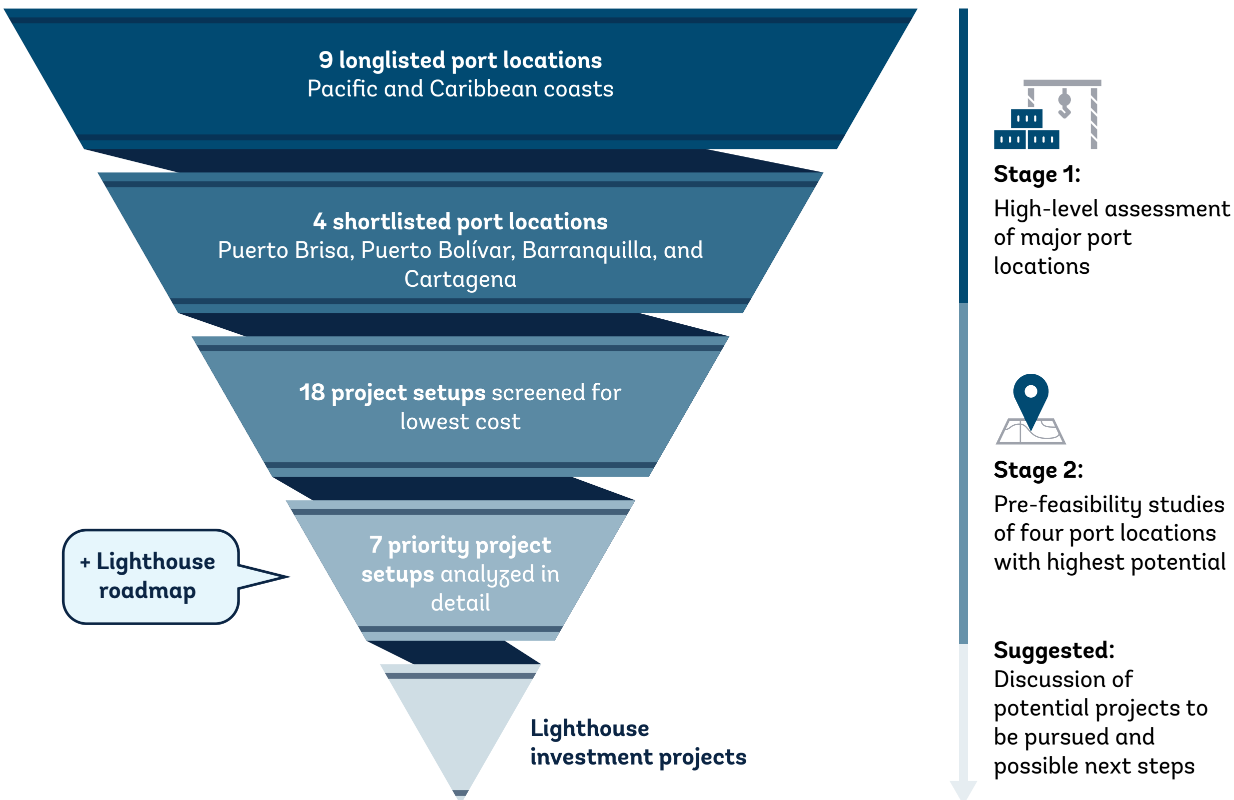
The Government of Colombia[6] and the World Bank joined forces to explore the role of Colombia's port sector in the country's emerging hydrogen economy. The aim was to identify and pre-assess the feasibility of lighthouse investment projects to produce, store, supply, and export green hydrogen-based fuels, such as green ammonia or methanol, in Colombian ports. With that goal in mind, the joint analysis was divided into two subsequent stages.

Stage 1 gauged nine major port locations in Colombia through a high-level assessment.

Stage 2 zoomed in on four port locations (Cartagena, Barranquilla, Puerto Brisa, and Puerto Bolívar), with the highest potential to produce, store, supply, and export green hydrogen-based fuels in the future, from the early 2030s.

Figure 2.1 shows the two-stage structure of the analysis.

Figure 2.1. Overview of two-stage approach of current analysis completed



Source: World Bank.

[6] The collaboration happened mainly with the National Planning Department, which coordinated closely with the Ministry of Transport, the National Agency for Infrastructure (ANI), the General Maritime Directorate (DIMAR), the Ministry of Mines and Energy, and other relevant governmental entities.

2.1. Stage 1: High-level assessment of major port locations

During Stage 1, the analysis covered all major port locations in Colombia, assessing their potential to produce, store, supply, and export green hydrogen-based fuels in the future. This high-level assessment looked at Tumaco and Buenaventura on the Pacific Coast, as well as Antioquia,[7] Morrosquillo, Cartagena, Barranquilla, Santa Marta, Puerto Brisa, and Puerto Bolívar on the Caribbean Coast. Figure 2.2 provides a geographic overview of the nine Colombian port locations considered.

Figure 2.2. Overview of the nine major port locations considered in Colombia

Source: World Bank.

Based on a multicriteria analysis,[8] this high-level assessment estimated each port location's individual short- to medium-term potential for green hydrogen-based fuels. As indicated in Table 2.1, seven key criteria with individual sub-criteria were defined through consultations (including a workshop in Bogotá) with key stakeholders.

The key criterion "C2: Energy potential and infrastructure" was assigned the largest weight for two main reasons.

1. It appeared most important from a financial perspective of any future lighthouse project, and thus, essential to attract future investments.
2. In contrast to other key criteria, a favorable (or unfavorable) levelized cost of hydrogen—which is mostly dependent on the given wind and solar potential of a location — appeared most difficult to be changed and/or improved by any developer's or policymaker's action.

[7] Puerto Antioquia was still under construction at the time of the analysis.

[8] The multicriteria analysis used the Analytical Hierarchy Process (AHP) technique. The AHP, devised by Thomas L. Saaty, simplifies complex decision-making by structuring it into a hierarchy of criteria and alternatives. This method evaluates alternatives through pairwise comparisons against each criterion, thus bringing clarity and rigor to the decision-making process.

A full overview of all criteria, sub-criteria and relative weights applied can be found in Annex 2.

Table 2.1. Criteria, sub-criteria, and weights applied in the multicriteria analysis under Stage 1

Criteria	Examples of main sub-criteria	Weight
C1: Port infrastructure	• Adequate infrastructures to handle draught of vessels • Availability of land and port development/expansion plans	15%
C2: Energy potential and Infrastructure	• Levelized cost of hydrogen for 2030 and 2050 • Water resources and existence of transmission lines in vicinity	45%
C3: Security	• Infrastructure vulnerability or exposure to climate change • Safety radius for handling explosive or toxic substances	5%
C4: Financial & Economic	• Foreign direct investment and existence of free trade zone • Traffic volume and local alternative off-takers	15%
C5: Environmental	• Existence and type of licenses for chemicals • Areas of environmental protection	7.5%
C6: Social	• Existence of ethnic or protected groups • Skilled workforce	7.5%
C7: Political	• Institutional performance • Prior consultation (Consulta previa) on energy/port project	5%

Source: World Bank.

This high-level assessment resulted in the selection of four Caribbean port locations:

1. Puerto Brisa (in La Guajira, halfway between Santa Marta and Riohacha)
2. Puerto Bolívar (in La Guajira, east of Cabo de la Vela)
3. Barranquilla (in Atlántico, East Bank of the Magdalena River)
4. Cartagena (in Bolívar, to be precise: Puerto Bahía, located south of Cartagena)

The exact geographic locations of the specific ports selected is shown in Figure 2.3. The final ranking of the high-level assessment under Stage 1 is displayed in Table 2.2. The relative dominance of Caribbean ports over Pacific ports can be explained with the geographical distribution of Colombia's renewable energy potential across the country (Minergia, 2022). This analysis focused on wind[9] and solar conditions.[10] The country's best wind—both onshore and offshore—as well as solar resources can be found along the Caribbean coast, specifically the Eastern part towards La Guajira. With a few minor exceptions, the same is true for Colombia's solar potential.[11]

Figure 2.3. Geographic locations of the four specific ports selected

Source: Google Maps. edits by World Bank. The location of ports are approximate only.

9 Given the planned start of commercial operations in the early 2030s, the analysis focused on on-shore wind which is considered more mature than off-shore wind. Still, it is important to note that Colombia has excellent off-shore wind power generation potential which can be taken advantage of in the medium to long term (Minergia, 2022).

10 This analysis focused on green hydrogen-based fuels produced through electrolysis. Theoretically, green hydrogen can also be produced through biomass gasification. Yet, in the current analysis, biomass gasification was considered mainly to generate biogenic carbon dioxide, with hydrogen being a by-product only. Pure bioenergy was beyond the scope of this analysis. Yet, it has been explored through other studies. Bioenergy appears most relevant to ports along the Pacific coast where regions such as Buenaventura offer a lot of biomass.

11 In contrast to Colombia's wind resources, the country's best solar resources are not only along the Caribbean coast, mainly La Guajira, but can also be found in the departments of Santander and Boyacá. In return, these two departments have very unfavorable wind conditions, preventing the desirable complementarity of wind and solar resources for maximum full load hours.

Table 2.2. Final results of the high-level assessment under Stage 1

#	Port location	Code	Individual score	Specific port targeted
1	**Puerto Brisa**	**P8**	**15.58%**	**Puerto Brisa**
2	**Puerto Bolívar**	**P9**	**14.61%**	**Puerto Bolívar**
3	**Barranquilla**	**P6**	**12.07%**	**Puerto de Barranquilla**
4	**Cartagena**	**P5**	**11.92%**	**Puerto Bahía**
5	Santa Marta	P7	11.19%	
6	Buenaventura	P2	9.66%	
7	Antioquia	P3	9.59%	
8	Morrosquillo	P4	8.25%	
9	Tumaco	P1	7.12%	

Source: World Bank.

2.2. Stage 2: Pre-feasibility studies of four port locations with highest potential

During Stage 2, the analysis focused on developing pre-feasibility studies for the four selected port locations to outline possible lighthouse investment projects. The goal was to understand the extent to which such lighthouse projects could be further pursued and eventually developed in Puerto Brisa, Puerto Bolívar, Barranquilla, and Cartagena, considering financial, technical, safety, environmental, social and regulatory aspects.

2.2.1 Key features of ports

Table 2.3. Highlights the key features of each of the ports shortlisted during Stage 1.

Table 2.3. Key characteristics of each port shortlisted under Stage 2

<table>
<tr><th>Port location</th><th>Key features</th></tr>
<tr><td>Puerto Brisa (La Guajira)</td><td>

Figure 2.4. Puerto Brisa

Source: © Puerto Brisa. Used with the permission of Puerto Brisa. Further permission required for reuse.

Small dry bulk port, mainly for coal exports, with strong owner's interest in attracting new (green) business

- **History, location, and usage:** Built from 2011 to 2014, this relatively new, family-owned port in the Western part of La Guajira started operations in 2015. It mostly handles coal exports arriving by truck from coal mines in the interior of the country.
- **Infrastructure, industry, and expansion:** The port's underutilized single quay, which allows for a maximum vessel draft of approximately 17.5 meters, is equipped with a conveyor belt and chip loader; it could accommodate much more vessel traffic. Additionally, the port hosts a "Zona Franca" (Special Economic Zone) spanning 15,000 m², which has considerable potential for further development. There is no local industry nearby, yet.

</td></tr>
</table>

- **Resources available**: The port has access to its own freshwater resources, the Rio Cañas, with the license to use 300 liters per second. The adjacent space for renewable power production is geographically constrained due to the Sierra Nevada de Santa Marta in the South. Yet, conditions slightly further east are very good.
- **Environmental and social challenges:** Currently, 700 MW of onshore wind power equipment (originally worth about US$ 1,400 million, in total) is sitting idle at the port due to a stalled renewable power project in La Guajira. This situation highlights critical social and environmental challenges related to indigenous communities that renewable power projects in the region may face.

Puerto Bolívar (La Guajira)

Figure 2.5. Puerto Bolívar, La Guajira

Source: jvillegas, https://commons.wikimedia.org/wiki/File:El_Cerrejon.jpg, licensed CC BY-SA 4.0.

Medium dry bulk port, currently exclusively dedicated to coal exports, but located in Colombia's prime spot for renewable power production

- **History and usage:** This is the largest coal exporting port in Latin America, located at the northeastern-most tip of La Guajira. It has been in operation at least since 1985, using a direct loading system for the coal. The port is operated by "El Cerrejón", a subsidiary of the multi-national mining company, Glencore.
- **Infrastructure, industry, and expansion:** The port has its own railway line by which coal is transported from the coal mine "El Cerrejón", about 150 km south-west of the port. The port also features its own airport nearby. There is almost unlimited land available for further development. There is no local industry nearby, yet.
- **Resources available:** The port is located in Colombia's top location for renewable power generation, thanks to the world-class complementary wind and solar conditions of La Guajira. Thus, it is ideal for green hydrogen production. There is no access to fresh water, though.

- **Social and environmental challenges:** This region of La Guajira is particularly affected by social challenges related to Indigenous communities.
- **Miscellaneous:** In 2033, the existing port concession and its affiliated operations of the coal mine "El Cerrejón" are expected to end. The Government of Colombia, including state-owned enterprises such as Ecopetrol, has a strong interest in facilitating Colombia's energy transition. However, Glencore has remained silent so far on what to do with Puerto Bolívar after the end of the concession and/or whether to convert the port, maybe even before 2033.

Barranquilla (Atlántico)

Figure 2.6. Puerto de Barranquilla

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Medium multi-purpose port with direct access to prime offshore wind resources and relevant local industry nearby

- **History, location, and usage:** Situated at the mouth of the Magdalena River, this port with a long history provides direct sea and river access to the interior of Colombia. It serves all key trade segments such as dry bulk, liquid bulk, and containers.
- **Infrastructure, industry, and expansion:** The port benefits from local industry for which green hydrogen is of interest. This includes, for instance, the Venezuelan fertilizer company, Monómeros, with strong interest in green ammonia production. Vopak, a leading Dutch gas operator, is actively interested in exporting hydrogen derivatives to their main bases in Europe (e.g., Rotterdam), capitalizing on its current concession that is set to expire in 2033. The port's Palermo cluster has land of at least 100 hectares under a free trade regime within national customs territory available.
- **Resources available:** The Magdalena River boasts a plentiful freshwater supply. The port is ideally located close to Colombia's prime offshore wind resources, for which the first exploratory concessions were auctioned in 2024.
- **Miscellaneous:** The Government of Atlántico, specifically the Governor, has shown keen interest in advancing the hydrogen economy in this region.

Cartagena (Bolívar)

Figure 2.7. Cartagena's Puerto Bahía

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Small to medium multi-purpose port with local industry, namely refinery and fertilizers, already using hydrogen or ammonia

- **History, location, and usage:** Puerto Bahía is a relatively new port which commenced operations in 2015. It is strategically situated at the entrance of the Canal del Dique. Financed by the International Finance Corporation, among others, the port hosts a multi-modal terminal. So far, the port specializes in roll-on/roll-off commodities (i.e., vehicles), as well as liquid hydrocarbons.
- **Infrastructure, industry, and expansion:** The port boasts abundant space, with only 30 percent currently in use. Reficar, an Ecopetrol refinery which is situated nearby, already utilizes hydrogen (not yet green hydrogen). Reficar has made a commitment to support local green ammonia production, targeting 440,000 tons annually by 2030. Currently, a hydrocarbon pipeline between Reficar and Puerto Bahía is being planned. Additionally, Yara, a leading fertilizer producer with green subsidiaries such as Yara Clean Ammonia, already operates a fully equipped berth for ammonia imports nearby.
- **Resources available:** The area has relatively good solar conditions, but only moderate wind conditions. There are ongoing concerns regarding contamination of freshwater resources from the Canal del Dique and its impact on Cartagena Bay.

Source: World Bank.

2.2.2 Demand analysis

With ports of the future playing a triple role (as seen in Figure 1.2), this analysis estimated the potential future demand for green hydrogen-based fuels in Colombia. This was based on three categories: bunkering for ships, local industry, and exports.

Bunkering for ships

The future demand for green ammonia and green methanol for the years 2030, 2040, and 2050 was gauged based on anticipated port calls by vessels with international destinations. For this, the analysis used a database with all port calls (including information size, cargo carrying capacity, average speed, average energy consumption by ship) for the calendar year 2023 (DIMAR confidential port data, 2024). Additionally, the future demand was calculated in light of the decarbonization targets set by the International Maritime Organization, specifically those linked to the uptake of zero or near-zero shipping fuels.

The analysis shows that the most demand for green hydrogen-based fuels can be expected in the port location of Cartagena, followed by Barranquilla and Puerto Bolívar. Table 2.4 shows the projected demand for green hydrogen-based shipping fuels at the four shortlisted ports.

With about 70 percent of the bunkering demand, Cartagena accounts for the largest share of future potential demand. This is because it represents the largest and busiest port location in Colombia. There are also various related ports in proximity, including the international container port of Cartagena, which serves as the largest transshipment hub in the Caribbean. All these ports in or next to Cartagena could easily be supplied with green hydrogen-based fuels from adjacent Puerto Bahía by bunkering barge.

The Port of Barranquilla, Puerto Bolívar, and Puerto Brisa account for the remaining 30 percent of the estimated future demand. Even here, the distances would be short enough to consider the production and storage of green hydrogen-based fuels in Puerto Brisa, for example, and the supply of these fuels by bunker barge to vessels at the Port of Barranquilla.

Table 2.4. Green hydrogen-based shipping fuel demand in shortlisted ports in Colombia

	Green hydrogen-based shipping fuel demand [kt H_2eq/year]		
	2030	**2040**	**2050**
Cartagena	21	330	453
Barranquilla	5	77	106
Puerto Bolívar	4.3	65	90
Puerto Brisa	0.4	6	8
Total	**30.7**	**478**	**657**

Source: World Bank.

The demand for green hydrogen-based shipping fuels at the four shortlisted port locations is expected to grow rapidly from 2030. In 2030, the selected ports could be in demand of up to 31 kt H_2eq annually to supply zero-carbon fuels to ships. With stringent policy that is currently being developed at the International Maritime Organization, this demand is likely to grow rapidly in the future — to 478 kt H_2eq by 2040 and 657 kt H_2eq by 2050.

Local industry

The potential demand for green hydrogen and its derivatives by the local industry was estimated by analyzing the composition and gauging the interest of nearby industrial players. This involved screening the industrial setting for potential off-takers in the key sectors of chemical and fertilizers (including refineries), iron and steel, heavy-duty transport like aviation or trucking, as well as identifying minor opportunities in glass or energy generation. Table 2.5 displays the estimated demand by the local industry at the four shortlisted port locations.

Table 2.5. Local industry demand in shortlisted port areas in Colombia

	Local industry demand [kt H_2eq/year]		
	2030	**2040**	**2050**
Cartagena	4.8	20.4	82.8
Barranquilla	2.1	24.8	77.9
Puerto Bolívar	0	10.2	27.2
Puerto Brisa	0.1	0.3	0.5
Total	**7.0**	**55.7**	**188.4**

Source: World Bank.

In this context, the port locations of Cartagena and Barranquilla, with their strong local industry bases, offer the greatest potential for the additional off-take of green hydrogen and its derivatives. In Cartagena's port location, for instance, the presence of key off-takers like Ecopetrol's refinery (Reficar) or Yara, a multi-national fertilizer company, results in an estimated annual hydrogen-equivalent demand of approximately 5 kt H_2eq by 2030 and 83 kt H_2eq by 2050. In Barranquilla, home to the Venezuelan fertilizer producer, Monómeros, the demand is estimated at 2.1 kt and 77.9 kt H_2eq by 2030 and 2050, respectively. Given the current absence of any major local industry at Puerto Brisa or Puerto Bolívar, the potential demand there is considerably lower, with less than 0.5 kt H_2eq and 28 kt H_2eq annually by 2030 and 2050, primarily for the operation of heavy-duty trucking.

Exports

Given Colombia's geographic location and the anticipated supply-demand balance across different world geographies, the key foreign markets for the country's hydrogen consist mainly of the European Union, in terms of east-bound exports, South Korea and Japan, in terms of west-bound trade, and Panama, in terms of proximity trade.

Table 2.6. Hydrogen import demand in major countries and region

	Hydrogen demand for exports[12] [kt H_2eq/year]		
	2030	**2040**	**2050**
European Union	7,600	12,200	23,900
Japan and South Korea	4,300	12,800	32,300
Panama	76	1,333	2,014
Total	**11,976**	**26,333**	**58,214**

Source: World Bank.

In light of the scales anticipated, it becomes obvious that exports — specifically to the European Union, South Korea and Japan — currently appear as the most attractive option to commercialize green hydrogen and its derivatives produced in Colombia. It is projected that by 2030 — close to the expected start of the envisaged lighthouse investment projects — the total European Union demand for green hydrogen and derivatives will reach approximately 7,600 kt H_2eq per year by 2030 (Ministerio de Minas y Energía, 2022). This European market is expected to triple in size by 2050, partly due to the adoption of zero-emission fuels, driven primarily by regionally set targets and regulations. Meanwhile, the Asian market, primarily targeting Japan and South Korea, is anticipated to require about 4,300 kt H_2eq equivalent annually by 2030, with an almost eight-fold increase possible by 2050.

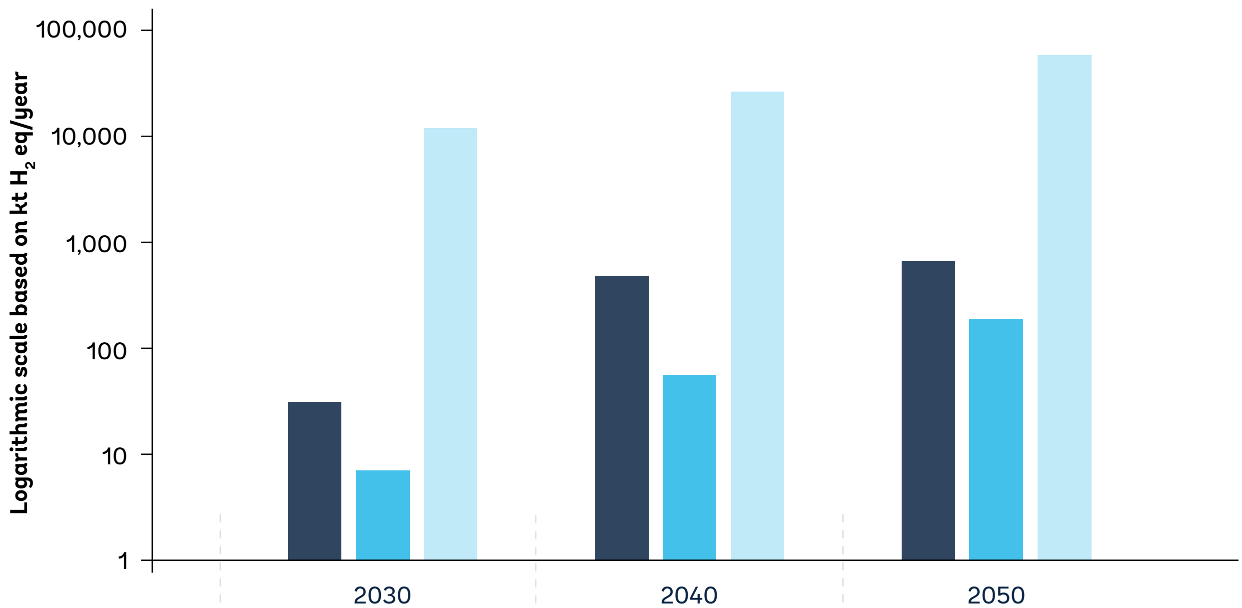
Additionally, Colombia, with its superior renewable power potential, is well-positioned to supply the Panamanian market with green hydrogen-based fuels at a significantly lower cost than Panama's own production. Among others, Panama envisions itself as a zero-carbon bunkering distribution hub, with an expected demand of 600 kt H_2 equivalent per year by 2030, expected to rise to 12,400 kt H_2 in 2050. This refers to demand both for green ammonia and green methanol by ships calling port in Panama. According to Panama's Green Hydrogen and Derivatives Strategy (Secretaría de Energía de Panamá, 2024), it is anticipated that, by 2030, green hydrogen-based fuels will account for 5 percent of the country's bunker fuel supply.

[12] This refers to the total demand, not only the market share that Colombia may be able to capture.

Aggregated demand

Currently, exports represent the largest business opportunity to commercialize green hydrogen-based fuels in Colombia. The market potential of selling green hydrogen or its derivatives to foreign markets such as the European Union, East Asia, or Panama far exceeds that of other demand centers, such as bunkering or local industry. The numbers for the maximum market potential suggest that the likely export market could be 60 to 65 times larger than the production planned for each project, as outlined in the pre-feasibility study. Figure 2.8 shows the differences in the orders of magnitude scale between the three demand types. As the bars for bunkering for ships and local industry would be hardly visible otherwise, the figure uses a logarithmic scale. The data table within the figure clarifies with the actual numbers.

Figure 2.8. Comparison of the market potential for green hydrogen-based fuels "made in Colombia" by demand type



	2030	2040	2050
Bunkering	31	478	657
Local industry	7	56	188
Export	11,976	26,333	58,214

Source: World Bank.

2.2.3 Supply analysis

To assess the technical and financial viability of the project setups, the analysis assumed large-scale designs with an annual output of approximately 50,000 tons per year of green hydrogen (t H_2). While there are plans for almost 600 green hydrogen production projects with capacities of more than 50,000 t H_2 per year (IEA, 2025), the largest green hydrogen production currently in operation is Sinopec's "Kuqa" project in Xinjiang, China, which targets 20,000 t H_2 production in 2025. This means that Colombia's project setups currently envisaged here for start operations in the early 2030s can be considered an ambitious interim target on the country's path towards becoming an important player in the emerging global green hydrogen economy.

The potential output of 50,000 t H_2 per year would allow for an annual production of roughly 300,000 to 400,000 tons of green ammonia or green methanol. In fact, the dominant business opportunity offered by foreign markets to which green hydrogen would possibly be exported is in the form of green ammonia or green methanol. This is thanks to their higher volumetric energy density.[13] This means that they can hold more energy per unit of volume, e.g., liters or cubic meters, which is important for ships where space (cargo) matters much more than weight. Therefore, all project setups were assumed to produce green ammonia or green methanol as main products (with green hydrogen as an intermediary output). This assumption was also in line with shipping's overall preference for derivatives like ammonia and methanol over pure hydrogen, in light of easier storage and/or handling.

Assuming cost-competitive Colombian production at the global scale, each lighthouse investment project's potential production of green hydrogen considered here could easily be absorbed by the large export demand. For instance, while any lighthouse investment project may produce around 50,000 t H_2eq, this would fulfill only 0.7 percent of the European Union's and 1.2 percent of Japan's and South Korea's import demand by 2030, and 0.2 percent of both regions' demand by 2050. In return, the demand for green hydrogen-based shipping fuels in Colombia would initially be quickly satisfied by one single lighthouse investment project becoming operational by the early 2030s (50,000 t H_2eq produced annually vs. 30,700 t H_2eq needed at the four port locations in 2030). Yet, in 2050, estimated demand would significantly outstrip the supply by the four projects considered (4x 50,000 t H_2eq produced vs. 657,000 t H_2eq in demand at the four port locations). This is owing to the stringent policies by the International Maritime Organization to be adopted in autumn 2025, eventually ramping up the demand for zero-carbon bunker fuels globally.

2.2.4 Value chains

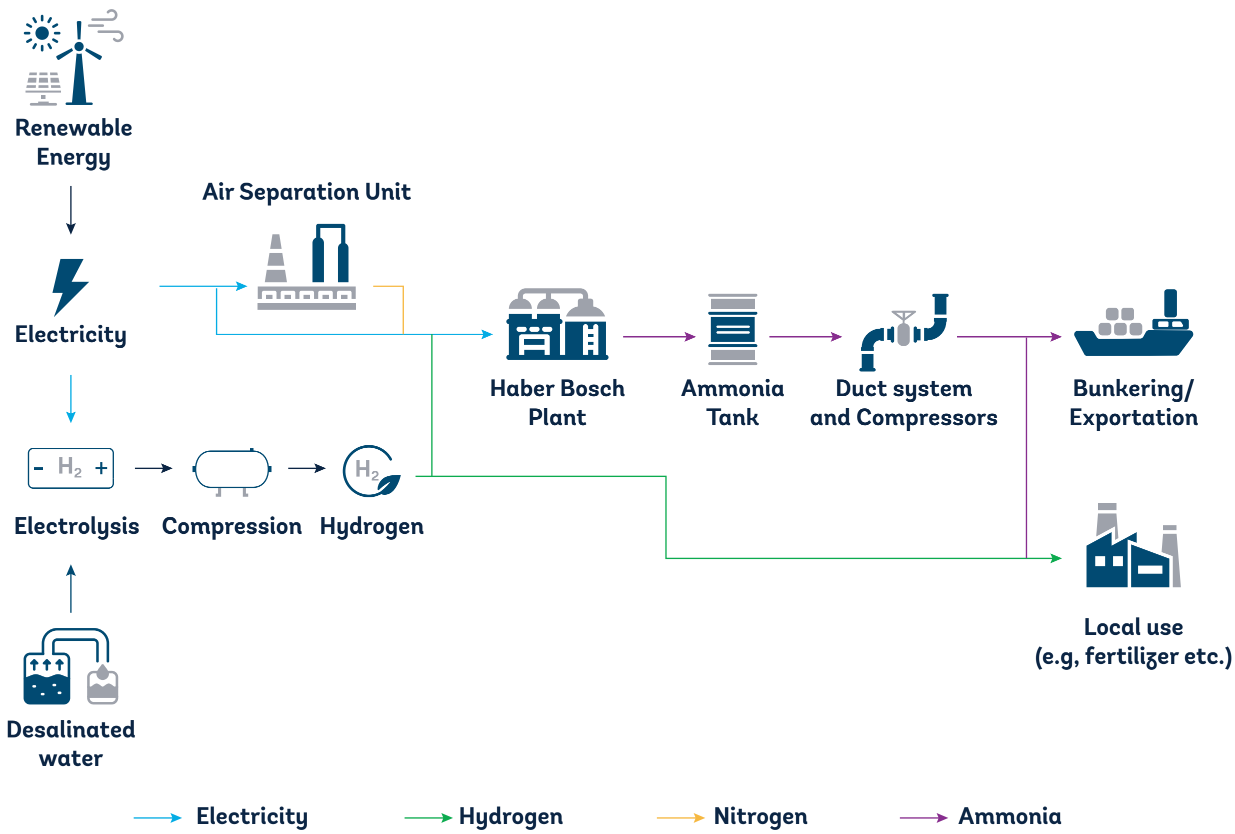
Having gauged supply and demand, the analysis focused on the technical configurations needed for any given green ammonia or green methanol value chain. This analysis included the definition of technical key components and flows of materials to cover the full value chain, from the production of renewable power to the usage of the green molecules, i.e., green hydrogen, green ammonia or green methanol by ships, local industry, and/or export markets. Depending on the choice of ammonia over methanol, or vice versa, the value chain will look slightly different.

[13] Volumetric energy density is different from gravimetric energy density, which relates to the energy content per unit of weight.

Green ammonia value chain

The common value chain of producing green ammonia is a relatively streamlined and well-established process. Although specific local conditions may vary, the value chain for green ammonia follows a relatively standardized production pathway, whose key components and steps are illustrated in Figure 2.9.

Figure 2.9. General value chain for a green ammonia project setup at the port locations



Source: World Bank.

As a first step, producing green ammonia requires the production of green hydrogen. Green hydrogen is produced through electrolysis, a process which splits water into hydrogen (H_2) and oxygen (O_2), using an electric current. This means that any electrolysis requires a constant supply of electricity and water.

In terms of electricity supply, the process requires a lot of electric power. To make the electrolysis process green or zero-carbon, it needs to be powered by renewable electricity—most commonly from wind and solar power. Certification is vital for hydrogen to be recognized as green or zero-emission. For example, the European Union mandates that, for grid-connected projects, at least 90 percent of the electricity sourced from the grid must come from renewable energy sources for the hydrogen produced to qualify as green or renewable hydrogen (EU, 2023). However, so far, Colombia's current power mix consists of 77 percent renewable energy sources (IEA, 2024). This makes it likely that initial projects will be planned off-grid to avoid any compliance issues with the certification requirements of key foreign markets such as the European Union.

In terms of water supply, purified water is needed. This can be either freshwater or desalinated seawater, the latter being very relevant in arid coastal areas which are freshwater constrained. During the electrolysis process, the hydrogen is captured and stored for further use and the oxygen is usually released into the atmosphere.

As a second step, the green hydrogen from electrolysis is combined with nitrogen separated from the air to produce green ammonia. Here, nitrogen (N_2) is first extracted from the air through an air separation unit[14]. Then, the Haber-Bosch process—the primary industrial method for producing ammonia—makes the hydrogen react with the nitrogen at high temperature and pressure to create ammonia (NH_3). To make this process green, it needs to be powered by renewable electricity, too. The resulting ammonia is then collected and stored in specialized tanks, ready for transportation, e.g., by ship.

Green methanol value chain

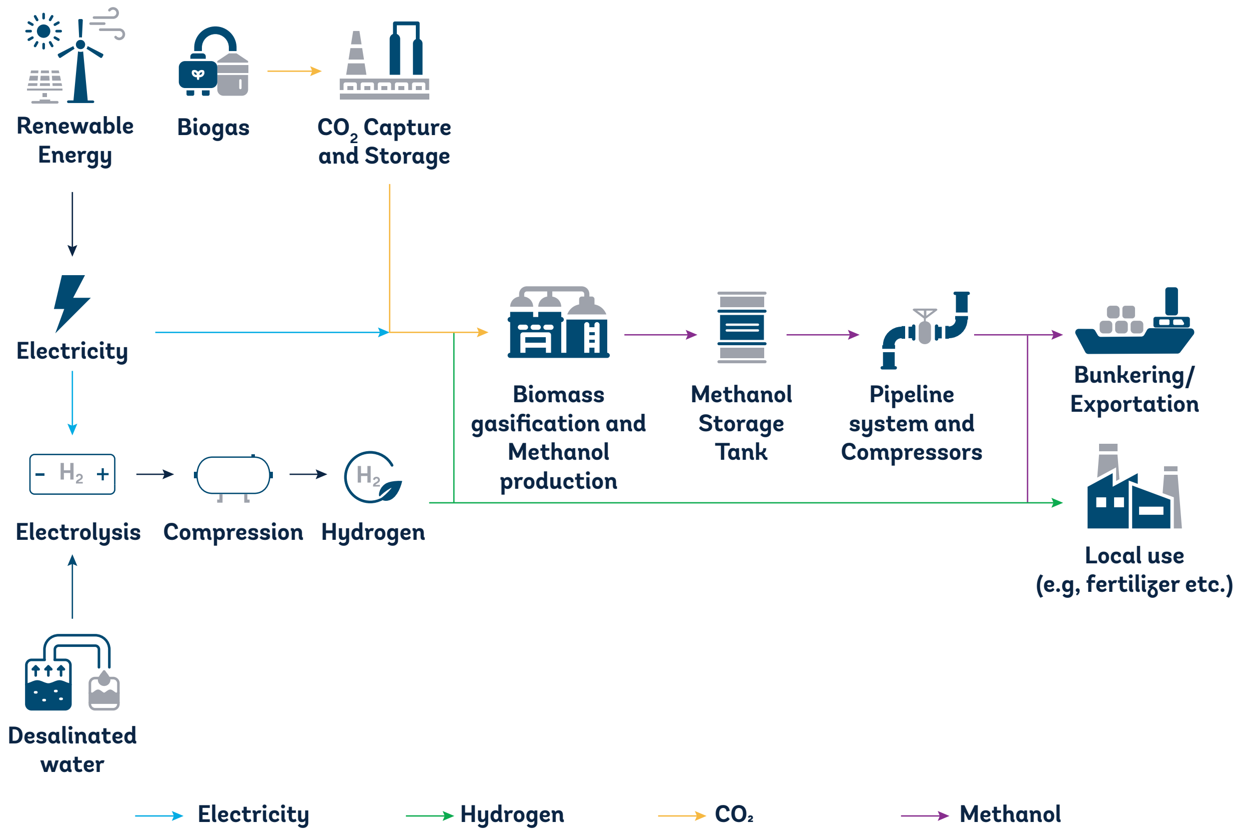
The value chain of producing green methanol is also relatively straightforward, though slightly more complex than producing green ammonia, due to the need for carbon dioxide. In contrast to green ammonia, green methanol can be produced via three pathways:

1. A biological pathway (anerobic digestion of biomass)
2. A thermo-chemical pathway (gasification of biomass)
3. An electrical pathway (power to methanol)

In this analysis, the focus was on the electrical pathway, with some auxiliary support from the thermo-chemical pathway, primarily to provide the indispensable carbon dioxide. The value chain considered in this analysis is illustrated in Figure 2.10.

[14] According to the stoichiometric calculation, it requires 177 kg of H_2 and 824 kg of N_2 for producing one ton of ammonia.

Figure 2.10. General value chain for a green methanol project setup at the port locations



Source: World Bank.

As a first step, producing green methanol via the electrical pathway requires the same green hydrogen as for green ammonia. This means splitting water into hydrogen (H_2) and oxygen (O_2) using electrolysis powered by renewable electricity from wind or solar energy.

As a second step, the green hydrogen from electrolysis is further synthesized with carbon dioxide to produce green methanol. This carbon dioxide synthesis is the main difference to combining green hydrogen with nitrogen, as required for green ammonia. There are two primary sources for the carbon dioxide needed. The first sourcing approach relates to capturing carbon dioxide from exhaust gas emissions from industry such as cement factories, refineries, thermal power plants, and direct air capture. The second sourcing option utilizes biomass gasification to produce so-called synthesis gas or syngas.

Sourcing carbon dioxide from the gasification of biomass is usually preferable over sourcing it from industrial processes. This is because of technical and environmental reasons. First, it is considered superior in terms of efficiency, as the process does not only produce carbon dioxide, but also a limited amount of hydrogen. This reduces the reliance on the main electrolytic hydrogen[15]. Analysis suggests that the absence of any hydrogen from the biomass gasification process may increase the need for electrolyzer capacity by up to 20 percent, thereby raising any green methanol project's overall capital expenditures. Second, green methanol produced through the recycling of industrial carbon dioxide emissions is subject to regulatory restrictions. This limits its consideration as true green methanol from the European Union's import perspective.

Once synthesized, the green methanol is collected, stored, and prepared for transport. After the synthesization process, the green methanol needs to undergo a purification process which eliminates any remaining impurities and excess water. Afterwards, it is stored in specialized tanks and made ready to be transported or loaded onto vessels.

[15] With CO_2 capture from an industrial source such as a cement plant or refinery, 0.19 ton of electrolytical H_2 is required to produce one ton of green methanol. In contrast, with CO_2 from biomass gasification, only 0.06611 ton of electrolytical H_2 will be needed to produce the same amount of methanol. The remaining H_2 would be supplied as a by-product during the biomass gasification.

03

Project Setups

- The analysis identified 18 potential project setups at the port locations of Cartagena, Barranquilla, Puerto Brisa, and Puerto Bolívar, with seven priority project setups retained for detailed technical and financial analysis.
- The analysis optimized these priority project setups for low-cost production efficiency, considering site-specific conditions like renewable energy, water, infrastructure, etc.
- Estimated capital expenditures ranged from US$ 1.6 billion (for green ammonia in Puerto Bolívar NH_3) to US$ 2.7 billion (for green ammonia in Cartagena).
- The financial viability of the priority projects remained highly dependent on the future market prices for green hydrogen-based fuels. These market prices, in turn, are primarily determined by international policy decisions.

As part of the pre-feasibility assessments, the analysis defined a pool of 18 potential project setups across the four shortlisted port locations. The key design options or design trade-offs included:

i. The choice of the end product (green hydrogen, green ammonia, and/or green methanol),

ii. The choice of energy supply (renewables only, power grid, or renewables with grid connection),

iii. The choice of water supply (freshwater or desalinated water), the choice of carbon dioxide source (industrial CO_2 or biomass), and

iv. The choice of energy transport (transport of electrons), i.e., electricity, or transport of molecules (i.e., hydrogen or derivatives).

The full list of these 18 technical project setups can be found in Annex 3.

These potential project setups were then screened against key evaluation criteria to identify those best suited for an even more detailed analysis. While the screening focused primarily on the anticipated levelized cost[16] of the final green molecule to be produced — i.e., green hydrogen, ammonia, or methanol — it also covered additional points for consideration at each port location. These included potential regulatory requirements, social or environmental issues, logistical challenges, and key considerations for entering the European market.[17]

Eventually, the analysis identified seven priority project setups for a final detailed technical and financial analysis. These projects have a target to start commercial operations in 2032, including

i. The production of green ammonia using desalinated seawater (one project at each of the port locations shortlisted),

ii. The production of green methanol using desalinated seawater (one each in Cartagena and Barranquilla, thanks to the abundant availability of biomass for gasification at these sites), and

iii. The production of green ammonia exceptionally using freshwater (one at Puerto Brisa, thanks to the unique fresh water access license at this site).

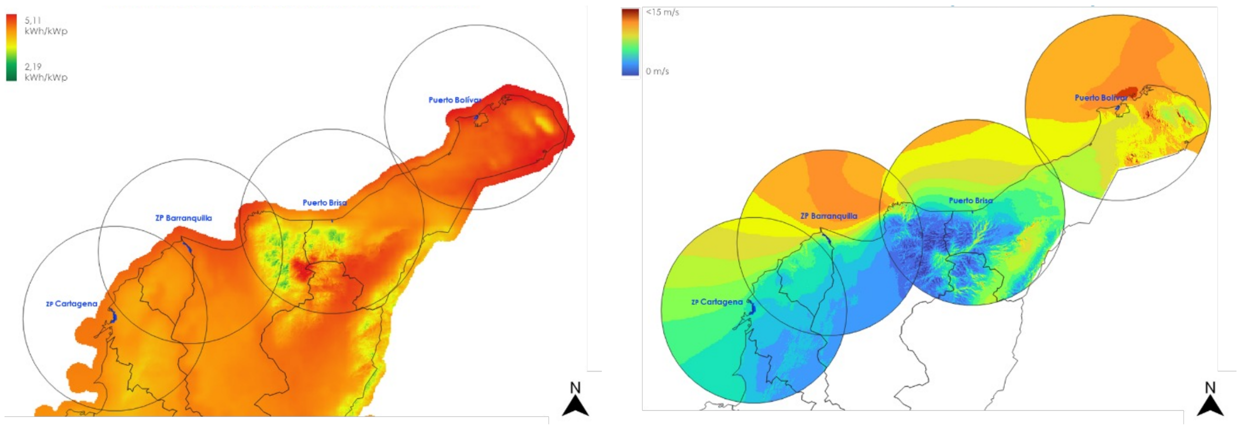
In all setups, the final markets for the molecules to be produced consisted of bunkering, local industry, and exports.

[16] Levelized cost of ammonia or methanol are a measure of the average net present cost of producing ammonia or methanol in US$ per t over the lifetime of a project.

[17] This included, for instance, European regulatory requirements for renewable fuels of non-biological origin.

3.1. Technical analysis

Figure 3.1. Left - Map of solar photovoltaic power generation potential, kWh/kWp per day; Right - Map of wind speeds at a height of 100 meters within a 100-km radius



Source: World Bank, based on Global Solar Atlas, globalsolaratlas.info, and Global Wind Atlas, globalwindatlas.info.
kWh/kWp means kiloWatt hour relative to the kiloWatt peak, or the ratio of energy produced relative to peak power capacity

These seven priority project setups were technically optimized to maximize the production of green hydrogen, green ammonia, or green methanol, while minimizing costs. It is important to remember that the targeted production levels are around 50,000 t H_2 or 300,000-400,000 t NH_3 or MeOH per year. The technical optimization included the strategic combination of the best renewable energy resources, i.e., wind[18] and solar, available within a maximum radius of 100 km. This step is illustrated in Figure 3.1.

Based on this input, the analysis derived a strategic design of the optimal generation capacities to be installed to maximize output and minimize investments. Other criteria such as the exclusion of areas with natural parks or indigenous reservations were also applied. The ideal technical perimeters derived from this optimization process are listed in Table 3.1.

Table 3.1. Optimized technical parameters of the 7 priority project setups

Port location and green target molecule	Photovoltaic solar	Wind	Space required	Annual production	Biomass consumption	Water consumption	Target market
Cartagena NH_3	• Renewable energy: Solar photovoltaic energy • Water: Desalination plant						
	2,308 MW (LF: 20.3%)	--	4,847 ha	377,994 t NH_3/year	--	2,983,329m³ H_2O/year (sea)	Bunkering Local industry Export

[18] For this analysis, only on-shore wind was considered, given the challenges of quantifying the potential and the projected timing of future offshore projects in Colombia.

<table>
<tr><th>Port location and green target molecule</th><th>Photovoltaic solar</th><th>Wind</th><th>Space required</th><th>Annual production</th><th>Biomass consumption</th><th>Water consumption</th><th>Target market</th></tr>
<tr><td rowspan="2">Cartagena
MeOH</td><td colspan="7">• Renewable energy: Solar photovoltaic energy
• Water: Desalination plant
• Biomass: Rice and Oil palm plantation located in the surroundings of the municipality of María La Baja, Bolívar</td></tr>
<tr><td>1,029 MW
(LF: 18.6%)</td><td>--</td><td>2,161 ha</td><td>381,268 t MeOH/ year</td><td>396,519 t biomass/ year</td><td>1,217,359 m^3 H_2O/year (sea)</td><td>Bunkering
Local industry
Export</td></tr>
<tr><td rowspan="2">Barranquilla
NH_3</td><td colspan="7">• Renewable energy: Solar photovoltaic energy and wind energy
• Water: Desalination plant</td></tr>
<tr><td>798 MW
(LF: 20.8%)</td><td>687 MW
(LF: 30.7%)</td><td>18,356 ha</td><td>314,206 t NH_3/year</td><td>--</td><td>2,400,290 m^3 H_2O/year (sea)</td><td>Bunkering
Local industry
Export</td></tr>
<tr><td rowspan="2">Barranquilla
MeOH</td><td colspan="7">• Renewable energy: Solar photovoltaic energy and wind energy
• Water: Desalination plant
• Biomass: Banana, yuca or oil palm, primarily from locations in the north-western part of the department of Magdalena</td></tr>
<tr><td>598 MW
(LF: 20.8%)</td><td>62 MW
(LF: 30.7%)</td><td>2,761 ha</td><td>289,921 t MeOH/ year</td><td>301,517 t biomass/ year</td><td>856,578 m^3 H_2O/year (sea)</td><td>Bunkering
Local industry
Export</td></tr>
<tr><td rowspan="2">Puerto Brisa
NH_3
(Fresh water)</td><td colspan="7">• Renewable energy: Solar photovoltaic energy and wind energy (located 42km northeast of the port area)
• Water: Existing concession authorized by the catchment from the Cañas river</td></tr>
<tr><td>649 MW
(LF: 20.1%)</td><td>654 MW
(LF: 33.7%)</td><td>17,242 ha</td><td>297,199 t NH_3/year</td><td>--</td><td>829,595 m^3 H_2O/year (fresh)t</td><td>Bunkering
Local use (trucks)
Export</td></tr>
<tr><td rowspan="2">Puerto Brisa
NH_3
(Desalination)</td><td colspan="7">• Renewable energy: Solar photovoltaic energy and wind energy (located 42km northeast of the port area)
• Water: Desalination plant</td></tr>
<tr><td>723 MW
(LF: 20.1%)</td><td>607 MW
(LF: 33.7%)</td><td>16,325 ha</td><td>292,432 t NH_3/year</td><td>--</td><td>2,231,490 m^3 H_2O/year (sea)</td><td>Bunkering
Local use (trucks)
Export</td></tr>
</table>

Port location and green target molecule	Photovoltaic solar	Wind	Space required	Annual production	Biomass consumption	Water consumption	Target market
Puerto Bolívar NH_3	• Renewable energy: Solar photovoltaic energy and wind energy • Water: Desalination plant						
	210 MW (LF: 23.3%)	632 MW (LF: 51.2%)	15,786 ha	315,963 t NH_3/year	--	2,370,117 m^3 H_2O/year (sea)	Bunkering Local use (trucks) Export

Source: World Bank. Units are presented as Load Factor (LF), megawatts (MW), and hectares (ha), cubic meter(m^3), respectively.

From a developer and investor perspective, several conclusions which highlight the dependence of each project setup on unique site-specific circumstances can be drawn. Site-specific circumstances for green ammonia or methanol projects are significantly determined by, for instance, the (non-) availability of local biomass, of favorable wind and/or solar conditions, of physical space, or of fresh water at the port location under consideration. Across the seven priority project setups identified, the suggestions from the configuration analysis include:

- Only Cartagena and Barranquilla were identified as suitable locations to produce green methanol. Such green methanol (MeOH) production could be envisaged as an alternative to green ammonia (NH_3) production, which is deemed possible at all four port locations. This exclusive green methanol potential at Cartagena and Barranquilla is mainly due to the local conditions, i.e., availability of biomass as a crucial feedstock input for methanol production within a maximum radius of 100 km. For projects of that size, around 300-400 tons of sustainable and reliable biomass would be required annually. In many locations, this significant supply challenge outweighs the advantage that green methanol projects otherwise offer. This advantage consists of the fact that projects with green methanol projects with biomass gasification usually require a lower amount of electrolytic hydrogen compared to green ammonia projects.
- The more important spatial needs for any green ammonia project — compared to any green methanol project — may pose a barrier at space constrained sites. This larger physical footprint required by ammonia over methanol is due to the increased need for electrolytic hydrogen generation through wind turbines and solar panels. In Barranquilla, for instance, the ammonia project would need approximately 18,300 hectares for the construction of the renewable energy infrastructure alone. Conversely, the alternative methanol project, using biomass gasification for the carbon dioxide supply and taking advantage of the "by-product" that is green hydrogen, would significantly reduce the amount of land required to just 2,761 hectares.
- Cartagena was designed to produce green molecules exclusively using a solar photovoltaic system. This system, working with a larger energy storage than other projects, would operate without any wind power. This is due to Cartagena's limited potential for on-shore wind generation. As a solar photovoltaic energy source can only operate approximately half the day, the solar farm would need to be significantly oversized to generate sufficient renewable electricity. This oversizing of the system could result in additional curtailment (unused energy) of up to 32 percent, depending on the project and the year of operation, when the electrolysis already operates at full load, the battery storage is fully charged, but the solar farm still produces renewable electricity.

- As the only port location, Puerto Brisa could take advantage of an underutilized concession for freshwater use. Despite this unique competitive advantage, an environmentally less intrusive project setup at Puerto Brisa was also taken into consideration. This alternative setup would make use of a seawater desalination plant in the vicinity of the port. In general, it can be expected that the green ammonia project consumes about three times more water (2,300,000 and 3,000,000 m^3 H_2O per year in Barranquilla and Cartagena, respectively) compared to green methanol projects of comparable size (850,000 and 1,250,000 m^3 H_2O per year in Barranquilla and Cartagena, respectively).

In summation, it is essential to consider all these site-specific circumstances not only as technical constraints but also as cost factors. As plant load factors and annual production levels may differ among port locations, it appears important to take into account all these circumstances in one uniform metric. Usually, this is the levelized (production) cost of the main green target molecule, i.e., either green ammonia or green methanol, across various project setups.

3.2. Financial and economic analysis

As a subsequent step, a financial analysis examined all seven priority project setups. To allow a comparison across all project setups, Table 3.2 lists the projects with the estimates of their respective levelized cost of green ammonia (LCOA), levelized cost of green methanol (LCOM), capital expenditures (CAPEX), as well operating expenditures (OPEX).

Table 3.2. Levelized costs, CAPEX and OPEX of each priority project setup

Priority project setup	LCOA [US$/t]	LCOM [US$/t]	CAPEX [MUS$]	OPEX [kUS$/year]
Cartagena NH_3	816	-	2,696	39,525
Cartagena MeOH	-	868	2,258	106,844
Barranquilla NH_3	729	-	1,979	32,014
Barranquilla MeOH	-	836	1,626	80,979
Puerto Brisa NH_3 (Fresh water)	738	-	1,875	31,737
Puerto Brisa NH_3 (Desalination)	734	-	1,890	29,116
Puerto Bolívar NH_3	604	-	1,608	30,458

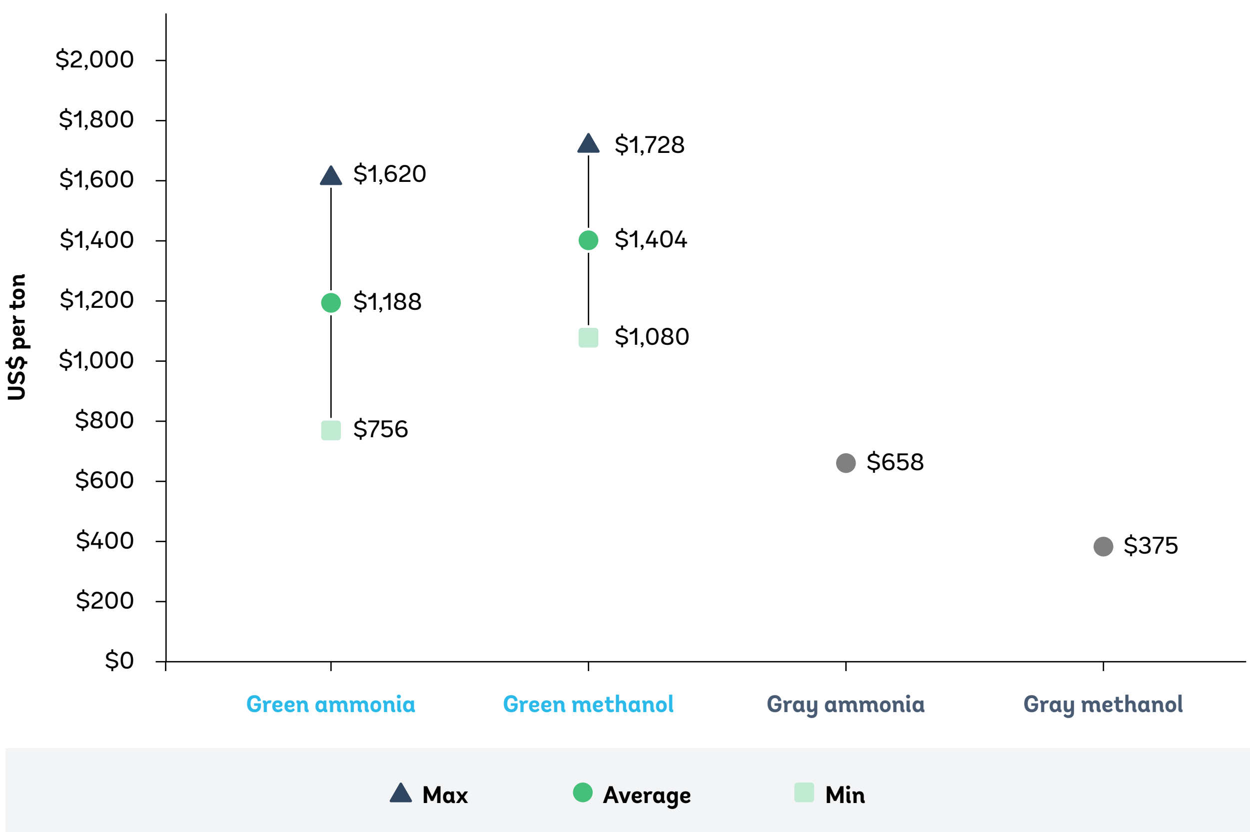
Source: World Bank.
MUS$: Million US dollars.
kUS$/year: Thousand US dollars per year.

In the financial analysis, Puerto Bolívar offers the lowest LCOA, while both Barranquilla and Cartagena offer similar LCOM. The lowest LCOA of around US$ 600 per t NH_3 could likely be achieved at Puerto Bolívar thanks to the outstanding complementary wind and solar energy resources on site. The LCOM at Barranquilla and Cartagena would be relatively similar, both falling into the narrow range of US$ 840 to 870 per t MeOH.

All estimates for the levelized cost of green ammonia or methanol "made in Colombia" at the four port locations can be considered competitive from a global perspective. For instance, Figure 3.2 shows reference prices derived from various willingness-to-pay studies for green ammonia and green methanol in the European Union (Hinicio, 2024), along with a comparison to the actual market prices of their gray counterparts. These benchmark values were cross-checked, for the hydrogen production component against the results of the first Pilot Auction for Renewable Hydrogen in the European Union in 2024. Based on this, the estimated average price for green ammonia was assumed at US$ 1,188 per t NH_3, which is significantly above the LCOA estimated in this analysis. Similarly, green methanol was assumed at an average of US$ 1,404 per t MeOH, also exceeding the LCOM estimated here.

However, two key considerations must be taken into account. First, these reference prices are based on a very limited sample of known green molecule transactions and willingness-to-pay studies, as there is currently no liquid market for green ammonia or green methanol. Second, the market prices of their gray counterparts remain substantially lower, at US$ 658 per t NH_3 (Trade Map, 2024) and US$ 375 MeOH (Bunker Price, 2024), respectively. Still, green ammonia from Puerto Bolívar, the most financially viable priority project in the analysis, could compete with these lower prices for gray ammonia.

Figure 3.2. Comparison of the market prices for green ammonia, green methanol, gray ammonia, and gray methanol



Source: World Bank.

CAPEX

In terms of CAPEX, all priority project setups are relatively capital-intensive, with CAPEX ranging from US$ 1.6 billion to US$ 2.7 billion. The project in Puerto Bolívar would incur the lowest CAPEX of US$ 1.6 billion. This comes from the outstanding renewable energy resources in terms of wind and solar, which allow for the highest full load hours across all projects.

The two projects in Cartagena show the highest CAPEX. This is primarily due to the least favorable wind power resources, mandating an exclusive focus on solar power. For the green ammonia project setup in Cartagena, the largest share of CAPEX would be needed for the solar farm (39 percent or US$ 1,050 million) and the electrolysis (35.3 percent or US$ 951 million). The green methanol project setup in Cartagena would require most CAPEX for the biomass gasification plant (53 percent or US$ 1,208 million), the solar farm (21 percent or US$ 468 million), and the electrolyzer (18 percent or US$ 412 million).

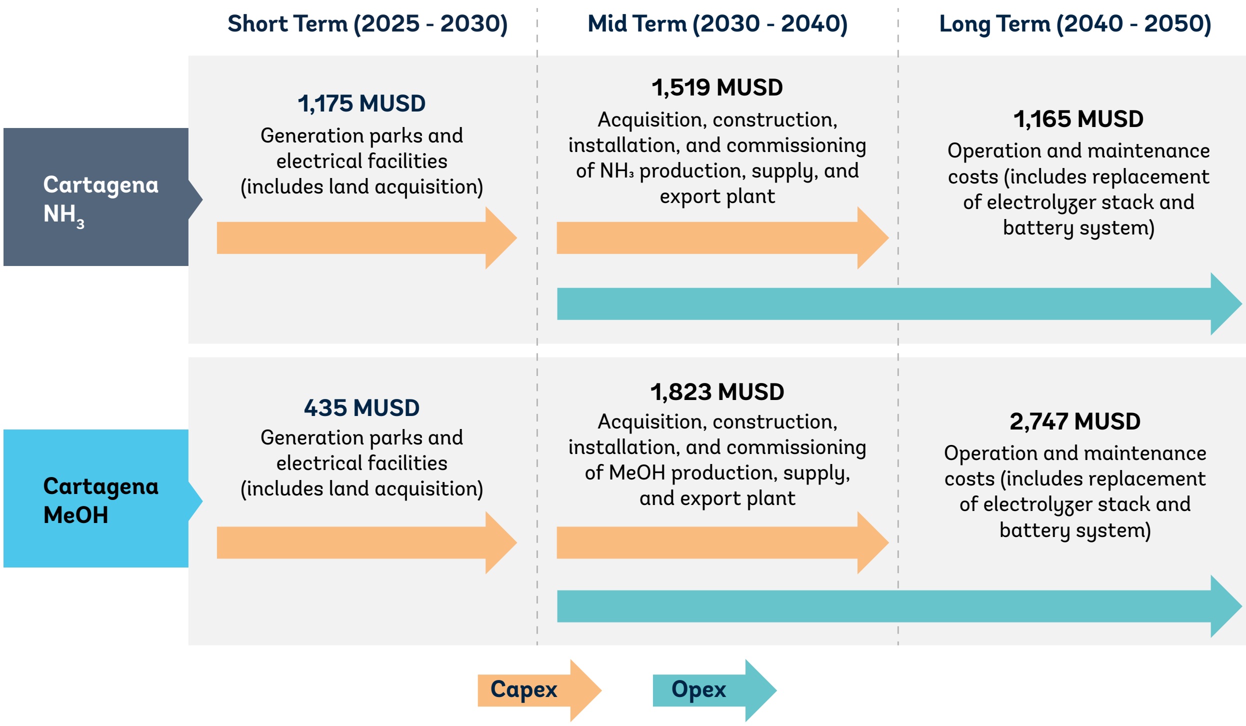
The case of Barranquilla shows a similar picture of CAPEX allocation need. This means that while the green ammonia project setups need most of their CAPEX (>50 percent) for their renewable energy capacity, the green methanol project setups need to dedicate the major share of their CAPEX (>50 percent) to the biomass gasification plant.

OPEX

In terms of OPEX, green ammonia projects turn out to be less costly than green methanol projects. While ammonia projects show relatively similar OPEX, ranging from US$ 29 million to 40 million per year, methanol projects demonstrate much higher annual OPEX of US$ 81 million to 107 million. This difference stems primarily from the higher OPEX required by green methanol projects to ensure the steady supply of biomass and the operation of the methanol synthesis plant.

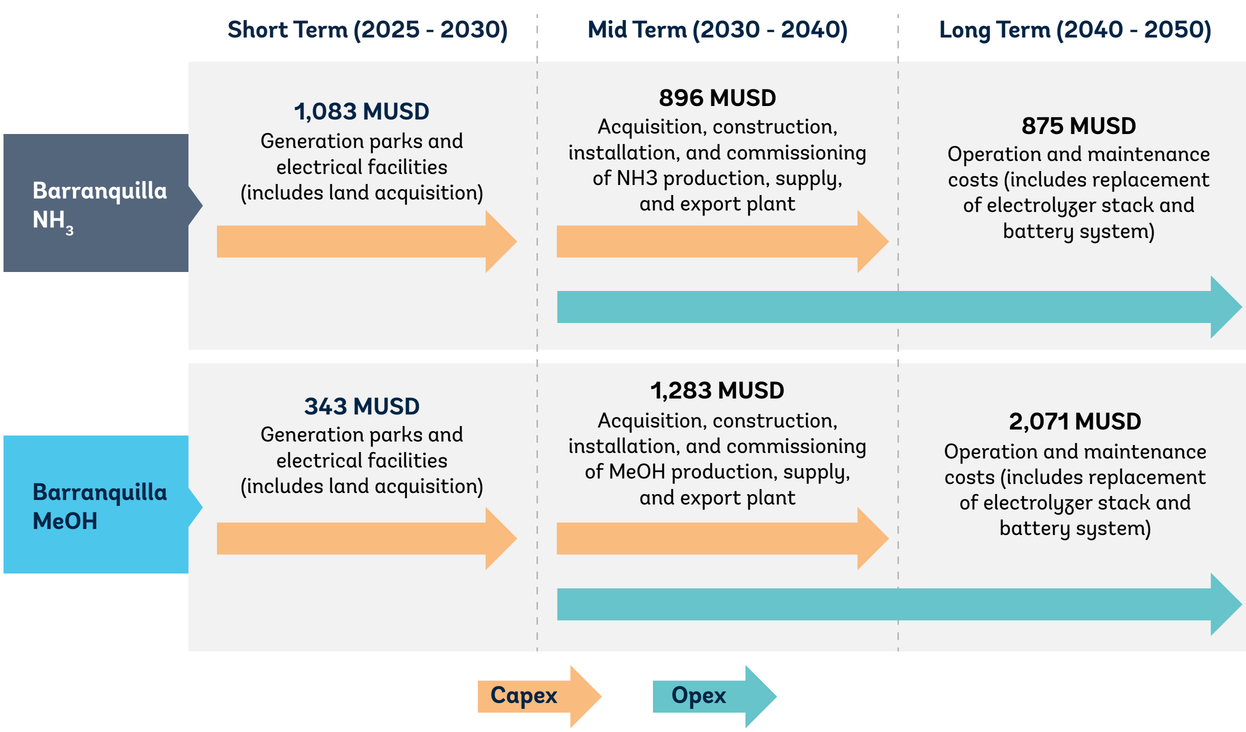
In Barranquilla, the green methanol project setup would require an annual OPEX of around US$ 107 million, with 63 percent needed for the biomass supply and 23 percent for the operation of the biomass gasification plant and methanol reactor. In return, the green ammonia project setup at the same port location would necessitate OPEX of approximately US$ 40 million per year, where operating the wind park (36 percent) and the electrolysis (21 percent) account for the two largest OPEX positions.

Figure 3.3. Overview of CAPEX and OPEX for the two priority projects in Cartagena



Source: World Bank.

Figure 3.4. Overview of CAPEX and OPEX for the two priority projects in Barranquilla



Source: World Bank.

As a result, it can be concluded that green ammonia projects usually face higher CAPEX and lower OPEX, while green methanol projects face lower CAPEX and higher OPEX. This becomes evident where the two project types were considered in parallel at the same port locations, e.g., in Cartagena or Barranquilla. The higher CAPEX requirements by green ammonia usually come from the need for a larger renewable energy production capacity in terms of wind and solar power to produce more electrolytical hydrogen. In return, the higher OPEX of green methanol are due to the need for a steady supply of biomass and the constant operation of the methanol synthesis. These differences are illustrated in Figure 3.3 and Figure 3.4.

Eventually, Colombia's choice of target export markets will also need to consider shipping distance. The transport costs to foreign markets have not yet been taken into account in the current analysis. Shipping costs for ammonia are estimated at around 4 US$ per t NH_3 per 1,000km (Deloitte, 2023) and slightly lower for methanol, at around 2 US$ per t MeOH per 1,000km. However, some studies report a wider range of 4–12 US$ per t NH_3 per 1,000 km, potentially due to the inclusion of port-related costs (Salmon & Bañares-Alcántara, 2021). Despite concerns about transport distance, Colombia's shipping routes to European markets are, for instance, not significantly longer than those from Saudi Arabia, a key competitor. If exporting to Panama, Colombia would not face any transport cost disadvantages compared to neighboring countries such as Costa Rica, Panama or Trinidad and Tobago, while being able to produce green hydrogen-based fuels at a much lower cost.

The financial analysis reveals that in the base scenario sales prices, five out of seven priority project setups would show a positive net present value (NPV). This base scenario assumes average green premium sales prices for the green molecules, a weighted average cost of capital (WACC) of 13.75 percent, and a project lifetime of 25 years, as displayed in Table 3.4.

In this scenario, all project setups except green ammonia production in Cartagena would be at a positive NPV. All other project setups show internal rates of return (IRRs) ranging from 14 percent to 24 percent and payback periods between six and 11 years. The main results of the financial analysis are presented in Table 3.3.

Table 3.3. Comparison of the main results of the financial analysis in the base case scenario

Priority project setup	Net present value (US$)	Internal rate of return	Payback (Years)	Debt-service coverage ratio
Cartagena NH_3	-188,537,829	11.24 %	13	1.25
Cartagena MeOH	320,724,516	19.32 %	8	1.55
Barranquilla NH_3	52,715,867	14.74 %	10	1.38
Barranquilla MeOH	299,273,688	21.07 %	7	1.61
Puerto Brisa NH_3 (Fresh water)	34,422,151	14.43 %	11	1.37
Puerto Brisa NH_3 (Desalinated water)	35,390,963	14.45 %	11	1.37
Puerto Bolívar NH_3	419,753,961	24.24 %	6	1.72

Source: World Bank.

For green ammonia, the priority project setup in Puerto Bolívar shows the best financial results. This is largely due to the world-class renewable energy resources in Eastern La Guajira, which would enable the project to produce green ammonia most cost-effectively, thus yielding the highest profit margins with green premium prices. In general, it can be said that the IRR of the green ammonia projects increases from West to East—thereby correlating with the improving renewable energy conditions from good to excellent.

For green methanol, the priority project setup in Cartagena may be financially slightly more competitive than the one in Barranquilla. The small difference in the results stems primarily from the different market demand potential that each project may meet. Based on the estimates of this analysis, Cartagena could generate approximately 33 percent higher total revenues (around US$ 3 billion) than Barranquilla (around US$ 2.3 billion). This is a result of Cartagena's ability to serve a potentially larger market for bunkering and local industry.

Table 3.4. Key parameters for Scenarios for sensitivity analysis of financial viability

	Optimistic scenario (green vs. green)	Base scenario (green vs. green)	Pessimistic scenario (green vs. green)	Worst-case scenario (green vs. gray)
Sales price assumption	Green molecules can be sold at maximum premium prices	Green molecules can be sold at average premium prices	Green molecules can be sold at minimum premium prices	Green molecules can be sold at prices for gray molecules only
Ammonia sales price per t NH_3	US$ 1,620	US$ 1,188	US$ 756	US$ 658
Methanol sales prices per t MeOH	US$ 1,728	US$ 1,404	US$ 1,080	US$ 375
WACC	13.75% with upwards and downwards variations			
Lifetime	25 years, entry into operation in 2032			

Source: World Bank.

Although the LCOA and LCOM of Colombia are relatively competitive compared to other parts of the world, the financial viability heavily relies on the final sales price of the green molecules. The large differences in these prices, e.g., between green molecules and gray molecules, are illustrated again in Table 3.4 and visualized in Figure 3.2. Thus, the question remains whether future markets will sufficiently reward green ammonia or green methanol as green premium products, which can achieve higher prices than their gray competitors. These markets are policy-driven and largely depend on the stringency of climate policies adopted by the European Union, South Korea, and Japan for exports, and the International Maritime Organization for shipping fuels.

The sensitivity analysis also reveals that no project would be financially viable if the green molecules needed to compete directly with their gray counterparts. If the "made in Colombia" green ammonia or green methanol could not be sold at premium prices thanks to their intrinsic decarbonization value, but would need to be sold at current market prices for the same molecules produced with fossil fuels, then all priority project setups would become financially unviable. This risk is particularly substantial for methanol, where the price of gray methanol is 73 percent lower than the average premium price of green methanol assumed in the base scenario. Similarly, the price of gray ammonia compared to green ammonia is 55 percent lower.

If the green molecules could be sold at minimum premium prices only—instead of average premium prices, financially unviable projects can be made viable again with support. In the sensitivity analysis, the minimum premium prices for green molecules were set at US$ 756 per t NH_3 and US$ 1,080 per t MeOH. Under these low premium prices, all projects show a negative NPV. Yet, some of them can become financially viable again—mostly with a lowered WACC. For instance, even under minimum premium prices, green methanol from Cartagena and Barranquilla would show a positive NPV if the WACC could be decreased from 13.75 percent to 10 percent (or if sales prices increased by 1 percent annually). Similarly, for green ammonia in Puerto Bolívar, under minimum premium prices, a positive NPV could still be achievable if the WACC was lowered to 10 percent.

Alternatively, the financial viability of the priority project setups could be restored through subsidies to the CAPEX. Assuming that the green molecules could only be sold at minimum premium prices, CAPEX subsidies could make the difference. For the green ammonia projects, these subsidies would need to range from 23 percent in Puerto Bolívar to 44 percent—the worst case—in Cartagena. For the green methanol projects, subsidies of 16 percent to 18 percent would be sufficient to make the projects financially viable again. These subsidy levels would obviously need to be justified by the expected socio-environmental benefits.

Additional options can improve the financial viability of the priority project setups under consideration.

First, additional revenues could be generated if the commercialized surplus energy from the projects, which is not needed to produce green molecules, is fed into the power grid. This potential revenue stream as well as the sale of surplus desalinated water have not yet been considered in the financial analysis.

Second, the Law 1715 of 2014 allows for a 50 percent deduction of total investments from taxable income. While this does not affect the project's cashflow, NPV and IRR directly, it still improves the shareholders' cashflow, thereby increasing their IRR.

Third, the financial structuring of the projects could be optimized. For instance, involving a development bank, or engaging in a public-private partnership could mobilize concessional finance, improve overall risk allocation, and enhance investment profitability.

Furthermore, Colombia could draw on a variety of support platforms offered by development partners to foster green hydrogen projects in developing countries. The World Bank and other development finance institutions have introduced dedicated technical support and financing mechanisms designed to secure steady, adequate financing over a project's duration. These seem particularly important in cases of fiscal austerity. For example, the 10 Gigawatt (GW) Clean Hydrogen Initiative aims to advance green hydrogen projects ranging from 100 MW to 1 GW to Final Investment Decision in Emerging Markets and Developing Countries by 2030 (World Bank, 2023).

Additionally, the new World Bank's Fondo de Transición Energética envisages combining concessional financing with private capital to mitigate risk and reduce costs in critical energy transition projects in Colombia.

Next to the financial benefits, each priority project setup at the respective port locations is expected to yield socio-economic benefits in terms of economic development, climate action, and support to indigenous communities. In a first step, these socio-economic benefits relate primarily to increased tax revenues, industrial innovation, and employment opportunities in green quality jobs in Colombia. Furthermore, they would be linked to broader climate change mitigation. For instance, if the projects started feeding surplus electricity into the national power grid, this would help decarbonize Colombia's power grid[19].

Finally, surplus electricity from wind parks and solar farms as well as surplus water from desalination plants could be supplied to indigenous communities in energy- and water-constrained areas in La Guajira, improving their livelihoods.

[19] One of the many consequences of an increasing grid decarbonization would be that the national electricity mix would eventually reach 90 percent of renewable energy sources, which would allow the country to produce EU-compatible green hydrogen, ammonia, or methanol directly through grid-connected projects.

04

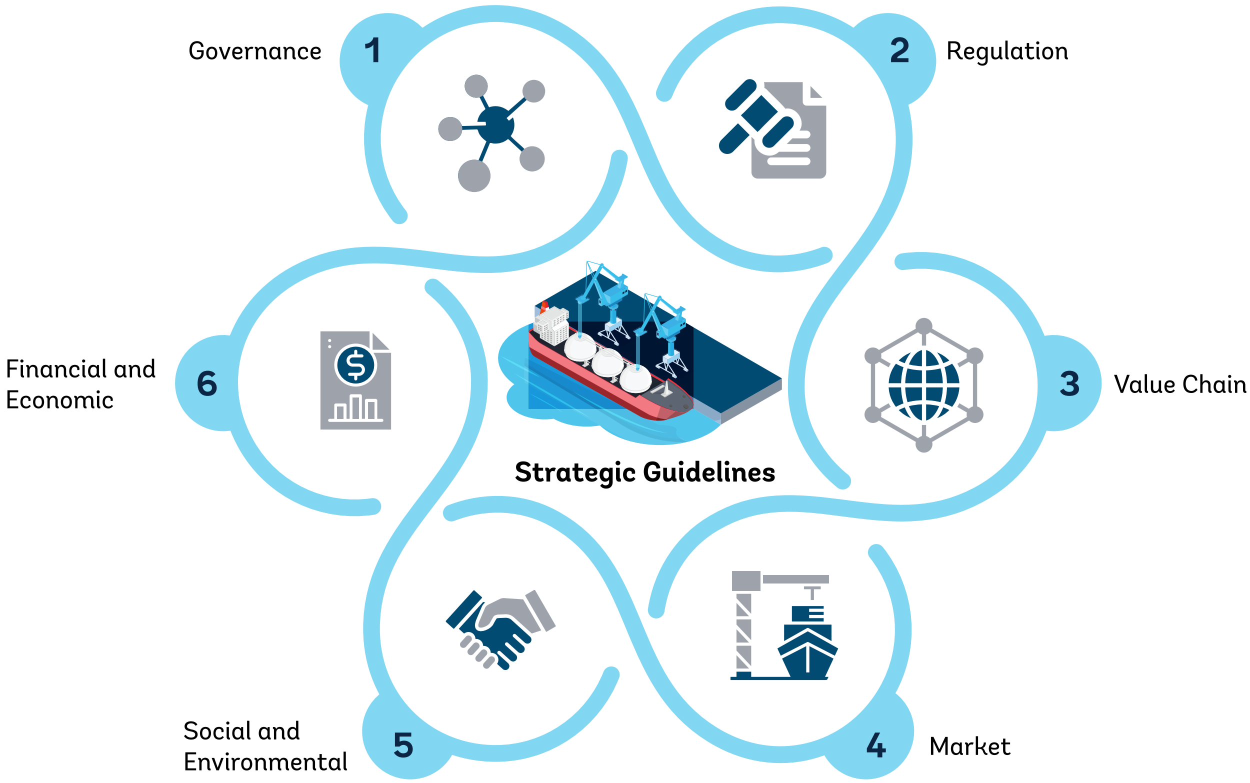
Lighthouse Roadmap

- The goal is to position Colombia as a leading player in the international green hydrogen economy, and develop one or more green ammonia and green methanol projects at the four shortlisted port locations.
- To support this goal, a lighthouse roadmap structured around six strategic axes was developed: (i) Governance, (ii) Regulation, (iii) Value chain, (iv) Market, (v) Social and Environmental, and (vi) Financial and Economic.
- Given the time needed to develop green hydrogen-based value chains and markets at large scale, the lighthouse roadmap distinguished the following timelines in its recommended actions: (i) Short term: 2025-2030; (ii) Medium term: 2031-2040; (iii) Long term: 2041-2050.

Based on the findings from Stage 1 and Stage 2, a lighthouse roadmap was developed to facilitate the positioning of Colombia as a key player in the emerging global green hydrogen economy. This lighthouse roadmap was specifically aimed at supporting the development of one or multiple of the green ammonia and green methanol projects identified at the four shortlisted port locations. This is primarily to contribute to Colombia's economic development in terms of foreign direct investments, green innovation, and job creation. Furthermore, the lighthouse roadmap seeks to support the decarbonization of Colombia's industry, the decarbonization of the maritime transport sector, and further climate change mitigation in industrial sectors of Europe or East Asia.

The lighthouse roadmap applies a framework based on six strategic axes. These six axes are (i) Governance, (ii) Regulation, (iii) Value chain, (iv) Market, (v) Social and Environmental, and (vi) Financial and Economic. The framework is illustrated in Figure 4.1.

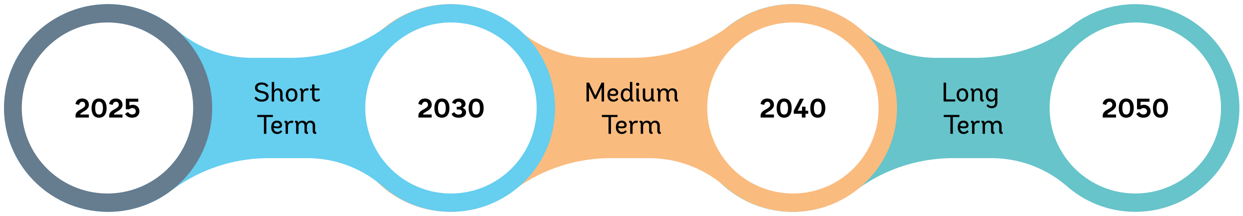
Figure 4.1. Six-axes framework of the lighthouse roadmap



Source: World Bank.

The lighthouse roadmap puts forward recommended actions in a three-phased approach. Given the time needed to develop green hydrogen-based value chains and markets at large scale, the following phases considered are: (i) Short term: 2025-2030; (ii) Medium term: 2031-2040; (iii) Long term: 2041-2050. This timeline is illustrated by Figure 4.2. Based on a gap analysis identifying key challenges, the lighthouse roadmap makes specific recommendations for action.

Figure 4.2. Time frame for recommended actions under the lighthouse roadmap



Source: World Bank.

4.1. Challenges and gaps

Next to these financial and socio-economic benefits discussed above, the development of the priority project setups faces various challenges. A gap analysis was conducted to identify, document, and compile the main challenges to address in the pursuit of developing one or more priority project setups. Many of these challenges are closely linked to the nascent nature of the hydrogen economy. This is a common issue that all countries interested in producing green hydrogen-based fuels are currently facing. Table 4.1 outlines and groups the main challenges or gaps identified which are likely to deserve the most attention in the next steps of project development.

Table 4.1. Main challenges or gaps identified for further project development

Axis	Main challenges or gaps identified
1 Governance	• **Roles, responsibilities and coordination:** Limited clarity regarding the specific roles and responsibilities of public and private entities in developing green hydrogen-based value chains and insufficient coordination by one or few central players that can harness all the individual interests and skills. • **Governmental support:** There is potential for clearer governmental endorsement of and support to specific green hydrogen projects, e.g., by recognizing selected projects as strategic "Projects of National Interest" and/or by strategically aligning updates of the Plan de Ordenamiento Físico Portuario y Ambiental (POFPA) with the national hydrogen economy.
2 Regulation	• **General:** As of today, Colombia lacks an adequate policy and regulatory framework for the safe production, storage, supply, and export of green hydrogen-based fuels in Colombia (as a fuel, not as a feedstock). • **Ports:** Colombia's port regulation misses, so far, the recognition of hydrogen-based fuels as a distinct shipping fuel for bunkering.

Axis	Main challenges or gaps identified
3 Value chain	• **Choice of molecule type:** Uncertainty remains regarding the best type of green molecules (e.g., ammonia or methanol) to be produced at each port location. This primarily depends on commercial (e.g., future sales prices to be achieved) and technical (e.g., availability of biomass) considerations. • **Land availability:** Further analysis is warranted on how much and what kind of land is effectively available at each port location, given the enormous physical footprints required by the renewable power production infrastructure foreseen (particularly where producing green ammonia is planned). • **Port infrastructure:** There is little knowledge yet whether new, specialized port infrastructure for green hydrogen-based fuels may be needed or what existing port infrastructure (e.g., currently used for other fuels or chemicals) could be retrofitted and reused. • **Shared infrastructure:** There is a need for further studies on enabling infrastructure that could be strategically shared by multiple projects (e.g., port infrastructure, desalination plants, pipelines, transmission lines, etc.) to minimize the overall cost of green hydrogen-based fuels. • **Skills and training**: Managing large-scale projects for green hydrogen, ammonia, or methanol will require new skills in the workforce. Thus, there will be demand for new skilled labor, which Colombia's labor market may not be able to fully satisfy yet. This could be addressed through training programs in preparation for more specialized labor at the national level.
4 Market	• **International market development:** Colombia needs to strengthen its strategic engagement and advocacy in key export markets and in some international fora (e.g., at the International Maritime Organization) to foster the emergence of a global market for green hydrogen-based fuels. • **Port infrastructure:** Colombian ports lack adequate infrastructure to accommodate ships bunkering, carrying, and/or transferring hydrogen-based fuels. • **Market research:** More public studies are needed to gauge the demand by specific sectors for green hydrogen-based fuels in specific geographic areas of Colombia. • **Local incentives:** Current policy incentives are insufficient to encourage any local use of green hydrogen-based fuels in Colombia's various industrial sectors.

Axis	Main challenges or gaps identified
5 Social and Environmental	• **Local indigenous communities:** In the past, building trusted relationships with local indigenous communities and socializing the impacts and benefits of renewable power and green hydrogen production have often not been as successful as hoped. • **Sustainable brine management:** There is no clear regulatory framework for the environmental-friendly management of the brine[20] of desalination plants in Colombia yet.
6 Financial and Economic	• **Revenue uncertainty:** The nascent nature of the market is responsible for the lack of transparent and robust price signals. This renders reliable revenue forecasting challenging. The sensitivity analysis revealed that future profitability will be heavily dependent on the sales prices that the green molecules can achieve. • **Additional investments for additional benefits:** Creating additional revenues across the green hydrogen-based value chains envisaged, e.g., through the sale of renewable electricity surplus or desalinated seawater for domestic or industrial consumption, would require further enabling (shared) infrastructure. To unlock these benefits, further investments in (preferably shared) infrastructure would be needed. • **Financing and risk-sharing**: Given the scale of CAPEX estimated, access to existing or new specialized financing or risk-sharing schemes will be required. • **Valuation of port concessions:** There is no clarity—neither for the government nor developers—how future port concessions for the exploitation of green hydrogen-based fuels should be valuated (e.g., based on previous concession valuations or based on a new approach given the novelty of the operation). This makes it difficult for developers to price in the potential costs and for the government to estimate the potential revenues.

Source: World Bank.

4.2. Recommended actions

Following the same 6-axes framework, the lighthouse roadmap puts special emphasis on the creation of an enabling environment for developing green hydrogen-based value chains. In this context, it is important to note that while any further supply- or demand-specific (pre-)feasibility studies can often progress independently their successful advancement towards final investment decision largely hinges on strategic enablers which are often interdependent.

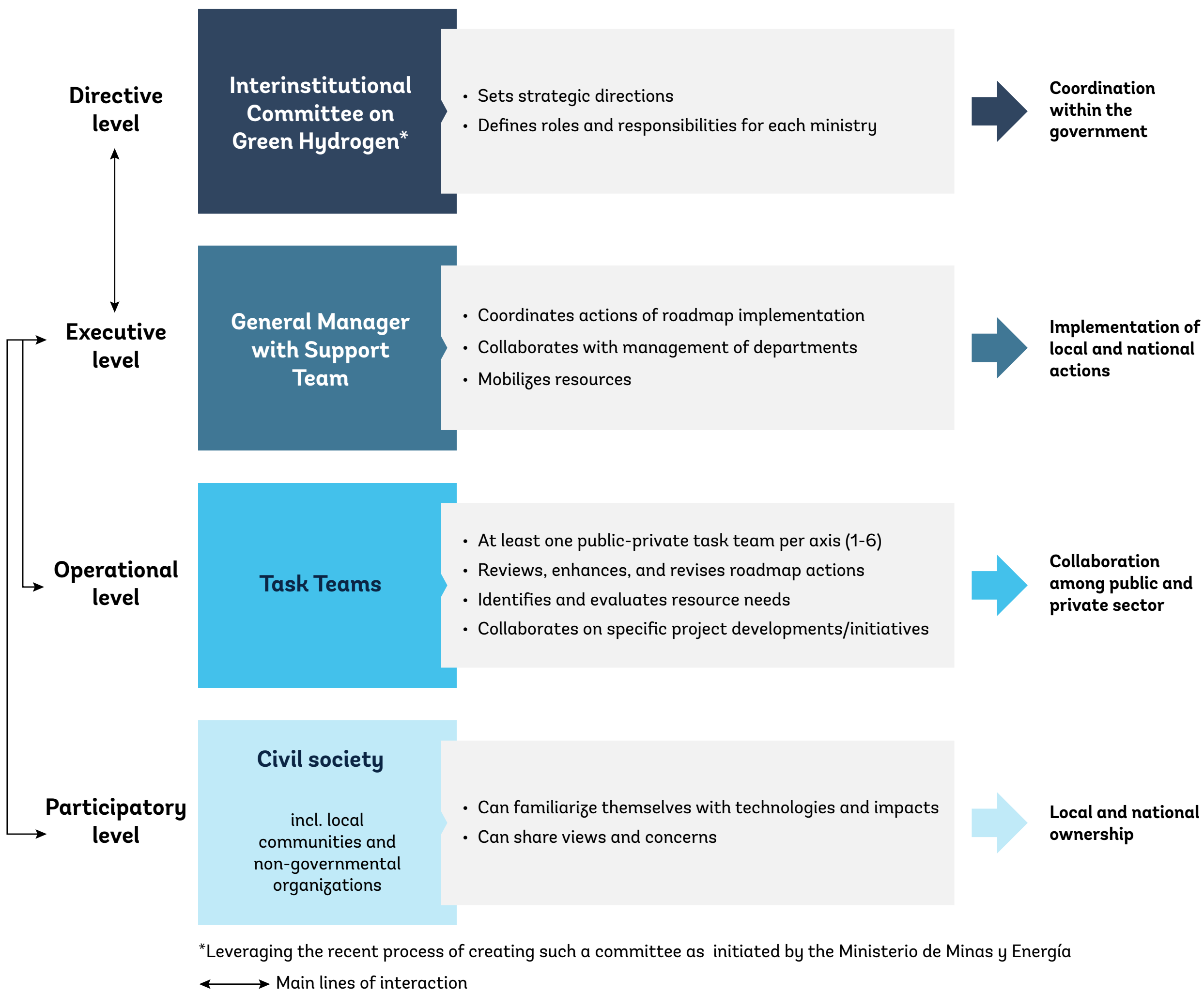
[20] Brine is a concentrated, salty waste product created when seawater is desalinated to produce freshwater.

These are, for instance, Axis 1: Governance, Axis 2: Regulation, Axis 5: Social and Environmental, and to a certain extent, also Axis 6: Financial and Economic. Collectively, their recommended actions are crucial for creating an enabling environment by increasing investment certainty and reducing investment risk. The details of the lighthouse roadmap can be found in Annex 4.

4.2.1 Axis 1: Governance

The lighthouse roadmap proposes to establish a governance mechanism connecting the national government with other key players. These other key players include, for instance, the departmental governments of Bolívar, Atlántico, Magdalena, and La Guajira, along with potentially catalytical private sector actors such as Ecopetrol. This intensified exchange aims to advance the priority project setups at the four port locations in a more collaborative manner. A potential structure of this governance mechanism is illustrated in Figure 4.3.

Figure 4.3. Potential structure for governance mechanism



Source: World Bank.

It seems an opportune time to further pursue the development of at least one green ammonia and one green methanol project, designating them as "Projects of National Interest". This would ensure that Colombia strategically advances lighthouse projects to build its future green hydrogen economy and make sure that the country gains experience in both types of green molecules which are deemed crucial for export purposes and ship propulsion. Additionally, these and potentially other projects would benefit from being designated as strategic "Projects of National Interest" by 2026.

4.2.2 Axis 2: Regulation

This axis primarily targets the development of a transparent regulatory framework for green hydrogen-based fuels, as well as the adjustment of future port concession agreements and business models.

- **Developing a regulatory framework**: Ministerio de Minas y Energía (Ministry of Mines and Energy), Ministerio De Transporte (Ministry of Transport), Ministerio de Ambiente y Desarrollo Sostenible (Ministry of Environment and Sustainable Development), along with DIMAR, should establish a comprehensive regulatory framework for green hydrogen-based fuels. This framework is to set technical standards (e.g., safety, environment, etc.) for "made in Colombia" green hydrogen-based fuels across their full value chain.
- **Recognizing hydrogen-based fuels as new fuel and cargo type:** Although already recognized as an energy vector[21], hydrogen and its derivatives still lack the necessary fuel and cargo classification. Thus, it is crucial to categorize these green molecules officially as a fuel for zero-carbon ships or new cargo type for export purposes.
- **Updating/modifying port concession contracts:** Governed by Law 1 of 1991, port concession contracts in Colombia last up to 30 years and include the option of extension. Several contracts will expire soon, making it unattractive for ports to invest in green hydrogen-based fuel projects under the current terms. Updating the terms governing these contracts, by including the authorization to deal with hydrogen-based fuels, is essential to provide an incentive for ports interested in becoming part of the value chain.
- **Considering public-private partnerships (PPPs) in ports:** Properly financing green hydrogen projects is a critical success factor, requiring proper risk-sharing among stakeholders. The Colombian port sector primarily operates under a public works scheme.[22] The potential for PPPs, commonly used in other sectors like public transport or road infrastructure, remains largely untapped in the port sector. Analyzing the legal and practical feasibility of implementing PPPs at prioritized ports could allow for new financing and risk-mitigation approaches.

[21] This applies to green and blue (derived from natural gas in conjunction with carbon capture and storage) hydrogen only.

[22] This means that the port concession is awarded by a public entity, and the operator of each concession is usually from the private sector.

4.2.3 Axis 3: Value chain

As the priority projects considered target entry into operation by 2032, the following time-critical points should be taken into a consideration:

- **Pursuing continuous project development progress**: The potential projects deemed to move forward should do so in a timely manner, from current pre-feasibility to feasibility and then to front-end engineering, to be able to reach a financial investment decision towards the end of the 2020s.
- **Developing renewable electricity generation capacity**: It appears important to start any plans for land acquisition for renewable power generation as early as possible. For now, the initial focus should be set on onshore wind and solar photovoltaic systems. While this analysis considered onshore wind development only, offshore wind development should also be taken into consideration in the medium and long term. This would harness the business potential of Colombian ports and the offshore wind energy lighthouse roadmaps and projects currently being developed[23].
- **Ensuring sufficient biomass supply:** As green methanol projects will require a constant supply of biomass, it is important to develop plans for reliable and sustainable biomass. These plans should include improvements to the national practices for biomass collection (e.g., considering more centralized collection to lower collection costs).
- **Planning shared infrastructure:** To minimize overall costs and lower the individual cost per user, it often makes sense to enable multiple projects to benefit from the same shared infrastructure. This related specifically to port infrastructure, desalination plants, pipelines, or transmission lines. Such common-user infrastructure would also allow, the projects to supply local communities in need with clean power (using excess renewable electricity) or fresh water (using excess desalinated seawater). Here, the public sector is ideally positioned to plan and, in many cases, operate such common-user infrastructure—either on its own or through public-private partnerships.
- **Offering training programs:** It appears beneficial to start creating and rolling out training programs related to green hydrogen-based fuels. Such skilling and upskilling initiatives will be needed to prepare the Colombian workforce for the upcoming need for new specialized labor. It will also allow the emerging national green hydrogen economy to unlock its full potential for local job creation.

[23] For instance, see Offshore Wind Energy Lighthouse roadmap presented by the Ministerio de Minas y Energía in 2022.

4.2.4 Axis 4: Market

It appears beneficial to follow a prioritized step-by-step approach in accessing potential markets for "made in Colombia" green hydrogen-based fuels—first the export market, then the bunkering market, then the local industry market.

- **Accessing the export market:** To activate the largest and most attractive market, it is crucial to secure more Memorandums of Understanding and develop more contractual agreements that provide reliable long-term demand for Colombia's green hydrogen-based fuels. By formalizing energy supply contracts with partners like the European Union, Japan, South Korea, Panama, and others, Colombia can gradually establish itself as a regional hub for the supply of green hydrogen-based fuels.
- **Tapping into the bunkering market:** The bunkering market in Colombia consists of both international and domestic demand. For the larger international demand, Colombia can benefit from its own international vessels calling at Colombian ports, as well as from international vessels refueling in Panama, which represents one of the world's largest bunkering hubs. Here, proactive engagement and advocacy in terms of stringent climate policy at the International Maritime Organization—e.g., in the form of an ambitious GHG fuel standard and a meaningful carbon price for shipping fuels—can strategically shape the future level of demand. For the domestic demand, a regulatory framework that sets clear decarbonization goals for the national fleet in sectors like fishing, local transport, and tourism is needed, along with incentives to foster related infrastructure development and fuel supply.
- **Developing the local industry market:** Initial public studies to characterize and gauge demand across Colombia's industrial sectors are needed to develop the local market for green hydrogen and its derivatives near ports. Based on the results, policymakers can then set incentives to unlock this local demand. Ports are to examine how to meet that demand through strategic fuel production/procurement, storage, and supply.

4.2.5 Axis 5: Social and environmental

The recommended actions under this axis aim to reconcile the goal of advancing project development while making sure that social and environmental concerns are recognized and addressed.

- **Developing a social participation strategy:** The public sector needs to develop this strategy to bridge gaps among local indigenous communities, especially in terms of access to information on hydrogen technologies and their impacts, human capital development, and integral local development based on democratic participation. To support Colombia's transition to sustainable energy, it is necessary to focus on a community-based approach, promoting inclusion and respecting indigenous heritage. The main goal is to make communities central stakeholders in the project development process.
- **Resourcing the community engagement:** From the outset, the government should lead and allocate proper resources in order to engage with local indigenous communities. This refers, in particular, to facilitating dialogue with communities like the Wayuu in La Guajira, where past governmental efforts have been unsuccessful and private sector efforts have been isolated.

- **Creating environmental standards and guidance:** The government is well advised to create stringent environmental standards and guidance to contain unwanted environmental side effects. This relates, for instance, to environmental impact assessments of how by-products like brine from seawater desalination plants could be managed and disposed in the most environmentally friendly manner.
- **Certifying environmental experts:** In an effort toward standardization and quality assurance, the government should consider developing a certification program for professionals engaging in environmental impact assessments or consultas previas. This would signal to potential developers that the government is committed to facilitate the advancement of the projects to feasibility, design, and investment stages.

4.2.6 Axis 6: Financing and economic

The financial analysis made it clear that high levels of CAPEX, ranging from US$1,600 million (e.g., in Puerto Bolívar) to nearly US$2,700 million (e.g., Cartagena), next to significant OPEX (primarily for green methanol projects), would be needed. Financial resources for these need to be mobilized through special financial mechanisms. The analysis recommends that project developers and the governments explore opportunities such as:

- **Considering a CORFO-like investment fund**: An investment fund similar to Chile's CORFO[24]-led green hydrogen investment fund for catalyzing national green hydrogen projects could be beneficial. This new type of fund allows access to financing that attracts private investment and mitigates risks. This is deemed essential, given the magnitude of CAPEX and OPEX in the long-term.
- **Envisaging public-private partnerships in the hydrogen economy:** In addition, the use of public-private partnerships, regulated in Colombia by Law 1508 of 2014, could be an effective strategy to facilitate financing and distribute risks of building the nascent hydrogen economy. This structured financing approach would allow for initial risk-sharing between the private and public sector, create new alliances between them, and facilitate the inclusion of thematic capital market bonds, ultimately boosting investor confidence.
- **Exploring concessional financing from development partners:** At the multilateral development level, institutions such as the World Bank could offer concessional financing in the form of favorable loans or guarantees for the CAPEX of ammonia projects, where initial CAPEX are relatively high, but long-term OPEX are lower. Methanol projects could benefit from concessional financing from institutions that take a full lifecycle cost-amortization approach. These, and other venues for concessional financing, can be explored through strategic collaboration with initiatives such as the 10 GW Clean Hydrogen Initiative or the new Fondo de Transición Energética for Colombia.

[24] CORFO (Corporación de Fomento de la Producción) is Chile's economic development agency. With the support of American and European development banks, including the World Bank, CORFO developed a fund whose resources are to de-risk national green hydrogen projects. Currently, the fund has a capitalization of US$ 1 billion.

05

Conclusion

- Developing a green hydrogen economy in Colombia is likened to assembling a jigsaw puzzle where some essential pieces can be put in place from a maritime transport perspective.
- Understanding and proactively shaping the future role of shipping and ports will help Colombia position itself as a leader in the global green hydrogen market.

Developing a green hydrogen economy, as in the case of Colombia, can be compared to putting together a jigsaw puzzle. As illustrated in Figure 5.1, many different pieces need to be put together in the right places until a complete picture emerges.

Some of these puzzle pieces are defining the role of shipping and ports, and their place in and their contribution to, future value chains for "made in Colombia" green hydrogen, ammonia, and methanol. Other important pieces may be related to energy, water, land, industry, and so on. All of these need to be aligned by Colombia's evolving Green Hydrogen Roadmap and other guiding strategy documents to build functioning value chains.

Figure 5.1. Jigsaw puzzle metaphor of the green hydrogen economy with missing maritime and non-maritime pieces

Source: Adobe Stock and World Bank.

This analysis takes the first step toward highlighting and outlining the maritime transport decarbonization puzzle pieces in Colombia. It comes to these key conclusions:

1. The decarbonization of maritime transport will depend on green hydrogen-based fuels and the global green hydrogen economy will depend on maritime transport.
2. Seven key investment opportunities for lighthouse green H_2 projects were identified along the Caribbean Coast of Colombia.
3. The largest business opportunities for commercializing green hydrogen-based fuels from these potential projects lie in exporting them to foreign markets, followed by bunkering demand.

4. While being financially viable at average green premium prices, the priority projects' financial availability remains highly sensitive to the future market prices for green hydrogen-based fuels, determined by international policy decisions.

5. Following recommendations from the lighthouse roadmap, the public and private sector alike can maximize the contribution of Colombian ports to a national green hydrogen economy.

Like complex jigsaw puzzles, infrastructure projects take a long time to complete, and preparation should start as early as possible. Long timelines are required to develop large-scale infrastructure projects—especially cross-sectoral ones dealing with energy, transport, water, and agriculture, in parallel. At the same time, potential competition for global market share is emerging in other parts for the world. Thus, it is recommended to the Government of Colombia and private sector players to proactively continue and enhance their strategic efforts to build a national green hydrogen economy that is able to compete internationally. This includes advancing some of the lighthouse investment projects as well as creating the necessary enabling environment by addressing challenges and gaps in areas such as missing regulation, social and environmental issues, and financing options.

Understanding and shaping the puzzle pieces of shipping and ports will help Colombia to position itself as a hydrogen leader in the global market. Taking such a maritime perspective in future analysis and strategy development can allow Colombia to harness its full maritime potential—primarily in shipping and ports, but also in offshore wind, seawater desalination, etc. This approach can benefit sustainable economic development for its people. The World Bank stands ready to continue supporting the Government of Colombia in this regard, and looks forward to jointly completing the country's potential picture of "made in Colombia" green hydrogen-based fuels.

Annex 1. Main stakeholders involved

Public Sector	Private Sector	Academia/Consulting
Corporación Autónoma Regional Del Rio Grande De La Magdalena Cormagdalena	Asociación Colombiana De Hidrogeno	Cenit
Departamento Nacional de Planeación (DNP)*	Asociación Nacional de Empresarios de Colombia (ANDI)	Hinicio
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Cerrejón	Universidad de los Andes
Dirección General Marítima y Portuaria (DIMAR)	Ecopetrol	
Gobernación de Bolívar	Enertrag	
Gobernación del Atlántico	Monómeros	
Ministerio de Transporte	Palermo Sociedad Portuaria S.A.	
Ministerio Minas y Energía	Puerto Brisa	
Superintendencia Financiera de Colombia	Sociedad Portuaria de Puerto Bahía	
Unidad de Planeación de Infraestructura de Transporte (UPIT)	Vopak Colombia	
	Yara	

* Main governmental counterpart in this activity.

Annex 2. Stage 1 high-level assessment evaluation framework

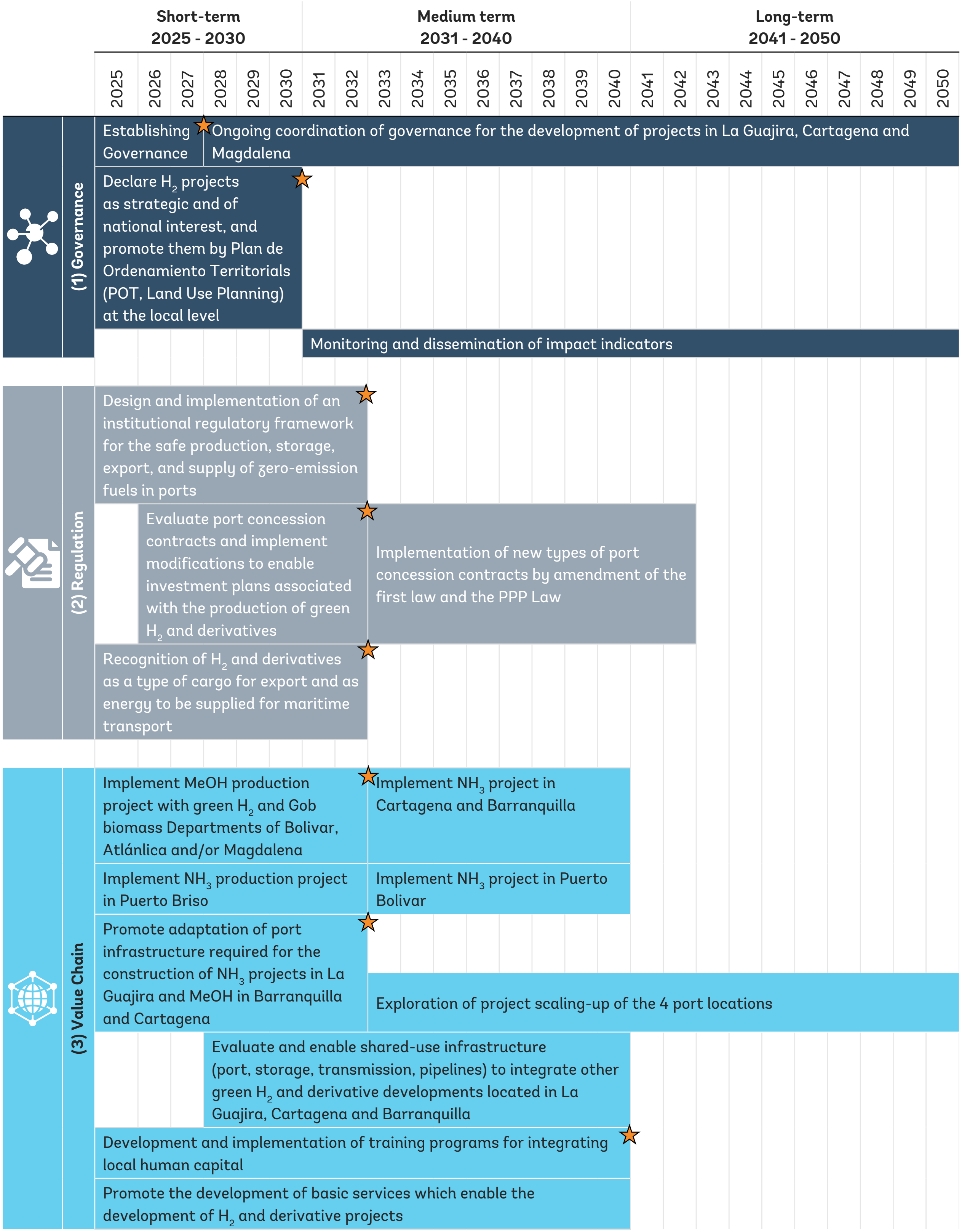
Criteria	Sub-criteria	Weight
C1: Port infrastructure	• Adequate infrastructure to handle draught vessels • Port development or expansion plans • Availability of land to build infrastructure in/near the port area • Potential for handling oversized loads	**15%**
C2: Energy potential and Infrastructure	• Levelized Green Hydrogen Production Costs 2030 • Levelized Green Hydrogen Production Costs 2050 • Water Resources • Existence and proximity of poly, oil or gas pipelines in the vicinity of the port area • Existence and projection of transmission lines • Synergy with renewable energy development	**45%**
C3: Security	• Previous experience in handling chemicals • Infrastructure vulnerability or exposure to climate change • Existence of illegal armed groups • Distance to population centers/safety radius for handling explosive or toxic substances	5%
C4: Financial & Economic	• Foreign direct investment • Local alternative off-takers • Traffic volume • Port offers a free trade zone	15%
C5: Environmental	• Existence and type of license to exploit chemical, petrochemical, or conventional resources • Areas for environmental protection	7.5%
C6: Social	• Orden Social (Social order) • Skilled workforce • Existence of ethnic or protected groups	7.5%
C7: Political	• Institutional performance • Consulta Previa (Prior consultations) related to energy projects • Consulta Previa (Prior consultations) related to port projects	5%

Annex 3. Detailed design options of 18 project setups

No.	Location	Molecule	Energy Sources	Water Source	Origin of CO_2	Transport of Molecules
1	Cartagena	Ammonia	Renewable Energy + Grid	Fresh water by Pipeline	--	--
2	Cartagena	Ammonia	Renewable Energy	Fresh water by Pipeline	--	--
3	Cartagena	Ammonia	Renewable Energy	Desalinated Water	--	--
4	Cartagena	Ammonia	Renewable Energy (transported to the port area)	Desalinated Water	--	--
5	Cartagena	Methanol	Renewable Energy	Fresh water by Pipeline	Biomass	--
6	Cartagena	Methanol	Renewable Energy	Fresh water by Pipeline	Industrial CO_2	--
7	Barranquilla	Ammonia	Renewable Energy + Grid	Fresh water by Pipeline	--	--
8	Barranquilla	Ammonia	Renewable Energy Grid (only for ammonia synthesis)	Fresh water by Pipeline	--	--
9	Barranquilla	Ammonia	Renewable Energy	Fresh water by Pipeline	--	--
10	Barranquilla	Ammonia	Renewable Energy + Grid (only for ammonia synthesis in Cartagena)	Fresh water by Pipeline	--	H_2 to Cartagena
11	Barranquilla	Ammonia	Renewable Energy	Fresh water by Pipeline	--	NH_3 to Cartagena
12	Barranquilla	Methanol	Renewable Energy	Fresh water by Pipeline	Biomass	--

No.	Location	Molecule	Energy Sources	Water Source	Origin of CO_2	Transport of Molecules
13	Barranquilla	Methanol	Renewable Energy	Fresh water by Pipeline	Industrial CO_2	--
14	Puerto Brisa	Ammonia	Renewable Energy + Grid	River Water	--	--
15	Puerto Brisa	Ammonia	Renewable Energy	River Water	--	--
16	Puerto Brisa	Ammonia	Renewable Energy (includes a solar farm installed directly at Puerto Brisa's facilities, but the wind park remains at its original location)	Desalinated Water	--	--
17	Puerto Bolívar	Ammonia	Renewable Energy	Fresh water by Pipeline	--	--
18	Puerto Bolívar	Ammonia	Renewable Energy	Desalinated Water	--	--

Annex 4. Details of the lighthouse roadmap



★ **Strategic Priority**

Short-term 2025 - 2030 | Medium term 2031 - 2040 | Long-term 2041 - 2050

2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050

(4) Market

- Create and consolidate the export market to Panama and Europe
- Expand the export market to Japan and South Korea
- Evaluate and create the market for the supply of marine fuels based on H_2 and derivatives, cabotage and international
- ★ Positioning Colombia as an energy hub for the supply of marine fuel based on H_2 and derivatives
- Promote domestic use of H_2 and derivatives for the four selected ports ★

(5) Social and Environmental

- Participatory Social Strategy for the Development of Zero Emission Fuel Projects - La Guajira, Cartagena and Barranquilla ★
- Review, update and standardize prior consultation (consulta previa) and environmental licensing processes for H_2 projects and derivatives ★
- Develop a circularity strategy associated with the production value chain of H_2 and derivatives
- Define and implement of good practices for brine management and land use for the development of renewable energy generation parks

(6) Financial and Economic

- Identification of financing schemes, including public participation ★
- Securing resources and attracting investors ★
- Design and creation of a dedicated financing mechanism for zero-emission fuel projects ★
- Creation and Evaluation of a sustainable financing scheme associated with zero-emission fuels
- Analyze and implement incentive schemes to promote the use of H_2 and derivatives in the local market (industry, fertilizers, mobility) for the short and medium term.

★ **Strategic Priority**

References

ANI. (2018). *Más de 70 navieras del mundo llegan a los puertos colombianos*. Retrieved from https://www.ani.gov.co/mas-de-70-navieras-del-mundo-llegan-los-puertos-colombianos.

Bunker Price. (2024). *median grey methanol price which was sold in Rotterdam, Singapore and Houston from 2021 to July 2024*. https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#MeOH.

Deloitte. (2023). *Green hydrogen: Energizing the path to net zero*. Deloitte. Retrieved from https://www.deloitte.com/global/en/issues/climate/green-hydrogen.html.

DIAN. (2020). *Estadísticas de Carga de las Importaciones y Exportaciones en Colombia*. Dian. Coordinación de estudios económicos.

DIMAR. (2024). *Contaminación y Emisiones atmosféricas*. Retrieved from Compromiso de Colombia: https://www.dimar.mil.co/proteccion_del_medio_marino/prevencion_de_la_contaminacion_marina/contaminacion_y_emisiones_atmosfericas#:~:text=Espec%C3%ADficamente%2C%20la%20navegaci%C3%B3n%20mar%C3%ADtima%20y,la%20fluvial%20en%20el%20pa%C3%ADs.

DIMAR confidential port data. (2024). *DIMAR confidential port data.*

Energy Sector Management Assistance Program (ESMAP), Organisation for Economic Co-operation and Development (OECD), Global Infrastructure Facility, and Hydrogen Council.. (2024). *Scaling Hydrogen for Development*. https://www.esmap.org/Hydrogen_Financing_for_Development.

EU. (2023). *Commission Delegated Regulation 2023/1184 of 10 February 2023, specifically Article 4*. https://eur-lex.europa.eu/legal-content/ES/TXT/PDF/?uri=CELEX:32023R1184.

Gischler, Christiaan; Boeck Daza, Eric Fernando; Galeano, Paola; Ramírez, Michelle; González, Julián; Cubillos, Fernando; Hartmann, Nuria; Pradelli, Valentina; Márquez, Juan Sebastián; Gutiérrez, Juan Antonio; Juárez Hermosillo, Juan Gerardo; Alonso Rodríguez, Carolina; Souilla, Laura; Rabinovich, Julieta. (2023). *Unlocking Green and Just Hydrogen in Latin America and the Caribbean*. Intra-American Development Bank. doi:http://dx.doi.org/10.18235/0004948.

Hinicio. (2024). *confidential internal data.*

IEA. (2023). *Global Green Hydrogen Review 2023*. https://iea.blob.core.windows.net/assets/ecdfc3bb-d212-4a4c-9ff7-6ce5b1e19cef/GlobalHydrogenReview2023.pdf.

IEA. (2024). Green Hydrogen Review 2024. https://www.iea.org/reports/global-hydrogen-review-2024/hydrogen-demand.

IEA. (2025). *Hydrogen Production and Infrastructure Projects Database*. https://www.iea.org/data-and-statistics/data-product/hydrogen-production-and-infrastructure-projects-database#data-sets.

IMO. (2020). Fourth Greenhouse Gas Study 2020. https://www.imo.org/en/ourwork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

IRENA. (2020). *Scaling Up Renewable Energy Investment in Colombia.*

IRENA. (2022). *Geopolitics of the Energy Transformation: The Hydrogen Factor*. https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen.

Minergia. (2022). *Offshore wind roadmap for Colombia*. https://www.minenergia.gov.co/documents/5859/Colombia_Offshore_Wind_Roadmap_VE_compressed.pdf.

Ministerio de Minas y Energía. (2022). *Hoja de Ruta del Hidrógeno*. https://www.minenergia.gov.co/es/micrositios/enlace-ruta-hidrogeno/.

Panamá, S. N. (2023). *Estrategia Nacional de Hidrógeno Verde y Derivados de Panamá*. Obtenido de https://www.gacetaoficial.gob.pa/pdfTemp/29771_B/98196.pdf.

Procolombia. (2024). *¿Por qué Colombia?* Retrieved from https://compradores.colombiatrade.com.co/por-que-colombia.

Salmon, N., & Bañares-Alcántara, R. (2021). Green ammonia as a spatial energy vector: a review. *Sustainable Energy & Fuels*, 5, 2814-2839. doi:doi.org/10.1039/D1SE00345C.

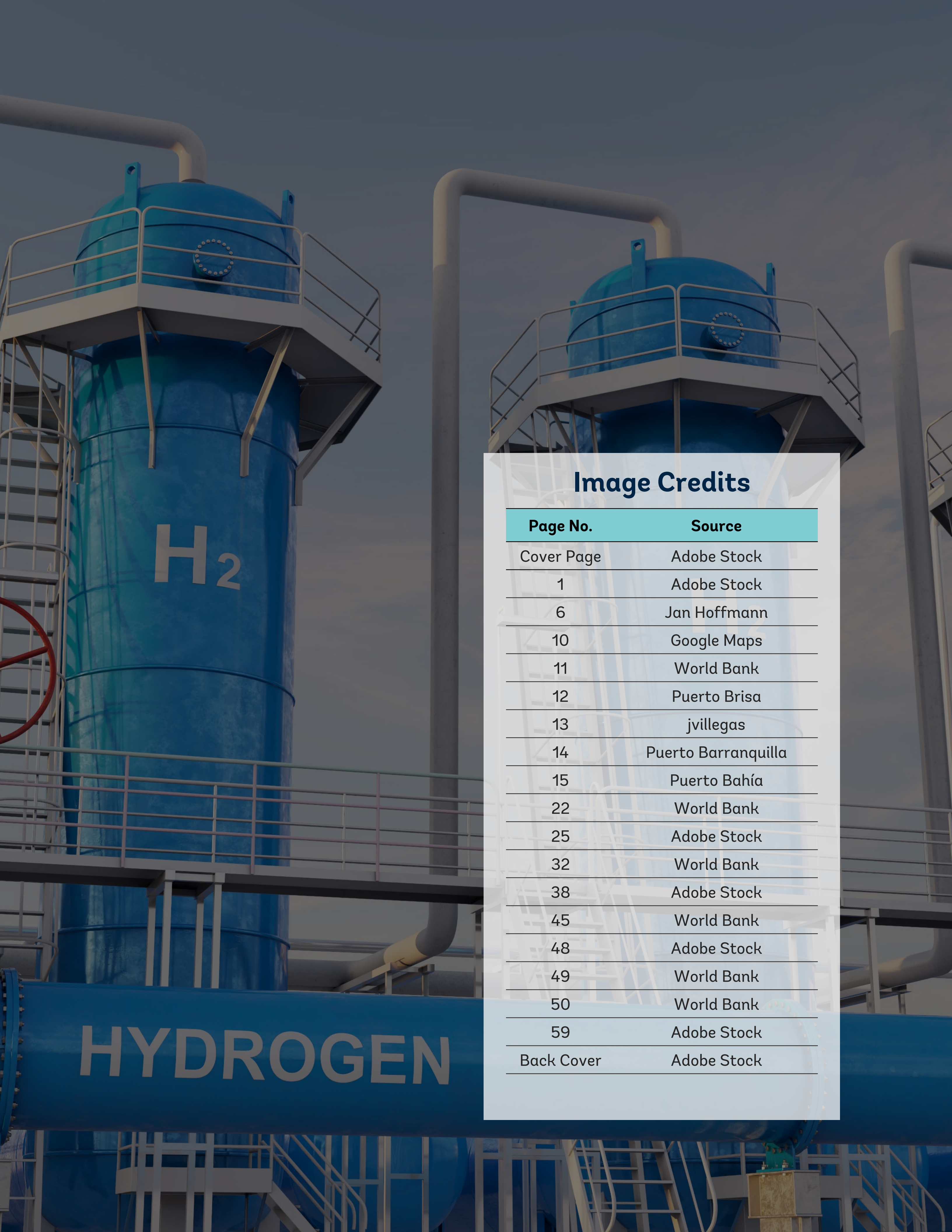
Secretaría de Energía de Panamá. (2024). *Estrategia Nacional de Hidrógeno Verde y Derivados de Panamá*. Retrieved from https://h2lac.org/wp-content/uploads/2024/01/Estrategia-H_2-Verde-PA.pdf.

Supertransporte. (2023). *Trafico Portuario 2022*. Obtenido de https://www.supertransporte.gov.co/documentos/2023/Febrero/Puertos_28/BOLETIN-TRAFICO-PORTUARIO-2022.pdf.

Trade Map. (2024). *Price of Ammonia*. https://www.trademap.org/Country_SelProductCountry_TS.aspx?nvpm=3%7c170%7c%7c%7c%7c2814%7c%7c%7c4%7c1%7c1%7c2%7c2%7c1%7c2%7c3%7c1%7c1.

World Bank. (2021). *Charting a Course for Decarbonizing Maritime Transport (English).* https://documents.worldbank.org/en/publication/documents-reports/documentdetail/680021617997493409.

World Bank. (2023). *World Bank Proposes 10 GW Clean Hydrogen Initiative to Boost Adoption of Low-Carbon Energy*. Obtenido de https://www.worldbank.org/en/news/press-release/2023/11/17/world-bank-proposes-10-gw-clean-hydrogen-initiative-to-boost-adoption-of-low-carbon-energy.



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