International Hydrogen Ramp-up Programme – H2Uppp

GREEN HYDROGEN IN COLOMBIA – MARKET AND REGULATORY STUDY – AKUAIPPAHY PROJECT

Executive Summary: Regulation and Market Component

Federal Ministry
for Economic Affairs
and Energy

VIRIDI

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EXECUTIVE SUMMARY

AkuaippaHy has a credible basis for a large-scale Power-to-X export project in La Guajira. The consultancy assesses the project across three areas: technical, environmental, and regulatory and market. The latter two are covered in this scope, using a preliminary project configuration of approximately 400 MW of electrolysis, 460 MW of wind generation and 540 MWp of solar generation. This configuration results in an indicative production range of 230–270 kt/year of renewable ammonia or 220–250 kt/year of e-methanol. These figures are used as a basis for the regulatory and market assessment and remain subject to confirmation and optimization in the technical study, which will also define the final plant configuration and location.

The market assessment points to Europe as the primary destination for the project, with Germany, the Netherlands and Spain offering the strongest combination of policy support and emerging demand for renewable molecules. Rotterdam, Antwerp-Bruges and Hamburg are particularly relevant as import and distribution hubs, with established links to industrial and maritime consumers. The Caribbean location also provides a relatively favorable shipping position compared with projects further south in Latin America.

Asia provides a second potential market, particularly Japan, South Korea and Singapore. These markets are developing support mechanisms and infrastructure for low-carbon molecules and could provide additional offtake opportunities for both ammonia and e-methanol. Their inclusion in the commercial strategy should, however, take into account longer shipping distances and exposure to Panama Canal transit conditions. The study therefore places Europe first while keeping Asia as a relevant alternative market.

Renewable ammonia currently offers the clearest route to market. Its production technology is mature, international demand is well established and the logistics chain is considerably more developed than that for e-methanol. E-methanol remains commercially attractive, particularly for maritime applications, but the project would first need to secure a reliable supply of certified biogenic CO_2 and meet the associated traceability and carbon accounting requirements.

The commercial assessment indicates potential premium-market price ranges of USD 700–1,100/t for renewable ammonia and USD 900–1,300/t for e-methanol, depending on market and regulatory conditions. These ranges reflect the value that can be obtained in markets where RFNBO (Renewable Fuels of Non-Biological Origin) compliance, CBAM (Carbon Border Adjustment Mechanism), ETS (Emissions Trading System), FuelEU Maritime and other environmental attributes influence the economics of renewable molecules. The key commercial question is how much of this value can be secured through long-term contracts and available support mechanisms.

The economics remain sensitive to the cost gap versus conventional ammonia and methanol. International projects reaching advanced stages have generally relied on a combination of long-term offtake agreements and public or market-based support, including CfDs (Contracts for Difference) and H2Global-type mechanisms. AkuaippaHy will need a comparable revenue structure if it is to achieve the required returns and support project financing.

This is reflected in the current bankability assessment. Firm offtake is the main missing element. The study identifies coverage of approximately 60–70% of project capacity through long-term agreements with creditworthy buyers as a critical condition for financing. Contract tenor, take-or-pay commitments, price indexation, guarantees and alignment with debt tenor will also be important. A 15–20 year offtake period is considered a relevant reference for a Project Finance structure.

The regulatory review has not identified a fundamental regulatory obstacle to the project. Colombia does not yet have a single framework specifically tailored to large-scale Power-to-X (PtX) developments, however, and the project will need to navigate requirements across energy, environmental, industrial, land-use, port and safety regulation. The institutional experience with integrated projects combining renewable generation, electrolysis, chemical production and export infrastructure is also limited. These factors create additional development and scheduling risks.

For La Guajira, territorial and environmental management will require early attention. Land availability is not considered a structural constraint, but land-use requirements, environmental licensing and engagement with Wayúu communities may affect both schedule and cost. These issues should therefore be incorporated into the project development plan from the outset.

The preliminary assessment also indicates that an off-grid configuration with dedicated renewable generation currently provides the strongest basis for demonstrating compliance with RFNBO additionality and traceability requirements. The final configuration, including generation and electrolysis capacity, will be determined through the technical study. That study will also need to confirm the plant location and address the detailed requirements for water supply, desalination and integration of the different process units.

Overall, the regulatory and market assessment supports continued development of AkuaippaHy as a potential export project, while highlighting a limited number of issues that will determine its ability to reach FID (Final Investment Decision). The immediate priorities are to secure strategic offtakers, establish the revenue structure needed to close the economic gap, confirm certification pathways, resolve the CO_2 supply for e-methanol, advance the port and logistics solution, and address regulatory and territorial risks. The technical and environmental workstreams will provide the remaining inputs required to define the project configuration and establish its overall feasibility.

INTRODUCTION

The study comprehensively assessed the market conditions, international competitiveness, market access, bankability, logistics, regulatory framework, and institutional environment required for the development of low-emission e-methanol and ammonia projects aimed at export markets from Colombia.

The analyses conducted indicate that the primary challenge for industrial-scale Power-to-X (PtX) projects lies in structuring projects that simultaneously meet the requirements for market access, international certification, long-term contracting, and bankability demanded by investors and lenders, going far beyond merely ensuring the technological feasibility of hydrogen and derivative production.

Within this context, AkuaippaHy is well positioned to participate in international renewable fuels markets, particularly by leveraging the competitive advantages offered by La Guajira in terms of renewable resource availability, strategic location, and potential integration with export logistics corridors.

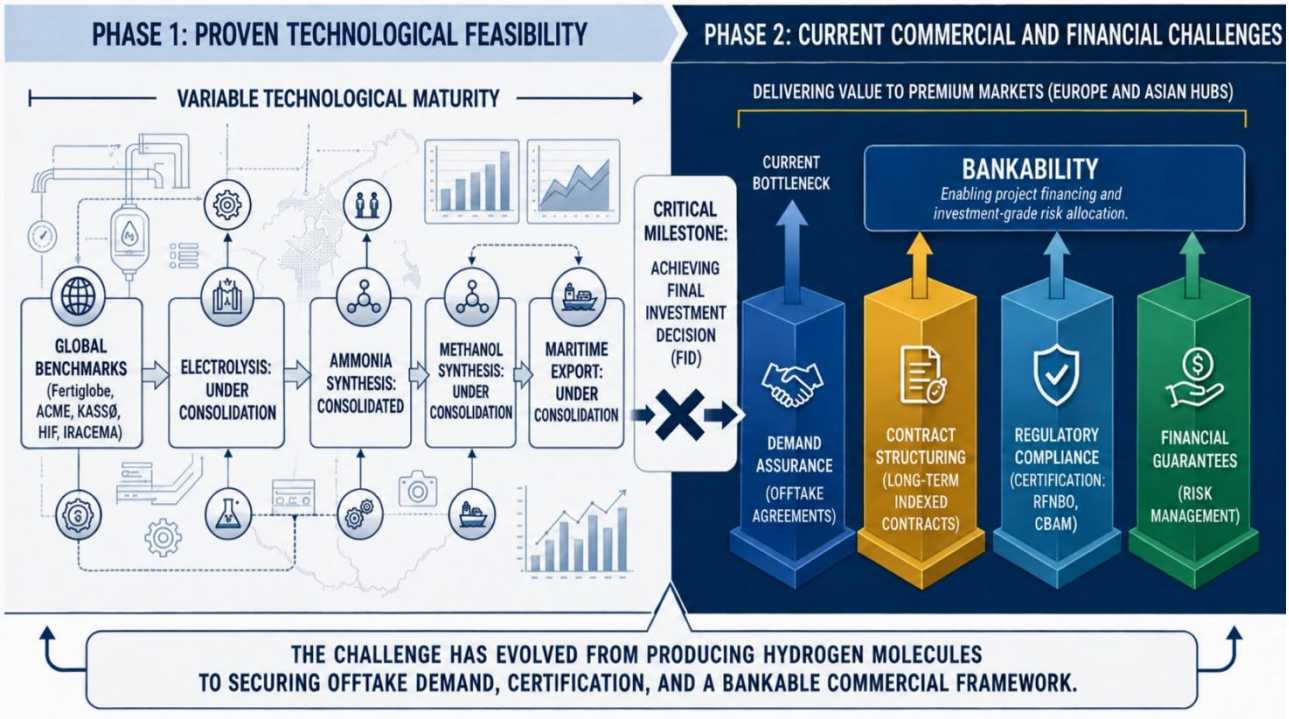


Figure 1. Shift in the bottleneck: from technological feasibility to commercial and financial feasibility.
Source: own elaboration, Óptima Consultores (2026)[1]

[1] he classification is based on the technology readiness levels (TRLs) published by the IEA [16] and the techno-economic study conducted by Fraunhofer ISE [9]. Ammonia synthesis through the Haber-Bosch process has been operating at industrial scale since the 20th century (TRL 9). Alkaline and PEM electrolysis have reached commercial maturity in individual installations of up to 200 MW; however, experience with integrated 400–500 MW projects coupled with the synthesis of derivatives remains limited. Renewable e-methanol production has had its first industrial-scale references since 2025 (reference: the Kassø project in Denmark, with 52 MW of PEM electrolysis and a methanol production capacity of 42 kt/year). Maritime export of conventional ammonia is an established practice, whereas the export of renewable derivatives certified under the RFNBO framework remains in its early commercial stages. It is important to note that technologies are not necessarily mature at every scale, and that the project's main bottleneck has shifted from technology availability toward commercial and financial structuring.

The analysis concludes that the European Union constitutes the priority target market for AkuaippaHy, with an initial focus on the Rotterdam and Antwerp hubs, as it offers the highest degree of regulatory certainty through the RFNBO/RED III (Renewable Energy Directive) framework and the FuelEU Maritime Regulation, the most mature logistics infrastructure for the reception and distribution of renewable molecules, and the most advanced long-term contracting mechanisms to support the Final Investment Decision. Regarding the sequencing of derivatives, the study concludes that renewable ammonia represents the most suitable entry pathway for the project's initial development phase, as it combines greater technological maturity, deeper market demand, existing logistics infrastructure, and lower dependence on external carbon sources, resulting in reduced implementation complexity in the short term. E-methanol emerges as the principal medium-term commercial opportunity, driven by maritime sector demand under FuelEU Maritime; however, its development will depend on the sustainable and traceable availability of biogenic or captured CO_2 within the context of the project.

Alkaline and PEM (Proton Exchange Membrane) electrolysis have reached commercial maturity at the individual project scale, with operational installations of up to 200 MW. Ammonia synthesis using the Haber-Bosch process benefits from decades of established industrial experience at any relevant scale. Renewable e-methanol production has had its first operational industrial-scale references since 2025. Nevertheless, in all three cases, experience with large-scale integrated export projects that combine renewable generation, electrolysis, derivative synthesis, port logistics, and the certification of green attributes under a single financial structure remains nascent. It is precisely this integration that presents the greatest execution challenges [9][16]. The central challenge has therefore shifted toward the ability to structure projects that can demonstrate firm demand, comply with stringent international certification standards, and secure bankable contracts with counterparties of sufficient credit quality.

Core premise of the study

AkuaippaHy
The future competitiveness of PtX projects will not depend exclusively on the availability of renewable resources or on the ability to produce hydrogen at low cost. The decisive factor will be the ability to develop certifiable, marketable and financeable projects, capable of accessing premium markets through long-term contracts, regulatory compliance and risk-mitigation structures compatible with the requirements of international financing.

1 Description of the AkuaippaHy Project

AkuaippaHy is an initiative of Viridi Energías Renovables aimed at producing low-emission e-methanol and ammonia in La Guajira, Colombia, from electrolysis powered by wind and solar energy. Preliminary configurations contemplate approximately 460 MW of wind and 540 MWp of solar capacity, with an estimated electrolysis capacity of around 400 MW, able to produce between 230-270 kt/year of green ammonia (NH_3) or 220-250 kt/yr of e-methanol (CH_3OH). Unlike most domestic initiatives focused on local industrial applications, AkuaippaHy has been conceived from the outset as a platform for the production and export of renewable derivatives, oriented toward international markets with growing requirements for decarbonization, traceability and environmental certification.

Table 1. Description sheet of the AkuaippaHy project

Source: Viridi Energías Renovables Colombia S.A.S. / GIZ H2Uppp (2026). AkuaippaHy project data.

Dimension	Description
Location	La Guajira, Colombia – Caribbean Coast, access to Puerto Bolívar and Puerto Brisa
Energy resource	World-class wind (capacity factor >50%) + hybrid solar photovoltaic
Products	E-methanol (CH_3OH) and Ammonia (NH_3) low-emission
Electrolysis capacity	~400 MW (PEM/ALK), estimated production 230-270 kt/year NH_3 or 220-250 kt/yr e-MeOH
Electrical configuration	Off-grid with dedicated renewable generation (preferred option for RFNBO compliance)
Target markets	European Union (anchor), Asia: Japan, South Korea (expansion)
Developer	Viridi Energías Renovables Colombia S.A.S.
Technical cooperation	GIZ H2Uppp – International Hydrogen Ramp-up Program

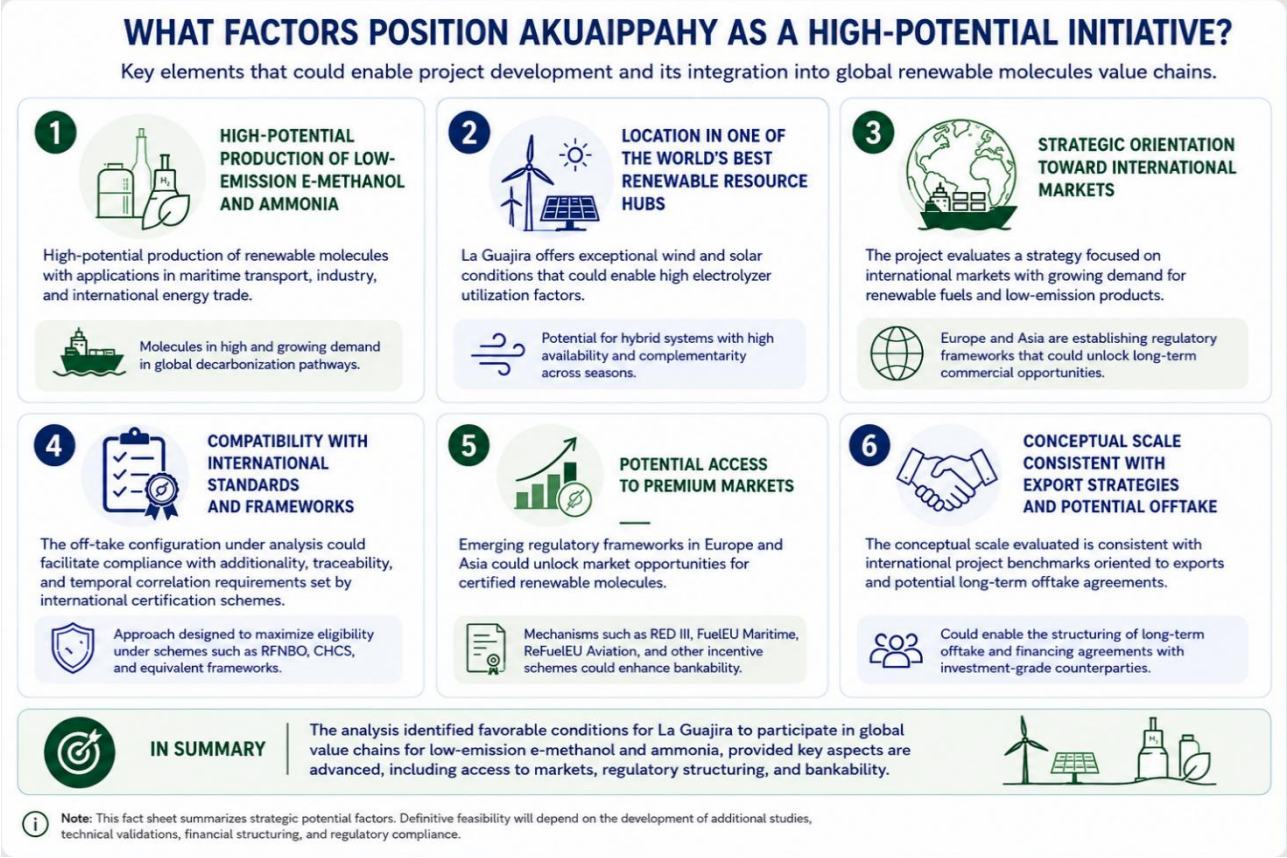


Figure 2. Positioning of AkuaippaHy

Source: own elaboration, Óptima Consultores (2026).

The project's name comes from the Wayuunaiki language, spoken by the Wayúu people who inhabit La Guajira. The territory where the project is located concentrates the best renewable conditions in Latin America, with wind speeds of up to 13 m/s

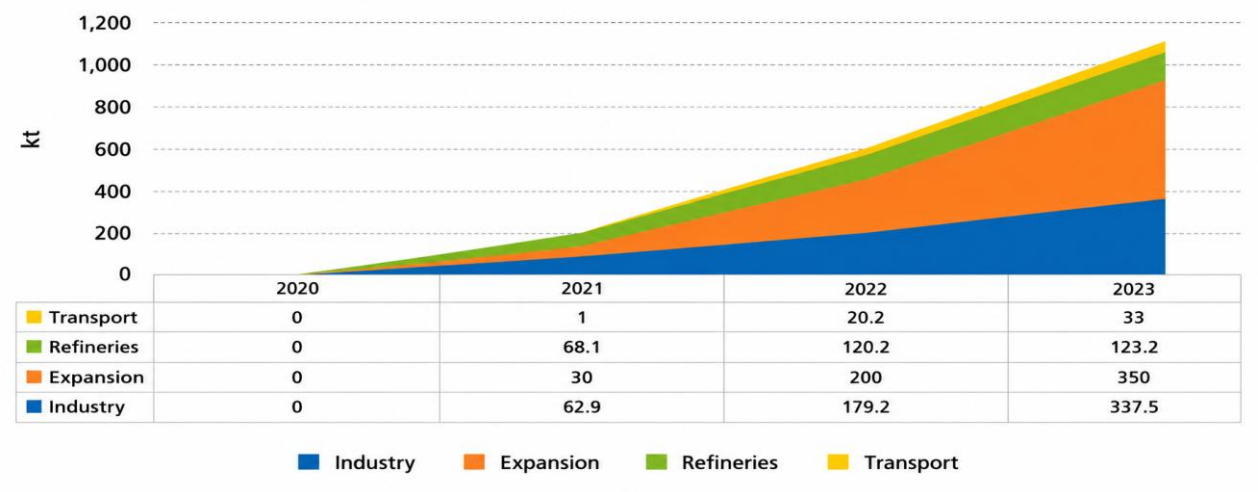
at 100 meters of altitude, wind capacity factors above 50%, and hybrid wind-photovoltaic systems with more than 7,000 hours of annual electrolyzer operation, according to the analysis by Fraunhofer ISE. These conditions allow high electrolysis utilization factors to be reached, improve the competitiveness of the derivatives produced and position La Guajira as one of the territories with the greatest potential to integrate into the global supply chains of renewable synthetic fuels.

The proposed configuration, based on dedicated renewable generation (off-grid), also responds to the need to facilitate compliance with international standards such as RFNBO, particularly regarding additionality, temporal correlation and traceability of the renewable energy used in the production process. In this regard, the project's design seeks not only to optimize technical and economic variables, but also to maximize its eligibility to access premium markets and financing mechanisms associated with the global energy transition.

2 Market Context

2.1 Domestic market for hydrogen and derivatives

Hydrogen production in Colombia has historically been linked to local industrial demand, supplied almost entirely through steam methane reforming (SMR). According to the Just Energy Transition Roadmap of the Ministry of Mines and Energy, national hydrogen demand stood at around 144 kilotons (kt) in 2023, distributed among the refining sector (132 kt), ammonia production (10 kt) and the food industry (1 kt). This figure represented a slight decrease compared to the 150 kt of 2022, explained by natural gas supply shortages. Nevertheless, the market remains concentrated in traditional industrial uses and is limited in scale relative to the production capacity contemplated for export-oriented PtX projects. [5]
The first relevant milestone of the national transition was recorded in 2021, when Yara began hydrogen production at its Cartagena plant, with output of 3.56 kt that year, 20.59 kt in 2022 and 10 kt in 2023. The reduction between 2022 and 2023 illustrates the structural dynamics of the market: when the price of natural gas rises or its availability falls, local hydrogen production loses competitiveness against ammonia imports, leading to the substitution of domestic production with external purchases. This direct relationship between the cost of gas and the volume of derivative imports explains the interannual variations observed and confirms the fragility of the current production model, based on an imported and volatile feedstock. This process marked the beginning of the transition from a market focused exclusively on domestic industrial consumption to an ecosystem oriented toward the development of new value chains associated with renewable fuels and hydrogen derivatives [6]



	2020	2021	2022	2023
Transport	0	1	20.2	33
Refineries	0	68.1	120.2	123.2
Expansion	0	30	200	350
Industry	0	62.9	179.2	337.5

Figure 3. Prospective hydrogen demand in Colombia
Source: Ministry of Mines and Energy of Colombia. Just Energy Transition Roadmap, 2025 [5].

Looking ahead, the Just Energy Transition Roadmap projects significant growth in hydrogen demand in Colombia, with the export component as the main driver. [5]

The projected growth in domestic demand should be interpreted mainly as a signal of market maturation rather than as the main economic driver of large-scale projects. Even under accelerated growth scenarios, most of the demand potential associated with initiatives such as AkuaippaHy lies in international markets, particularly in those where decarbonization is being driven by regulatory instruments specifically targeting renewable fuels.

The figures confirm that the growth in demand is not concentrated in domestic consumption of gaseous hydrogen, but in higher-value-added derivatives oriented toward export. For a project of the scale of AkuaippaHy (with estimated production in the range of 210-270 kt/year of e-methanol or green ammonia), the local market could absorb only a limited fraction of the supply, even under full import-substitution assumptions. The project's commercial feasibility therefore depends on its structural integration into international markets through long-term contracts. This trend is consistent with the evolution observed in the world's leading PtX markets, where renewable e-methanol and ammonia are emerging as the molecules with the greatest potential for commercial scale-up due to their logistical advantages and the growing regulatory pressure to decarbonize hard-to-abate sectors.

Colombia exhibits a structural dependence on ammonia and methanol imports, both used as critical industrial inputs. Yara, the country's only ammonia production plant, has a capacity of 130 kt/year but produced only 83 kt in 2023 due to natural gas supply constraints. To this production, 43 kt of imports were added, sourced mainly from Trinidad and Tobago (around 90%). During 2025, ammonia imports reached 108 kt at an average FOB value of 0.47 USD/kg. It is worth noting that, since 2015, Colombia has imported more than 650 kt of this input. [6]

Methanol, for which there is no domestic production, reached imports of 108 kt in 2023, 112 kt in 2024 and 108 kt in 2025. The origin of supply shows a high concentration in Trinidad and Tobago (historical source of approximately 750 kt since 2015) and the United States (225 kt over the same period), which configures a supply-concentration risk. Methanol is allocated mainly to biofuels (transesterification for biodiesel) and industrial chemical chains, with the three main importers being CI Acepalma (40%), Andino Chemical Colombia (25%) and Interquim S.A.S. (14%), plus Ecopetrol with 11%. [6]

The behavior of prices was particularly revealing, since imported ammonia rose from 0.23 USD/kg in 2021 to around 1.00 USD/kg in 2022, coinciding with the peak of the European energy crisis triggered by the Russia-Ukraine conflict and the collapse of Russian gas supplies, which increased the cost of natural gas (a fundamental input for SMR) on a global scale. This episode highlighted the structural vulnerability of the Colombian market, since its dependence on ammonia imports produced from natural gas exposes it directly to international price shocks and logistical disruptions, opening up economic space for locally produced low-emission energy carriers at more stable costs. [6]

For AkuaippaHy, structural dependence on imports represents a direct opportunity, although not one of securing an anchor offtaker, as discussed later. First, imported volumes (108 kt of ammonia and 107 kt of methanol in 2025) act as a reference ceiling price for assessing the project's competitiveness in the domestic market. Second, the volatility of international prices of fossil derivatives strengthens the value proposition of products with more stable production costs, anchored in renewable energy. Third, supplier concentration (mainly Trinidad and Tobago) introduces a supply risk that a local or regional low-emission alternative could partially mitigate, especially in segments with ESG (Environmental, Social and Governance) or traceability objectives.

The high dependence on imports confirms the existence of consolidated regional demand for these molecules; however, it also shows that the competitiveness of new projects will depend on their ability to compete against international price references set by large-scale producers. Accordingly, the opportunity for projects such as AkuaippaHy lies not only in substituting imports, since it is important to develop differentiated renewable products capable of capturing premiums associated with decarbonization, traceability and regulatory compliance.

The Colombian market provides a positive demand signal and reveals opportunities for partial import substitution; however, the economic scale of AkuaippaHy requires a strategy oriented primarily toward international markets, where demand for renewable e-methanol and ammonia is being driven by regulation, certification and long-term decarbonization targets.



Figure 4. There is a market: demand driven by regulation and decarbonization.

Source: own elaboration based on IEA (2024) [16], IRENA (2022) [17], Ministry of Mines and Energy of Colombia [5] and World Bank (2025) [8].[2]

2.2 National pipeline and project positioning

There are several sources of information showing a set of projects to be developed in the coming years. The most extensive of these comes from the Chamber of Hydrogen and Renewable Gases; however, a significant share of these initiatives consists of pilot, demonstration or early-stage projects. Considering only the projects with the highest level of structuring reported by the Colombian Hydrogen Association and GIZ, the country could reach an aggregate electrolysis capacity of approximately 18.15 GW by 2040, reflecting the growing interest in developing an economy based on hydrogen and renewable molecules. [7]

[2] The figure distinguishes between directly applicable instruments, such as Regulation (EU) 2023/1805 (FuelEU Maritime), Delegated Regulation (EU) 2023/1184 (RFNBOs), and Regulation (EU) 2023/956 (CBAM), and Directive (EU) 2023/2413 (RED III), whose sector-specific obligations regarding the uptake of renewable hydrogen in industry and transport depend on transposition into the national legislation of each Member State. This transposition was still pending in several key countries at the time this study was finalized, introducing uncertainty regarding the timeline for the materialization of part of the projected demand. Certification schemes that verify compliance with RFNBO requirements (ISCC EU (International Sustainability and Carbon Certification), CertifHy, REDcert, Enagás GTS (Gestor Técnico del Sistema), among others) are developed and operated by private and public entities recognized by the European Commission, rather than by the European Union as an institutional entity.

- 10 operational projects, with a combined capacity of 2.64 MW.
- 1 project with FID approved or under construction: Ecopetrol's CORAL project (5 MW), aimed at supplying hydrogen demand at the Cartagena Refinery.
- 17 projects at the feasibility study stage, totaling approximately 8,431 MW of potential capacity.
- 8 projects at the conceptual or early pre-feasibility stage, with potential capacity of approximately 9,717 MW.

The distribution of projects by maturity level shows that the Colombian sector is still in an early phase of development. Although there is a significant volume of announced initiatives, most of the projected capacity remains in feasibility, pre-feasibility or conceptual stages, a situation consistent with the evolution observed in other emerging hydrogen markets internationally.

Among the most advanced projects, PROTIUM (HEVOLUCIÓN) stands out as the country's first industrial-scale project to reach a final investment decision (FID), with 2.3 MW of electrolysis aimed at producing low-emission hydrogen and ammonia for local industrial uses (mobility, fertilizers, food and chemical industries). Although its scale is significantly smaller than that contemplated for export-oriented PtX projects, it constitutes a relevant benchmark for the regulatory, operational and commercial development of low-emission hydrogen in Colombia.

The technology landscape shows a preference for PEM and ALK (Alkaline electrolysis) technologies among the projects that have already defined this aspect, although 60% have yet to do so. In terms of end uses, projects target refineries, biofuels, mobility and ammonia production. This pattern confirms that the Colombian market is currently focused on domestic industrial applications, with still limited participation from projects oriented to the production of renewable derivatives for export.

In this context, AkuaippaHy presents differentiating features within the national pipeline. While most Colombian projects target the supply of domestic demand for hydrogen or ammonia, AkuaippaHy is exploring a strategy based on the production of low-emission e-methanol and ammonia with an export vocation, leveraging La Guajira's competitive advantages in terms of renewable resource quality, geographical location and potential to comply with international certification standards. This approach makes it possible to explore opportunities associated with international markets where demand for renewable molecules is being driven by regulatory instruments, decarbonization targets and long-term contracting schemes.

Differentiated approach

The Colombian pipeline shows growing activity around low-emission hydrogen; however, most initiatives remain focused on domestic industrial applications. AkuaippaHy differentiates itself by exploring a strategy of renewable derivatives production oriented toward international markets, a segment that could become one of the main growth opportunities for Colombia in the global PtX economy.

2.3 Outlook for domestic demand for derivatives

The study analyzing hydrogen derivatives value chains prepared by the World Bank in collaboration with the Ministry of Mines and Energy of Colombia projects the future demand for low-emission ammonia and methanol under three main uses in each case, with high and low scenarios. These projections make it possible to identify, in addition to potential market size, the segments with the greatest adoption and growth capacity for renewable molecules over the coming decades. [8]

For ammonia, the three contemplated uses are: (i) direct fertilizers, with substitution rates of 4-8% in 2030 and 83-93% in 2050, generating demand of 3.8-9.7 kt in 2030 and 114-328 kt in 2050; (ii) urea-import substitution (with an ammonia equivalence of 25% by weight), with demand of 8.6-22 kt in 2030 and 260-748 kt in 2050; and (iii) marine fuel, with substitution rates of 10-15% in 2030 and 56-76% in 2050, and demand of 0.3-1.2 kt in 2030 scaling up to 154-531 kt in 2050. Total demand for low-emission ammonia is estimated at between 13 and 33 kt in 2030, between 103 and 292 kt in 2040, and between 528 and 1,607 kt in 2050. The maritime segment, although small in 2030, shows the steepest growth slope and the highest

willingness to pay, being driven by mandatory regulatory requirements. The analysis shows that, although fertilizers and import substitution represent the main initial drivers of demand, marine fuel concentrates the greatest long-term growth potential due to the increasing regulatory pressure on international transport and the need to reduce emissions in one of the hardest-to-abate sectors. [8]

For methanol, the three projected uses are: (i) biodiesel (65% of non-maritime demand), with substitution rates of 11-15% in 2030 and 48-61% in 2050, generating demand of 9-12 kt in 2030 and 49-57 kt in 2050; (ii) chemical industry (35% of non-maritime demand), with 4-6 kt in 2030 and 24-30 kt in 2050; and (iii) marine fuel, which dominates long-term growth at an annual rate of 10.3%, reaching 1.2-6.7 kt in 2030, 19-90 kt in 2040 and 271-1,041 kt in 2050. Total demand for low-emission methanol will range between 339 and 1,128 kt in 2050, with the maritime segment accounting for more than 80% of this figure. Unlike other industrial uses, the maritime segment emerges as the main structural driver of future demand for low-emission methanol. By 2050, this sector could represent more than 80% of total projected demand, consolidating e-methanol as one of the molecules with the most promising growth prospects within the global energy transition. [8]

Demand projections show a relevant difference between traditional industrial applications and the new markets associated with decarbonization. While conventional sectors evolve gradually, segments linked to maritime transport show significantly higher growth rates, driven by international regulatory frameworks, corporate emission-reduction commitments and climate compliance mechanisms. These dynamics are particularly relevant for export-oriented PtX projects, since they allow capturing markets with a higher willingness to pay for verifiable environmental attributes.

The identified demand can be classified into three time horizons according to its level of market maturity: (i) existing demand (active at the time of the study), corresponding to industrial ammonia consumption in Colombia's agricultural and petrochemical sectors, where partial substitution with renewable ammonia is technically feasible in the short term [8]; (ii) probable medium-term demand (2027–2032), arising from the Colombian petrochemical and chemical industries pursuing decarbonization commitments, as well as export demand from markets with active blending mandates (FuelEU Maritime [28], RFNBO [14]); and (iii) long-term demand (post-2032), encompassing adoption in power generation using ammonia as a backup fuel, decarbonized heavy transport, and exports to markets with mature carbon regulatory frameworks [8] [16] [17]. This distinction is particularly relevant for project structuring, as the offtake agreements required to support the Final Investment Decision should rely primarily on existing and probable demand, while long-term demand should be regarded as the main driver of subsequent project growth.

From a commercial perspective, e-methanol presents additional advantages related to its logistics handling, compatibility with existing infrastructure and growing adoption by international shipping companies. These conditions have allowed it to consolidate as one of the main target molecules in PtX developments currently announced worldwide, particularly those oriented toward the maritime sector

.

Market trends

Domestic demand projections confirm that future growth of renewable derivatives will be concentrated in sectors associated with decarbonization, especially maritime transport. In this context, low-emission e-methanol and ammonia emerge as strategic molecules to serve markets with rapid growth, robust regulatory signals and the capacity to absorb premiums associated with certified renewable fuels.

3 Strategic Hubs for the Development of the PtX Value Chain in Colombia

The logistics hub analysis, carried out in combination with the techno-economic study by Fraunhofer ISE, identifies five zones with differentiated conditions for the development of value chains associated with hydrogen and low-emission derivatives. Beyond the geographical distribution of projects, the analysis makes it possible to understand how different territories could play complementary roles within a future PtX economy, integrating renewable generation, raw-material supply, logistics infrastructure, industrial demand and access to international markets. [9]

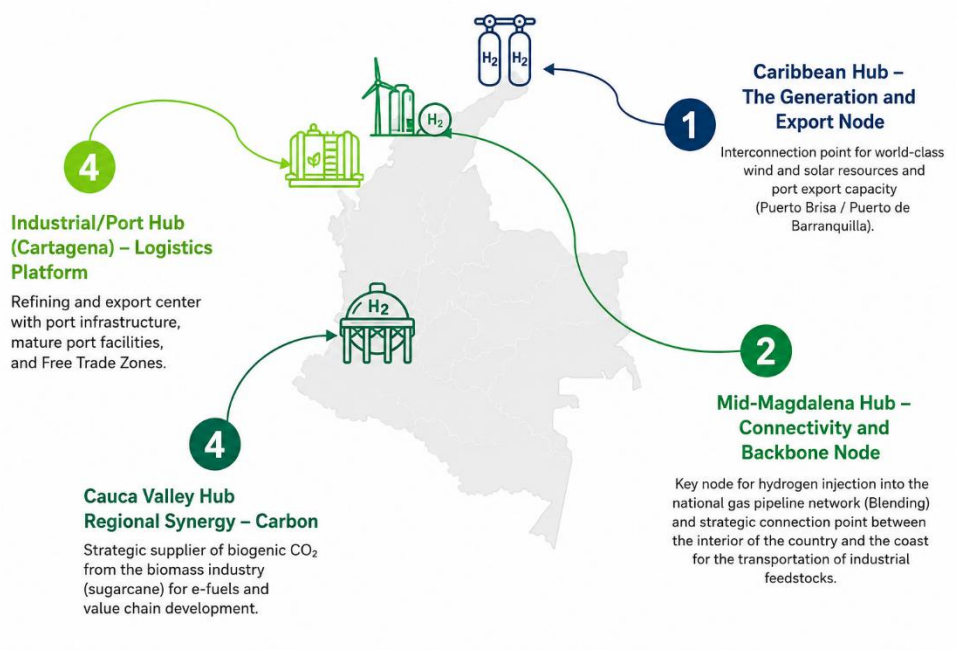


Figure 5. Logistics hubs of Colombia

Source: Fraunhofer ISE. Power-to-X Colombia, 2024 [9]. Own elaboration, Óptima Consultores (2026).

The notion of "hub" is understood as a functional hypothesis for articulating value chains, subject to regulatory, technological, commercial and infrastructural evolution. From this perspective, hubs are no longer interpreted as specific projects, but as potential spaces of convergence between supply, demand and enabling services for the development of renewable molecules.

The analysis shows that the competitive advantages required to develop PtX projects rarely concentrate in a single territory. While some regions stand out for the availability of renewable resources, others contribute port infrastructure, access to industrial markets, availability of biogenic CO_2 or logistical connectivity. Consequently, Colombia's future competitiveness will depend, on both the quality of its energy resources and on its ability to articulate these nodes into integrated, export-oriented value chains.

Integrated approach

Colombia's competitiveness in the global PtX economy will not depend exclusively on the availability of renewable resources. The ability to connect territories specialized in generation, carbon capture, industrial transformation and export logistics will be equally decisive for the development of internationally scaled projects.

3.1 La Guajira Hub (Puerto Bolívar – Puerto Brisa) — Energy pillar

The La Guajira hub is the central, differentiating node of the Colombian green-hydrogen ecosystem. It combines in a single territory four exceptional conditions that are unlikely to be matched in any other location in Latin America: (i) world-class wind resource, with wind speeds of up to 13 m/s at 100 meters height, capacity factors of up to 77% in the municipality of Uribia, and hybrid wind-photovoltaic systems reaching more than 7,000 hours/year of electrolyzer operation; (ii) land availability with identified renewable potential exceeding 95 GW; (iii) deep-water port infrastructure with Puerto Bolívar (depths close to 19 m, capacity above 175,000 tons) and Puerto Brisa (draft of 18.5 m), together with a coastline of approximately 450 km with unprotected zones available for new specialized ports; and (iv) almost exclusive orientation toward

export markets, aligned with the logic of European and Asian market demand. These conditions make La Guajira one of the few territories in Latin America with the potential capacity to develop internationally scaled PtX projects oriented to export markets, combining world-class renewable resources, maritime access and land availability for long-term expansions. [9]

The techno-economic analysis by Fraunhofer ISE positions La Guajira as Colombia's lowest-cost hub for the production and export of hydrogen and its derivatives. For 2030, estimated costs are: LCoPtX of 195 EUR/MWh (1,010 EUR/ton NH_3) for exporting ammonia, 191 EUR/MWh (6,372 EUR/ton LH_2) for hydrogen liquid, and 228 EUR/MWh (1,261 EUR/ton MeOH-DAC) for e-methanol with direct CO_2. Toward 2040, these costs decrease to 147 EUR/MWh (760 EUR/ton NH_3) and 154 EUR/MWh (854 EUR/ton MeOH-DAC), placing the hub within the thresholds of economic feasibility for European markets under RFNBO schemes. These ranges are competitive with global hubs such as Atacama (Chile), Pecém (Brazil), Dakhla (Morocco) and Lüderitz (Namibia). Beyond cost comparisons, these results confirm that La Guajira's potential competitiveness lies within the group of territories currently leading global PtX project development, an indispensable condition for competing in international markets where the final delivered price is a decisive factor for access. [9]

The potential reconversion of Puerto Bolívar (currently the main coal port of Colombia and one of the largest in South America) following the end of the coal concession introduces a strategic energy-transition opportunity, in which the port could shift from a fossil-fuel export node to an e-fuels platform (NH_3, e-MeOH, LH_2), retaining its role in international energy trade. This reconversion is consistent with the global trend of large ports adapting to handle low-emission energy carriers and represents one of the most relevant examples of the transition of fossil-energy infrastructure toward new value chains associated with renewable molecules, a trend currently observed in several international energy ports.

However, the hub faces a structural challenge that defines the maturation sequence of the PtX portfolio, based on the limited local availability of biomass and sources of biogenic CO_2. Unlike hubs such as Valle del Cauca or the Eje Cafetero, La Guajira does not have enough residual biomass to support large-scale e-methanol routes based on local renewable carbon, relying instead on direct CO_2 from air (DAC), which is the highest-cost option, or on logistical interregional schemes that integrate carbon sources from other territories. This condition does not limit the strategic role of La Guajira, but rather suggests a two-phase maturation sequence: the first, with green ammonia as the dominant vector (more direct in production and markets), and the second, with e-methanol as DAC technologies and CO_2 corridors mature. This finding has strategic implications for the project's development sequence. While green ammonia directly leverages La Guajira's main competitive advantage (the availability of renewable resources), the deployment of e-methanol requires simultaneously resolving access to sustainable carbon sources, the associated logistics, and the economic competitiveness of capture routes.

Additionally, the development of the hub must consider social and environmental challenges that differentiate it from other territories. More than half of the population lacks access to a water supply network, only 6 of 15 municipalities have potable water, and approximately 39% of households do not have electricity service. A significant part of the territory falls under Wayúu indigenous reserves, which makes it essential to structure projects with robust prior consultation processes, community participation and benefit-distribution mechanisms. Fraunhofer ISE and GIZ agree that social acceptance is an enabling condition as relevant as the energy resource itself. As a result, the long-term competitiveness of the hub will not depend exclusively on technical or economic variables. The capacity to build stable community relationships, generate shared benefits and consolidate territorial governance schemes will be equally decisive for the materialization of large-scale projects. [9]

Under this logic, La Guajira should be understood not as an isolated hub but as the primary generation point of a broader territorial system, in which different regions contribute infrastructure, markets, industrial capabilities and complementary raw-material sources. This network view is consistent with the way the leading PtX ecosystems are being configured internationally.

La Guajira Hub

La Guajira concentrates the most favorable conditions in Colombia for the development of export-oriented PtX projects. Its main strength lies in the combination of exceptional renewable resources, port infrastructure and scaling potential. Nevertheless, the maturation of e-methanol value chains will require addressing challenges related to sustainable carbon access, logistical integration and socio-territorial management.

3.2 Cartagena – Barranquilla Hub: Transformation and international gateway

The Cartagena–Barranquilla corridor is the main industrial and logistics hub of the Colombian Caribbean, with a consolidated petrochemical and refining base, an export-oriented port system and availability of renewable energy resources. Functionally, it should be understood as a corridor with complementary specializations: Cartagena as the primary node for transformation and international gateway (export, bunkering and advanced derivatives), and Barranquilla as an ammonia and fertilizer hub, with strong industrial demand and river logistics via the Magdalena River. Unlike La Guajira, whose main competitive advantage lies in the availability of renewable resources and generation capacity, the Cartagena–Barranquilla corridor concentrates industrial, logistical and commercial assets that are essential for the development of PtX value chains oriented to transformation, storage, distribution and export. [9]

Current industrial demand in the corridor includes approximately 136,000 tons/year of ammonia and 90,000 tons/year of hydrogen, mainly for the Cartagena Refinery (Reficar) and the Mamonal complex. Puerto Bahía, with only 30% of its area in use, emerges as an optimal point for PtX expansion, supported by its proximity to Reficar and Yara and by Reficar's commitment to support production of up to 440,000 tons/year of green ammonia by 2030. World Bank projections estimate that Cartagena will concentrate 70% of national demand for hydrogen-based marine fuels, reaching 453 kt H_2eq/yr in 2050. These figures position the corridor as one of the main potential centers for the consumption, transformation and marketing of renewable derivatives in Colombia. The concentration of existing industrial demand reduces risks associated with creating markets from scratch and facilitates the progressive build-up of PtX ecosystems around already established industrial players. [9][8]

The techno-economic analysis by Fraunhofer ISE shows competitive costs for the corridor: LCoPtX (Levelized Cost of PtX) of 205 EUR/MWh (1,064 EUR/ton NH_3) in 2040 for exporting ammonia, and 216 EUR/MWh (1,197 EUR/ton MeOH-CPS) for e-methanol with concentrated CO_2 source. These values position the hub as competitive for export to Europe, although strategically its function is transformation, storage, bunkering and gateway to international markets (rather than primary production), complementing the producer role of La Guajira. As a result, the corridor's competitiveness depends on its capacity to add value through port infrastructure, storage, industrial services, logistical integration and access to international markets. This role is consistent with the configuration observed in international hubs such as Rotterdam, Antwerp or Singapore, where the main strength lies in the concentration of infrastructure and industrial activity rather than in the local availability of renewable resources. [9]

In addition, the coexistence of petrochemical infrastructure, refining, fertilizer production and specialized ports makes the Cartagena–Barranquilla corridor a natural platform for the transition to low-emission molecules. This condition allows the use of existing industrial capabilities, reduces requirements for new infrastructure and facilitates the progressive integration of renewable fuels into already consolidated logistics chains.

Cartagena – Barranquilla Hub

Cartagena–Barranquilla is the main industrial and logistics hub of the Colombian PtX ecosystem. Its strategic value does not lie in primary renewable energy generation, but in its capacity to transform, store, consume and export hydrogen derivatives, acting as a bridge between production centers and international markets.

3.3 Other complementary hubs

- Valle del Cauca Hub (Buenaventura): oriented to domestic and industrial consumption; strategic supplier of biogenic CO_2 (sugar-cane residues, approximately 207,000 TJ/yr) and potential logistics node to the Pacific for Asian markets.
- Antioquia Hub: main domestic consumption hub; early validation of RFNBO traceability; logistical access to the Pacific via Puerto Antioquia in Turbo.
- Eje Cafetero Hub: enabler of biogenic CO_2 CO_2 (biomass >15,000 TJ/yr); supplier of critical inputs for the e-methanol route from La Guajira.

Together, these complementary hubs provide capabilities that are not necessarily available in La Guajira, particularly in terms of residual biomass, biogenic CO_2, industrial demand and logistics infrastructure. This reinforces the vision of a territorially articulated PtX value chain, in which different regions perform complementary roles within a national ecosystem of renewable molecules.

3.4 The critical gap for the development of certified renewable molecules

Throughout the territorial analysis carried out for Colombia, favorable conditions were identified for the development of value chains associated with hydrogen and low-emission derivatives. The availability of world-class renewable resources in La Guajira, the existence of industrial and port infrastructure in the Cartagena–Barranquilla corridor, as well as the potential supply of biogenic CO_2 and biomass in other regions of the country, together constitute a relevant competitive base for the development of PtX projects oriented to international markets.

However, the consolidation of these advantages does not depend exclusively on the availability of energy resources or physical infrastructure. The analysis shows that one of Colombia's main challenges is strengthening the mechanisms that allow demonstration, verification and certification of the environmental attributes of the molecules produced, an essential condition for accessing international markets with higher value added.

The target markets identified for AkuaippaHy, particularly in Europe and Asia, increasingly require robust mechanisms for traceability, certification and verification of the renewable origin of the energy used in the production process. Aspects such as additionality of renewable generation, temporal correlation between production and electricity consumption, geographical correlation, and the existence of reliable guarantee-of-origin systems are taking on a central role in project competitiveness.



Figure 6. The real bottleneck for Colombia: certification, traceability and demonstration of green attributes.
Source: own elaboration, Óptima Consultores (2026).

Against this background, the main gap identified relates to the ability to verifiably demonstrate that hydrogen and derivatives comply with the requirements set by international schemes such as RFNBO and other emerging certification systems. The difference is relevant since, while the production of renewable molecules depends mainly on technological and economic variables, access to premium markets depends on the existence of reliable accreditation and traceability mechanisms.

This situation is not exclusive to Colombia. Developers and authorities in countries such as Brazil, Chile, Namibia, Morocco and Egypt face similar challenges associated with building certification systems compatible with the requirements of the main importing markets. However, the speed at which these mechanisms can be consolidated may become a differentiating factor in attracting investment and facilitating early entry into the global supply chains of renewable fuels.

For initiatives such as AkuaippaHy, this reality implies that issues related to certification, measurement, traceability and regulatory compliance must be considered from the earliest stages of project design. Rather than an administrative requirement, these elements are structural components of the commercial model and of the international market-access strategy.

Strategic design

Colombia has renewable resources, infrastructure and favourable territorial conditions to participate in the global PtX economy. However, the ability to certify and verifiably demonstrate the environmental attributes of the molecules produced will be a decisive factor in accessing premium markets, attracting investment and consolidating large-scale export projects.

4 International Markets Analysis

4.1 International demand is concentrated in hydrogen derivatives

The international market analysis covers ten countries grouped in three regions: Latin America (Chile, Brazil, Panama), Europe (Germany, Netherlands, Spain) and Asia (South Korea, Japan, India). Latin American markets are analyzed as competitive benchmarks (supply), while European and Asian markets are analyzed as target demand markets. The selection responds to criteria of regulatory maturity, projected demand size, available infrastructure, contracting mechanisms and direct relevance to the project's commercial structuring. Together, these markets represent some of the main poles of development of renewable fuels and hydrogen derivatives worldwide, both from a production and a consumption perspective.

The analysis starts from the structural conclusion that the international hydrogen market is organized around renewable hydrogen derivatives, capable of responding to the transport, storage and consumption needs of hard-to-abate sectors. As a result, the competitiveness of PtX projects depends both on the ability to produce hydrogen at low cost and on the ability to transform it into molecules with growing demand, available logistics infrastructure, recognized certification schemes and marketing mechanisms compatible with the requirements of international markets.

Figure 7. Hubs are more important than countries.

Source: own elaboration based on Fraunhofer ISE (2024) [9], IEA (2024) [16] and IRENA (2022) [17].

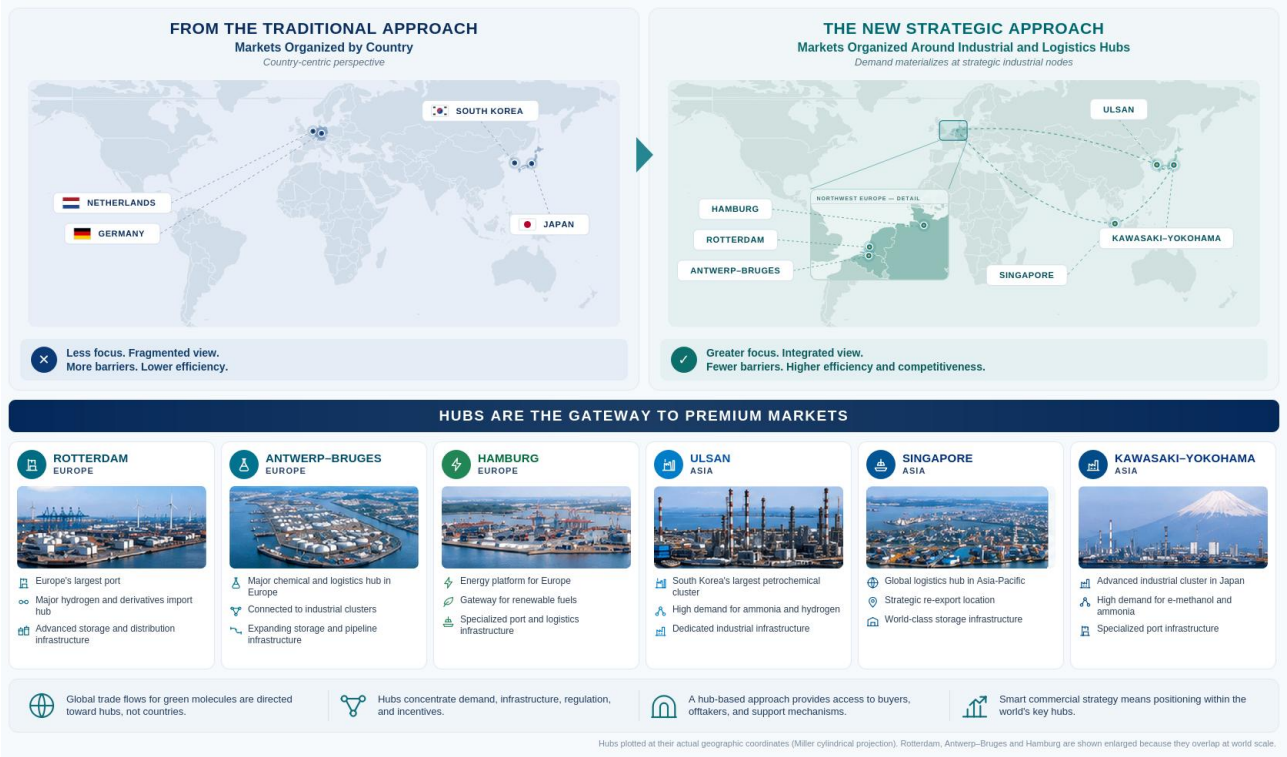
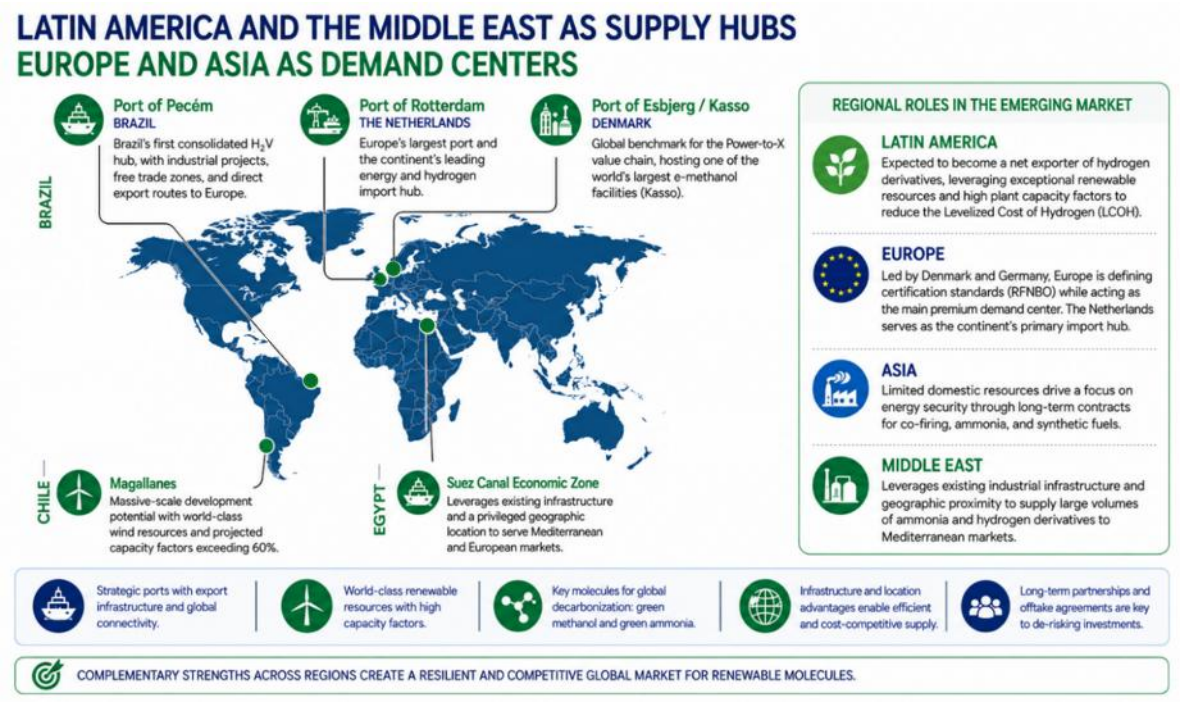


Figure 8. Regional roles in the hydrogen and derivatives market

Source: own elaboration, Óptima Consultores (2026).



The analysis shows that future demand for renewable molecules will tend to concentrate in specialized industrial, port and logistics hubs, rather than in countries considered in aggregate. Rotterdam, Antwerp-Bruges, Hamburg, Singapore, Ulsan and the Japanese industrial complexes associated with energy imports emerge as strategic nodes where infrastructure, regulation, industrial demand and long-term contracting mechanisms converge. This logic is particularly relevant for export-oriented projects, since commercial insertion will depend on the ability to connect with these ecosystems rather than on accessing national markets in a strict sense.

The regional distribution observed confirms an emerging functional division within the global hydrogen and derivatives economy. While Latin America and some Middle Eastern countries concentrate the advantages associated with competitive production of renewable molecules, Europe and Asia consolidate as the main demand centers, driven by decarbonization policies, constraints on their own energy resources and long-term energy security strategies.

Key message:

The commercial opportunity for projects such as AkuaippaHy goes beyond exporting hydrogen as a raw material. It must focus on the production of renewable derivatives capable of integrating into international hubs where regulated demand, logistics infrastructure, environmental certification and long-term contracting schemes converge.
In terms of market entry sequencing, the study recommends prioritizing the Rotterdam hub in the European Union. This recommendation is based on three structural considerations: (i) it offers the highest level of regulatory certainty through the RED III [14] and FuelEU Maritime [28] frameworks, thereby facilitating the negotiation of long-term offtake agreements with committed buyers; (ii) it possesses the world's most advanced infrastructure for the import, handling, and distribution of renewable ammonia and e-methanol, significantly reducing logistical risks along the export value chain [1] [2]; and (iii) the available pricing and contracting mechanisms (including H2Global and bilateral agreements with shipping companies and industrial off-takers) provide credible market signals that support the financial model underpinning the Final Investment Decision (FID) [29]. Asian markets (Japan, South Korea, and Singapore) are recommended as secondary markets to be developed in parallel once the initial European offtake agreements have been secured and the traceability of renewable attributes has been demonstrated in accordance with internationally recognized certification standards [16] [17] [33] [34].

4.2 Competitive benchmarks in Latin America

Chile and Brazil stand out as the main Latin American benchmarks in green hydrogen, although with different approaches. Chile seeks to consolidate itself as a global supplier of decarbonization solutions based on Power-to-X (PtX) derivatives, particularly certified ammonia and e-methanol, rather than as an exporter of hydrogen as a commodity. Its strategy is supported by large-scale projects, particularly in Magallanes, where wind resources enable the development of off-grid complexes oriented to supplying Asian and European markets. The Chilean experience demonstrates that competitiveness depends more on integration into global value chains, certification and logistics than on achieving the lowest hydrogen production cost. Also, that international competitiveness in PtX projects is not built exclusively on the availability of renewable resources, but on the ability to integrate certification, logistics infrastructure, market access and commercial strategies oriented to derivatives with growing international demand. [10]

Brazil, in turn, has the most robust hydrogen strategy in the region and is positioned as the main competitor thanks to its industrial scale, port infrastructure, access to financing and logistics integration. Its export hubs combine production, certification, logistics and long-term sales contracts, with a strong focus on green ammonia and growing interest in e-methanol. The Brazilian case also evidences the importance of developing complete industrial ecosystems around export hubs, where port infrastructure, financing instruments, public incentives and trade agreements evolve in a coordinated manner to reduce risks and accelerate the maturation of projects. [11][12]

Although Panama also promotes a strategy associated with green hydrogen, its advantage lies mainly in its geostrategic location and in the Panama Canal as a logistics platform for international maritime trade. Due to its high production costs, Panama is shaping up more as a complementary node for the export of energy derivatives than as a direct industrial competitor for projects such as AkuaippaHy. Its experience is particularly relevant for understanding the strategic value of maritime logistics

and services associated with the international fuel trade — factors that are becoming increasingly important as new global corridors for renewable molecules consolidate. [13]

Colombia has structural advantages over Chile and Brazil, given that the Caribbean–Rotterdam route is approximately 3,000–3,500 km shorter than the route from Magallanes (southernmost Chile), translating into estimated maritime freight costs that are USD 20–30 per tonne lower. The benchmark for the Caribbean route to Northwestern Europe is the historical freight rates on the Point Lisas (Trinidad and Tobago)–Europe route, which have remained around USD 50/t for ammonia, according to market records from ICIS and Argus Media [2][9]. For the Asian market, transportation costs to terminals in Ulsan or Kawasaki-Yokohama are structurally higher due to the longer distance (estimated at USD 70–90/t via the Panama Canal). This differential should be incorporated into the pricing model as an explicit variable when comparing the relative attractiveness of both markets.

However, the cases analyzed show that geographical advantages alone do not guarantee international competitiveness. The projects that have managed to advance into investment, contracting and commercial development stages are those capable of combining competitive renewable resources, internationally recognized certification, adequate logistics infrastructure, risk-mitigation mechanisms and early access to strategic buyers. This lesson is particularly relevant for AkuaippaHy, whose value proposition will need to be built on a balanced combination of these factors.

Competitiveness

Latin American benchmarks show that competitiveness in PtX projects does not depend exclusively on production cost. The effective integration of certification, logistics, infrastructure, financing and market access is as decisive a factor as the availability of renewable resources.

4.3 European markets: anchor of regulated demand

The three European markets analyzed (Germany, the Netherlands, and Spain) share a defining characteristic in that they are structurally net importers of renewable derivatives under binding regulatory frameworks. Before describing these frameworks, it is useful to clarify their institutional origin. The technical requirements for categorizing hydrogen as renewable (additionality, temporal correlation, and geographical correlation criteria) were established by the European Commission through directly applicable delegated acts, in particular Delegated Regulation (EU) 2023/1184 [15]. The certification schemes that demonstrate compliance with these requirements to buyers, financiers, and authorities are developed and operated by private and public entities recognized by the Commission: ISCC EU, CertifHy, REDcert and, in the case of Spain, Enagás GTS. This distinction is operationally relevant to the project because compliance with the Commission's technical requirements is a necessary condition, but effective accreditation vis-à-vis buyers also requires obtaining and maintaining certification under one of these recognized schemes, with the associated operational and auditing costs. [14][15]

Table 2. Comparative table of European markets

Source: own elaboration based on Fraunhofer ISE (2024) [9], IEA (2024) [16], IRENA (2022) [17], MIBGAS (2025) [30] and BloombergNEF (2024).

Market	Product	Imported price 2025	Imported price 2030	Imported price 2040	Projected volume 2030	Projected volume 2040	Strategic implication
Germany	NH_3	1,080 USD/t	500 USD/t	250 USD/t	7.65–15.3 Mton	17–43 Mton	Industrial anchor market; steel, chemicals, energy
	e-MeOH	860 USD/t	650 USD/t	390 USD/t	3–6 Mton	2–12 Mton	Maritime transport, FuelEU Maritime
Netherlands	NH_3	1,000 USD/t	600 USD/t	300 USD/t	0.5–1.5 Mton	1–10 Mton	Rotterdam: gateway to Europe; chemicals and shipping
	e-MeOH	860 USD/t	650 USD/t	290 USD/t	0.1–1 Mton	1–6 Mton	Continental logistics hub; redistribution to Ruhr clusters
Spain	NH_3	900 USD/t	700 USD/t	300 USD/t	0.6–1 Mton	0.8–2 Mton	Refining, chemicals, maritime; Colombian advantage in biogenic CO_2
	e-MeOH	1,500 USD/t	750 USD/t	450 USD/t	0.2–1 Mton	1–8 Mton	Potentially lower Colombian costs due to biogenic CO_2

The disaggregation of demand by country confirms the concentration of the European market in three industrial hubs. Germany is projected to have a total demand for hydrogen and derivatives of between 95 and 130 TWh in 2030 (equivalent to 2.4–3.3 Mt/year), of which between 50% and 70% (45–90 TWh) will need to be met through imports, primarily in the form of ammonia and e-methanol transported by sea. The chemical industry, steelmaking, and power generation are the sectors with the highest projected demand. The Netherlands will primarily act as a redistribution hub, with the Port of Rotterdam expected to concentrate a significant share of imported volumes destined for Germany and Northern Europe, given that domestic Dutch demand is comparatively lower, while its port infrastructure has the largest capacity on the continent. Spain presents a differentiated dynamic, as its industrial hydrogen demand is more limited than Germany's; however, the approval of its Royal Decree establishing RFNBO quotas in July 2026, with a target of 2.5% in the transport sector by 2030 and 11% by 2040, provides a relevant long-term regulatory signal for e-methanol. Furthermore, Spain represents a specific opportunity for Colombia due to the country's structural limitations in the availability of low-cost biogenic CO_2 for domestic e-methanol production. Overall, these three markets account for the largest share of regulated demand for renewable hydrogen derivatives in Europe over the commissioning horizon of AkuaippaHy [39][40][41].

The observed price ranges show that the economic value of renewable derivatives depends both on the production cost at origin and on the ability to meet the regulatory requirements set by destination markets. Consequently, effective access to these markets will be determined by the ability to demonstrate verifiable environmental attributes, traceability of the energy used, and compliance with international certification standards.

Europe represents one of the most attractive markets for green hydrogen derivatives, with Germany leading the demand for imported ammonia and e-methanol under regulatory frameworks that drive industrial and transport decarbonization. The German strategy is based on the recognition that domestic production will be insufficient to meet future demand, which is why it has developed specific mechanisms to secure international supply chains of renewable molecules. [2]

In this context, the Port of Rotterdam consolidates as the main entry and distribution gateway to the main European industrial clusters thanks to its specialized infrastructure and logistical connectivity. More than a national market, Rotterdam functions

as a continental energy hub, concentrating port infrastructure, storage, distribution, industrial transformation and access to final consumers in various European countries. This condition confirms that the commercial entry of exporting projects depends increasingly on their integration into specialized hubs rather than into individual national markets. [2]

In addition, Spain emerges as a strategic market for e-methanol, since its limitations in the availability of biogenic CO_2 increase the cost of local production, creating an opportunity for Colombia, leveraging its sources of CO_2 and logistical advantages, to offer derivatives with superior competitiveness even considering the cost of transport to Europe. This situation creates opportunities for producers capable of integrating renewable hydrogen and sustainable carbon sources, particularly in applications associated with maritime transport and the chemical industry. [9][14]

In sum, the European markets analyzed confirm that future demand for renewable derivatives will be increasingly associated with sectors subject to regulatory decarbonization obligations. For projects such as AkuaippaHy, this feature is particularly relevant because it makes it possible to build commercial strategies based on relatively stable demand signals, long-term contracts and premiums associated with regulatory and environmental compliance.

An additional clarification is essential for correctly interpreting demand signals in the European market. The instruments that create effective and immediate obligations are the directly applicable regulations: Regulation (EU) 2023/1805 (FuelEU Maritime) [28], Regulation (EU) 2023/956 (CBAM) [23], and Delegated Regulation (EU) 2023/1184 on renewable fuels of non-biological origin [15] do not require national transposition and already impose obligations on operators upon their entry into force. Directive (EU) 2023/2413 (RED III), by contrast, establishes targets and policy frameworks that each Member State must incorporate into its national legislation. The sector-specific renewable hydrogen quotas for industry and transport, which underpin a significant share of European demand projections, do not create direct obligations for companies until this transposition process is completed. The stipulated deadline was July 2025 and, as of the closing date of this study, several key countries had not completed the process: Germany, the project's priority market, was still processing its energy transition legislation; France had transposed some obligations but not the sector-specific hydrogen quotas; and the Netherlands had completed part of the transposition. This heterogeneity introduces an additional layer of uncertainty regarding the volume and timing of the materialization of part of the projected demand. Volumes associated with hydrogen quotas in industry and transport should therefore be treated as potential regulatory demand, with a longer activation horizon than suggested by the text of the directive. The most direct commercial mitigation of this risk is to prioritize agreements with buyers whose obligations are already in force (shipping companies subject to FuelEU Maritime, industrial importers exposed to CBAM, and buyers participating in mechanisms such as H2Global) before relying on quotas whose transposition remains ongoing. [14][15][23][28]

European Markets

Europe represents more than an export market; it stands as the main space for the formation of regulated demand for renewable molecules. Access to these markets will depend on the ability to comply with increasingly demanding certification, traceability and sustainability standards, factors that are becoming decisive for the commercial competitiveness of PtX projects.

4.4 Asian markets: structural importers

Japan, South Korea and India share a common structural constraint: they do not have sufficient renewable resources or competitive biomass to produce hydrogen and derivatives at a domestic scale. This limitation makes them long-term net importers, with active national strategies to secure international supply chains of ammonia and e-methanol. Unlike Europe, where demand is mainly driven by decarbonization regulatory obligations, in Asia energy-security objectives, industrial competitiveness and emission reductions converge, generating long-term structural demand for imported renewable molecules. [16][17][18]

Asian markets, especially Japan, South Korea and India, consolidate as structural buyers of green hydrogen derivatives, driving long-term contracting schemes for ammonia and e-methanol used in the decarbonization of power generation, industry and maritime transport. Japan and South Korea, in particular, have advanced specific mechanisms to facilitate the import of ammonia and synthetic fuels, including financial-support schemes, co-firing programs, long-term contracts and national strategies aimed at consolidating reception and distribution hubs for imported energy. [16][17][18]

Both Japan and South Korea rely significantly on imports due to their resource and territorial constraints, while India, in addition to being an importer, is contributing to the formation of international prices through public green-ammonia auctions. India's participation is particularly relevant because it introduces new price references and competitive contracting mechanisms that could progressively influence the formation of international markets for renewable derivatives. [16][17]

Taken together, these markets confirm that international demand for renewable hydrogen is being structured mainly around liquid derivatives traded through long-term contracts, public-support mechanisms and risk-mitigation schemes that facilitate the bankability of projects. Rather than hydrogen spot markets, what emerges is a commercial architecture based on stable contractual relationships, long-term regulatory signals and international supply chains of renewable molecules. [19]

For Asian markets, the study's strategic market selection matrix identifies CFR/Delivered price ranges of USD 900–1,300/t for renewable ammonia in Japan and South Korea, contingent upon the availability of government support mechanisms and anchor contracts under schemes such as the METI (Ministry of Economy, Trade and Industry)/JOGMEC ((Japan Organization for Metals and Energy Security) Contracts for Difference (CfD) program (USD 19.2 billion over 15 years), and USD 550–1,000/t for e-methanol in the maritime markets of Singapore, South Korea, and Japan, driven by emerging bunkering mandates [2]. These price ranges are broadly comparable to those of the target European corridor. However, their bankability is assessed as medium, compared with the high bankability of the European market, since Asian regulatory frameworks remain under development and exhibit greater sensitivity to freight costs and contractual certainty [2][33][34].

From AkuaippaHy's perspective, Asian markets represent a strategic medium- and long-term opportunity due to their potential demand scale and the growing consolidation of hubs specialized in energy imports. The evolution of poles such as Ulsan in South Korea and the industrial complexes associated with Kawasaki-Yokohama in Japan suggests that the future growth of international trade in renewable molecules will be closely linked to the ability to integrate into these industrial and logistical ecosystems.

Asian Markets

Asia is emerging as the main growth market for low-emission ammonia and e-methanol over the coming decades. The combination of structural resource constraints, energy-security objectives and decarbonization commitments is driving the creation of contracting and support mechanisms that could make the region one of the main destinations for export projects such as AkuaippaHy.

Both Europe and Asia show that demand for renewable molecules no longer depends exclusively on market signals. It is increasingly being driven by regulatory frameworks, public-procurement mechanisms, corporate decarbonization commitments and national energy-security strategies. This transformation favors the development of long-term contracts and commercial structures capable of supporting final investment decisions in large-scale PtX projects.

To assess the scale of AkuaippaHy within these markets, it is useful to compare its projected production with estimated demand in the main destination markets. With a projected capacity of 230–270 kt/year of green ammonia or 220–250 kt/year of e-methanol, the project would represent less than 2% of the projected demand for renewable ammonia in the European Union by 2030 (between 7.65 and 15.3 million tonnes per year, according to the Interntional Energy Agency - IEA [16]), less than 5% of the projected equivalent hydrogen demand in South Korea over the same horizon (1.94 million tonnes), and less than 1% of Japan's projected demand by 2040 (30 million tonnes of hydrogen equivalent). These figures have a direct commercial implication for the project: although AkuaippaHy does not face significant volume risk, it does face positioning,

certification, and contractual structuring risks. Even by capturing small shares of regulated demand in each of these markets, AkuaippaHy could achieve full utilization of its capacity under long-term contracts. [16][17][8]

5 Benchmark of Leading Projects: Lessons for AkuaippaHy

The analysis of international projects that have reached advanced development stages, final investment decision (FID) or construction makes it possible to identify common success patterns applicable to export-oriented PtX initiatives. Despite their technological, geographical and regulatory differences, the cases analyzed show notable convergence in the factors that explain their ability to attract investment and move toward execution. [2]

Table 3. Benchmark of leading PtX projects worldwide and lessons for AkuaippaHy

Source: Óptima Consultores (2026). Market and Regulatory Study of the AkuaippaHy Project – Volume II [2].

Project	Country	Vector / Scale	Offtake mechanism	Key lesson for AkuaippaHy
Egypt Green Hydrogen – Fertiglobe	Egypt	NH_3 green ~60 kt/year 100 MW electrolysis	H2Global: 397 kt at 935 USD/t (2027-2033); tiered take-or-pay	H2Global is the lowest-uncertainty route for Europe. RFNBO certification directly impacts CAPEX due to hourly correlation.
Gopalpur – ACME Group	India	NH_3 green 400 kt/year ~400 MW	SECI/SIGHT: 641 USD/t; IHI (Japan) as anchor offtaker with a 30% equity stake	The offtaker + equity-partner model aligns incentives and strengthens bankability. Market-design threshold defines the cost structure.
Kassø PtX – European Energy	Denmark	E-methanol 42 kt/year 52 MW PEM	Maersk (bunkering anchor); LEGO and Novo Nordisk (industrial); Danish CfD subsidy ~1.07 USD/kg H_2 for 10 years	CO_2 Local certified biogenic CO_2 is an enabling condition. Public-bank investment (DGIF) was critical for FID.
Haru Oni / Cabo Negro – HIF Global	Chile	E-fuels Pilot phase -> 175 kt/year MeOH	Shell (e-fuels); Mabanaft 100 kt/year e-MeOH; Porsche/VW (equity+offtake)	Defines the final market from initial design. Progressive scaling from pilot ->to commercial reduces technical risks.
Iracema Project	Brazil (Pecém)	NH_3 green 400 kt/year -> 2.2 Mt/year	Shared port infrastructure; World Bank financing USD 175M	Integrated hub (production+certification+logistics+offtake) as architectural reference. The Caribbean–Rotterdam route is 3,000-3,500 km shorter than Pecém–Rotterdam.

The projects studied show that competitiveness does not depend exclusively on the cost of producing hydrogen or its derivatives. Recurring elements include the existence of strategic buyers committed through long-term contracts, access to public-support mechanisms, logistical integration with ports and destination markets, availability of internationally recognized certification schemes and a progressive scaling strategy that reduces technological and commercial risks. [2]

In particular, the cases analyzed show that successful projects tend to develop around integrated ecosystems where renewable generation, infrastructure, logistics, certification and demand converge. International evidence also suggests that investment decisions are based more frequently on robust contractual structures and risk-mitigation mechanisms than on advantages associated solely with the available energy resource. [2]

The analysis of international projects that have reached advanced development, construction or final investment decision stages allows the identification of common patterns applicable to AkuaippaHy. Despite the technological, geographical and regulatory differences between the cases analyzed, all share recurring elements: early integration with strategic buyers, access

to public-support or risk-mitigation mechanisms, compliance with internationally recognized certification standards, and alignment with export-oriented logistics infrastructure. [2]

The main lesson for AkuaippaHy is that the competitiveness of PtX projects is not built exclusively around production cost. The reference cases show that the ability to secure demand through long-term contracts, structure bankability mechanisms, demonstrate regulatory compliance and develop integrated production, logistics and marketing ecosystems is decisive in moving toward FID and financial close. [2]

Lessons for AkuaippaHy

- ✓ Prioritize the early structuring of strategic offtakers.
- ✓ Design the project under criteria compatible with international certification.
- ✓ Develop a progressive route of maturation and scaling.
- ✓ Integrate production, logistics and market access from early stages.
- ✓ Orient the commercial strategy toward bankable long-term contracts.

6 Economic competitiveness, price gap and commercial positioning

Based on the integrated analysis of international prices, logistics costs, regulatory support mechanisms and references observed in benchmark international projects, a Target Price Corridor was constructed for the molecules assessed in AkuaippaHy. This corridor makes it possible to identify the price ranges that could facilitate access to premium markets and the structuring of long-term contracts compatible with project-financing schemes. [2]

Table 4. AkuaippaHy target price corridor (CFR, long-term contracts in premium markets)
Source: own elaboration based on H2Global (2024), SECI auctions (2025) [19], Fraunhofer ISE (2024) [9], ICIS and BloombergNEF (2024).

Molecule	Lower range	Upper range	Main drivers
Green ammonia (NH_3)	700-800 USD/t	900-1,100 USD/t	CBAM/ETS + RFNBO premium + Caribbean–Europe freight cost (~50 USD/t)
E-methanol (CH_3OH)	900-1,000 USD/t	1,100-1,300 USD/t	FuelEU Maritime + RFNBO premium + maritime bunkering contract; bankable range, Kassø benchmark
Hydrogen equiv. (H_2) via cracking of NH_3	6.5-8.0 USD/kg	10-13 USD/kg	Price at European destination including cracking costs, energy losses and local logistics

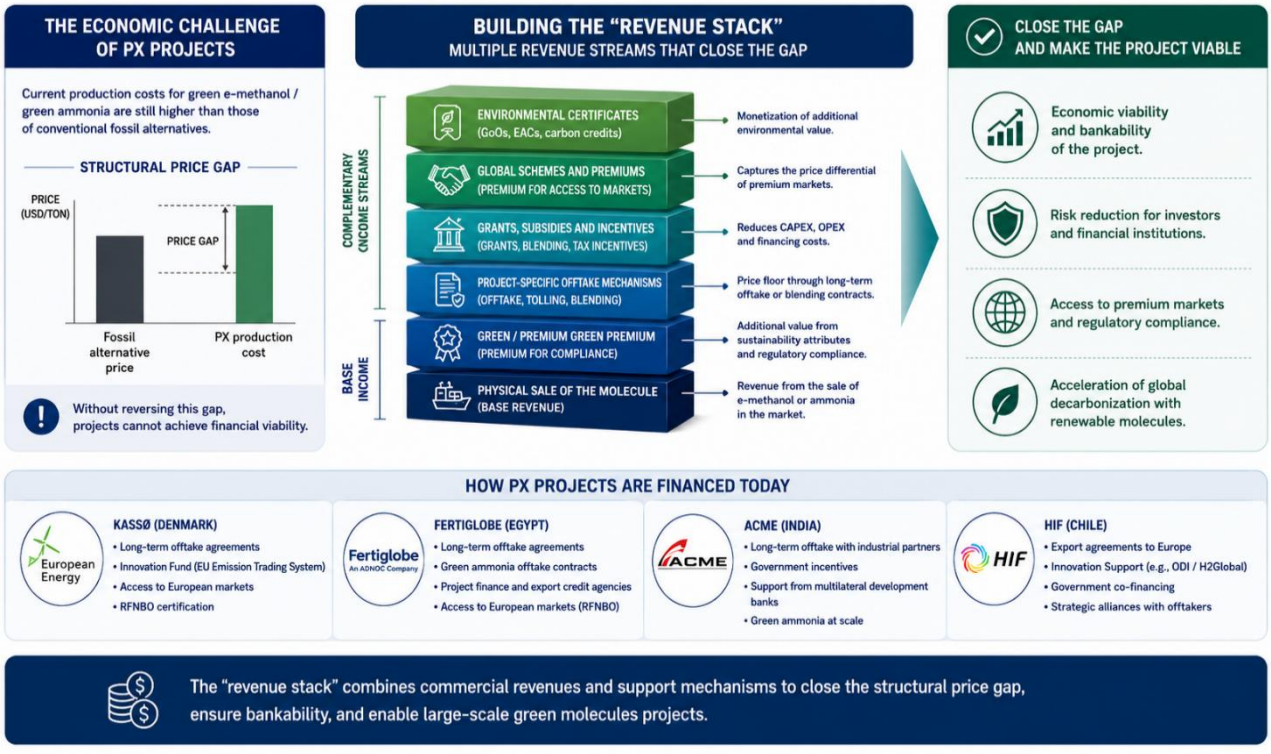
The analysis carried out shows that the target prices identified for green ammonia and e-methanol are rarely reached through the physical sale of the molecule alone. International experience shows that the most advanced PtX projects combine multiple revenue streams and support mechanisms, including green premiums, contracts for difference (CfD), public incentive programs, H2Global-type schemes and environmental certificates. This combination of instruments, known as the revenue stack, is currently one of the main mechanisms to close the economic gap with fossil alternatives. [2]

The ranges identified for green ammonia and e-methanol are consistent with the references observed in international markets, recent contracting mechanisms and support programs currently in force in Europe and Asia. Rather than representing market

spot prices, these values reflect the economic conditions under which it would be possible to structure long-term contracts compatible with the requirements of investors and financiers. [2]

Figure 9. Building the *Revenue Stack* and closing the economic gap

Source: own elaboration, Óptima Consultores (2026).



Colombia's competitive advantage

AkuaippaHy's future competitiveness will not depend exclusively on reaching the lowest possible production cost. International experience shows that the economic feasibility of PtX projects is built through the combination of long-term contracts, certification, support mechanisms and commercial structures capable of closing the economic gap with conventional fuels.

7 International Logistics Hubs: Market Access

The study analyzes seven international logistics hubs that are key to AkuaippaHy's commercial strategy: three European (Rotterdam, Antwerp-Bruges and Hamburg) and three Asian (Ulsan, Singapore and Kawasaki-Yokohama), plus the Panama Canal as a strategic transit hub. The most relevant elements for AkuaippaHy's commercial strategy are presented below. [2]

Table 5. International logistics hubs and market access for AkuaippaHy

Source: Óptima Consultores (2026). Market and Regulatory Study of the AkuaippaHy Project – Volume II [2].

Hub	Region	Priority product	Key infrastructure	Priority offtakers
Rotterdam	Europe	NH_3 and e-MeOH	ACE Terminal (Gasunie+Vopak) op. 2026; HyNetwork 1,200 km; Delta Rhine Corridor →Germany 2031	Yara (CBAM fertilizers); BASF/Lanxess (Rhine-Ruhr chemicals); Maersk/CMB.TECH (bunkering); Blue Circle Olefins (MeOH-to-Olefins)
Antwerp-Bruges	Europe	NH_3 and e-MeOH	Fluxys+Advario terminal (open access, op. 2027-28); Air Liquide: first industrial NH_3 cracking in Europe (op. 2025)	BASF, Borealis, Ineos (petrochemicals); Engie (co-firing); Maersk (bunkering)
Hamburg	Europe	NH_3 and e-MeOH	Mabanaft–Air Products terminal, 600,000 t/year NH_3 (approved 2024, op. 2027); HH-WIN network (op. 2026-27)	Aurubis (copper, high-temperature); Thyssenkrupp (steel); Hapag-Lloyd (transatlantic bunkering)
Ulsan	South Korea	NH_3	Hyundai Oil Terminal Namsin (MoU Oct. 2025): 2 tanks of 80,000 m^3, 1.25 Mt/year, op. Dec. 2028. Ammonia Bunkering Free Zone (May 2025)	Lotte Fine Chemical; POSCO (green H-DRI steel, 1.2 Mt/year from ~2035); Korea East-West Power (CHPS co-firing)
Singapore	Asia	NH_3	Banyan Vopak terminal: world's first NH_3 terminal-to-ship bunkering (2024). Air Liquide cracking (under development)	Trans-Pacific bunkering operators; redistribution to Japan and Korea
Kawasaki-Yokohama	Japan	NH_3 and e-MeOH	H_2 clusters2, coastal; CfD METI/JOGMEC USD 19.2bn over 15 years (first round 2025: JERA 490,000 t/year NH_3)	JERA (20% NH_3 co-firing in Hekinan); Mitsui, Sumitomo, Mitsubishi (trading houses)
Panama Canal	Transit	NH_3 and e-MeOH	NetZero Slot (Oct. 2025): weekly slot for dual-fuel vessels (≤75 gCO_2e/MJ). New Corozal+Telfers terminals 2029 (USD 2.6bn)	Monjasa (bunkering Colombia and Panama); redistribution on the Caribbean–Asia route

Europe

The main European hubs (Rotterdam, Antwerp-Bruges and Hamburg) concentrate port infrastructure, storage, distribution and industrial consumption of renewable derivatives. Their strategic relevance lies in their role as entry and redistribution platforms toward multiple European markets, integrating industrial demand, maritime transport and regulatory mechanisms that favor the adoption of low-emission molecules. For AkuaippaHy, these hubs represent priority access points for export strategies focused on certified ammonia and e-methanol. [2]

Asia

In Asia, Ulsan, Singapore and Kawasaki-Yokohama consolidate as the main nodes for the reception, transformation and consumption of renewable derivatives. These hubs are backed by national decarbonization programs, specialized infrastructure and long-term contracting mechanisms aimed at securing the future supply of low-carbon molecules. Their development confirms that Asian demand will tend to concentrate in specialized industrial and port ecosystems rather than in isolated national markets. [2]

Commercial strategy

The analysis confirms that AkuaippaHy's commercial strategy must focus on building relationships with specific logistics and industrial hubs, rather than with countries considered individually. Future competitiveness will depend on the ability to integrate into these ecosystems through certification, long-term contracts and efficient logistics solutions.

8 Offtake Contractual Mechanisms and Bankability

Table 6. Offtake contractual mechanisms[3]

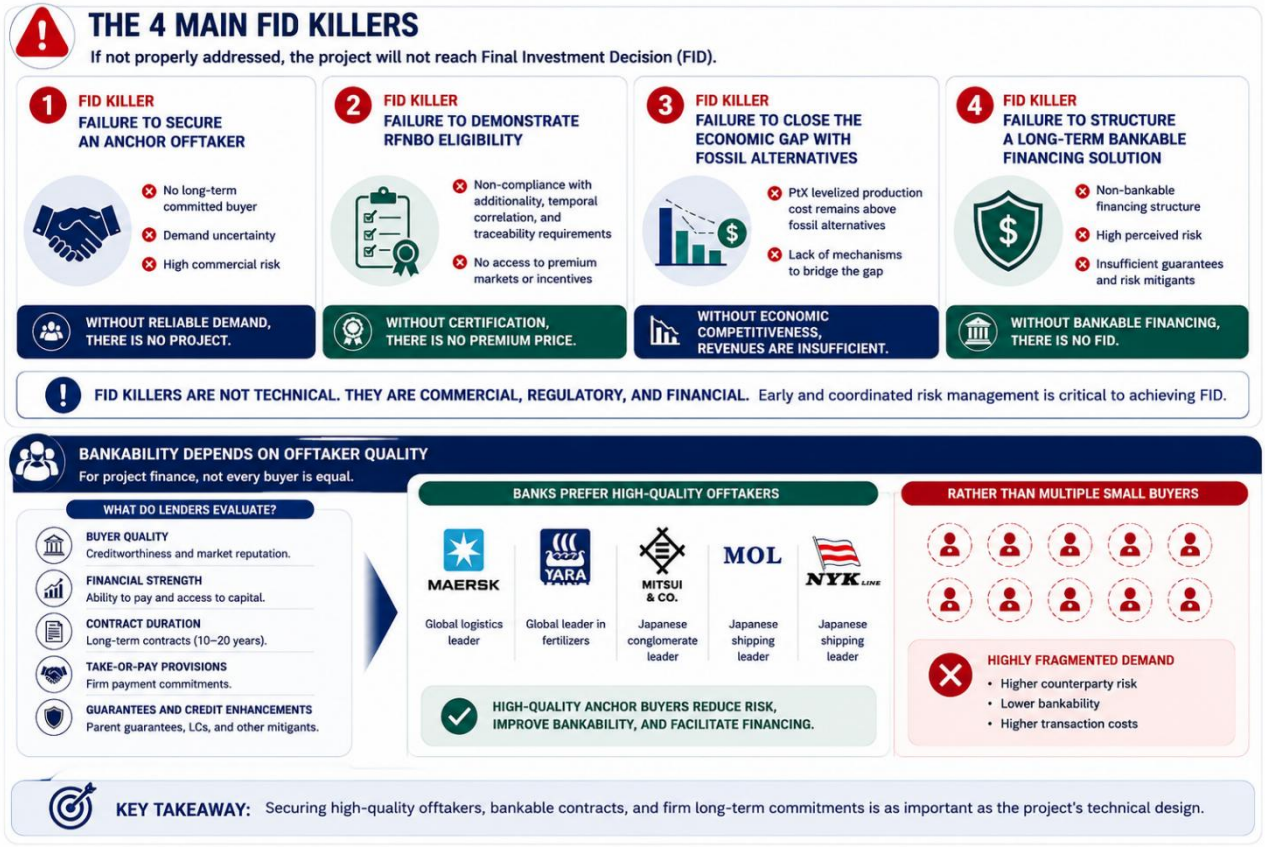
Source: Óptima Consultores (2026). Market and Regulatory Study of the AkuaippaHy Project – Volume II [2].

Contract type	Description and application for AkuaippaHy	Benchmark reference
Long-term with fixed or semi-fixed price	Price defined ex ante for 10-15 years; eliminates uncertainty for the producer. Compatible with Project Finance as a source of predictable revenues.	Kassø-Maersk; ACME-IHI
Take-or-pay with minimum volume	Buyer assumes the obligation to purchase a minimum volume regardless of actual consumption. Reduces the risk of asset underutilization for the producer.	Fertiglobe-H2Global (397 kt fixed 2027-2033)
Indexed to ETS/CBAM/RFNBO	Variable price linked to the cost of carbon in Europe or to regulatory premiums. Automatically captures the value of regulatory tightening over time.	Standard in European contracts post-2025
Ramp-up / tiered	Increasing volumes over time, starting with smaller commitments and scaling up as the project demonstrates performance. Reduces initial risk for the buyer.	Fertiglobe: 19.5 kt (2027) → 40 kt/year (2028+)
Contract for Difference (CfD)	The public mechanism covers the difference between the production price of green fuel and the market price of the conventional alternative. Transfers price risk to the public sector, improving bankability.	H2Global (EU), SECI-SIGHT (India), JOGMEC-CfD (Japan), HBM (Korea)
Hybrid / combined	Combination of the above mechanisms, typical in projects with multiple offtakers. E.g., take-or-pay with anchor offtaker + indexed price with secondary offtakers.	ACME: combination of SECI + IHI + IFFCO contracts
Tolling / H_2 as a service	The buyer provides the energy input (H_{22}) and pays for the conversion to the derivative; or the producer offers decarbonization as a certified service. Reduces the producer's commercial risk but requires vertical integration.	Kassø: sale of green methanol as a "decarbonization service" to LEGO and Novo Nordisk

Access to regulated markets requires the design of specific contractual structures. The analysis shows that the bankability of PtX projects depends largely on the ability to secure predictable revenues through long-term contracts compatible with Project Finance financing schemes. [2]

[3] SIGHT: Strategic Interventions for Green Hydrogen Transition; IFFCO: Indian Farmers Fertiliser Cooperative Limited

Figure 10. FID Killers and the importance of offtaker quality.
Source: own elaboration, Óptima Consultores (2026).



International experience shows that the main obstacles to reaching the final investment decision are associated with commercial, regulatory and financial factors. Projects that have managed to advance toward construction share the ability to secure strategic buyers, demonstrate regulatory compliance, reduce the economic gap with conventional alternatives and structure solutions compatible with the requirements of financiers and investors. [3]

In this context, offtake contracts play a central role, becoming the main mechanism for transforming potential demand into bankable revenues. The quality of the buyer, the contract duration, the existence of take-or-pay clauses, indexation mechanisms and associated guarantees are as relevant as the agreed price. [3]

Rather than maximizing the number of buyers, international experience shows that the most advanced PtX projects seek to establish long-term relationships with counterparties of high credit quality, capable of supporting financing processes and reducing the perceived risk of the project. [3]

Table 7. What does a financier look for in a PtX project?

Source: own elaboration based on IFC / World Bank (2024) [29].

Critical factor	Why is it important?
Offtaker with strong credit standing	Reduces counterparty risk and increases confidence in the ability to pay over the life of the contract.
Long-term contract	Provides visibility on future revenues and facilitates the structuring of Project Finance financing.
Take-or-pay clauses	Guarantee minimum purchase levels, reducing the project's exposure to demand volatility.
Transparent indexation mechanisms	Allow prices to be adjusted in response to market variables, inflation or regulatory compliance, preserving the economic sustainability of the contract.
Verifiable regulatory compliance	Ensures eligibility for premium markets, certification schemes and support mechanisms associated with the energy transition.
Clear allocation of risks	Defines responsibilities among producers, buyers and financiers, reducing uncertainties over the life of the project.

Key message:

The main lesson from PtX projects that have reached FID is that bankability begins with the quality of demand. The existence of solid buyers, long-term contracts and adequate risk-mitigation mechanisms is as important a requirement as the technical or economic competitiveness of the project.

9 International Regulatory Framework: Barriers and Access Conditions

9.1 Preferential tariff access

Under the Trade Agreement between the European Union and Colombia, hydrogen, anhydrous ammonia and methanol benefit from a 0% import tariff into Europe, conditional on compliance with the rules of origin regime. This tariff preference is equivalent to that enjoyed by Chile, Mexico, Peru, Ecuador and the Central American countries under their respective agreements with the EU. Producers in the Middle East and North Africa (Saudi Arabia, Oman, United Arab Emirates) do not have equivalent preferential agreements and enter under the WTO (World Trade Organization) Most Favored Nation (MFN) tariff, which represents a structural advantage for Colombian projects in a tight-margin environment. While the tariff component alone is not a decisive competitiveness factor, it does contribute to improving the relative positioning of Colombia against competitors that do not have preferential access agreements to the main destination markets. [20]

The materialization of this tariff advantage is not automatic. The zero tariff is conditional on the full compliance with four rules-of-origin requirements: (i) the product must be wholly obtained or sufficiently transformed in Colombia, with substantial electrolysis, synthesis and purification stages carried out in national territory; (ii) the production process must involve sufficient transformation (complete chemical or energy conversion) in accordance with the technical rules of the agreement; (iii) insufficient operations such as repackaging, dilution or simple mixing must be excluded; and (iv) transport must be direct or, in case of transit through third countries, the product must remain under continuous customs control with full documentary traceability. The formal proof of origin is the EUR.1 certificate, issued by the Colombian Ministry of Trade, Industry and Tourism. Preservation of this benefit depends on effective compliance with the rules of origin established in each trade agreement, including requirements associated with substantial transformation, input traceability and maintenance of customs control during international transport. [20]

For projects based on e-methanol, the origin of the CO_2 and other strategic inputs may acquire relevance not only from the perspective of environmental certification, but also for compliance with rules of origin and preferential access to international markets. Consequently, decisions on carbon sourcing must be evaluated from the early stages of project structuring. [20]

Similarly, the Colombia–Korea FTA (Free Trade Agreement) provides preferential access for these products, subject to compliance with rules of origin and regional content. Unlike the European model, the Korean agreement incorporates quantifiable thresholds of regional value added, which implies that relevant changes in the cost structure or in the origin of inputs could affect the maintenance of the tariff benefits. [21]

Japan does not currently have an FTA in force with Colombia. The Colombia–Japan EPA (Economic Partnership Agreement) was reactivated in September 2025 but has not yet entered into force, so exports are governed by the MFN tariff. For anhydrous ammonia (HS 2814.10) and methanol (HS 2905.11), Japan applies a 0% tariff under MFN for industrial or energy uses, so the tariff component does not constitute a structural barrier for the project. Competitiveness in Japan will depend mainly on the ability to integrate into the support schemes of the Green Transformation (GX) strategy, not on differences in tariff access. Consequently, competitiveness in the Japanese market will depend mainly on access to support, certification and contracting mechanisms associated with the Green Transformation (GX) strategy, rather than on advantages derived from the tariff component. [22]

Key message:

Preferential access to Europe and Korea constitutes a competitive advantage for Colombia, but its effective exploitation depends on early decisions related to rules of origin, input traceability and supply chain structuring. In markets such as Japan, the determining factors of competitiveness will be associated mainly with certification, support mechanisms and demand access.

9.2 RFNBO, CHCS and JOGMEC certification

The main target markets for AkuaippaHy require formal certification mechanisms that allow verification of the carbon intensity and renewable origin of the molecules produced. More than a regulatory requirement, these schemes have become conditions for market access, participation in support programs, eligibility for long-term contracts and the capture of premiums associated with certified renewable fuels. [14][15]

- RFNBO (EU – RED II/III, Delegated Regulation 2023/1184): the most stringent. Requires renewable energy additionality, strict hourly temporal correlation from 2030 and a minimum emissions reduction of 70% (≤3.38 $kgCO_2e/kgH_2$). Certification mandatory by third parties under ISCC EU, Redcert or CertifHy. [14][15]
- CHCS (South Korea – MOTIE): classifies hydrogen into four grades according to intensity, with a maximum threshold of 4.0 $kgCO_2e/kgH_2$ (Well-to-Gate). Linked to access to auctions and reduction of exposure to the K-ETS. [23][24]
- JOGMEC CI (Japan – METI): threshold ≤3.4 $kgCO_2e/kgH_2$ (Well-to-Gate); technologically neutral. Enabling condition for CfD and structured long-term contracts. [25][26]

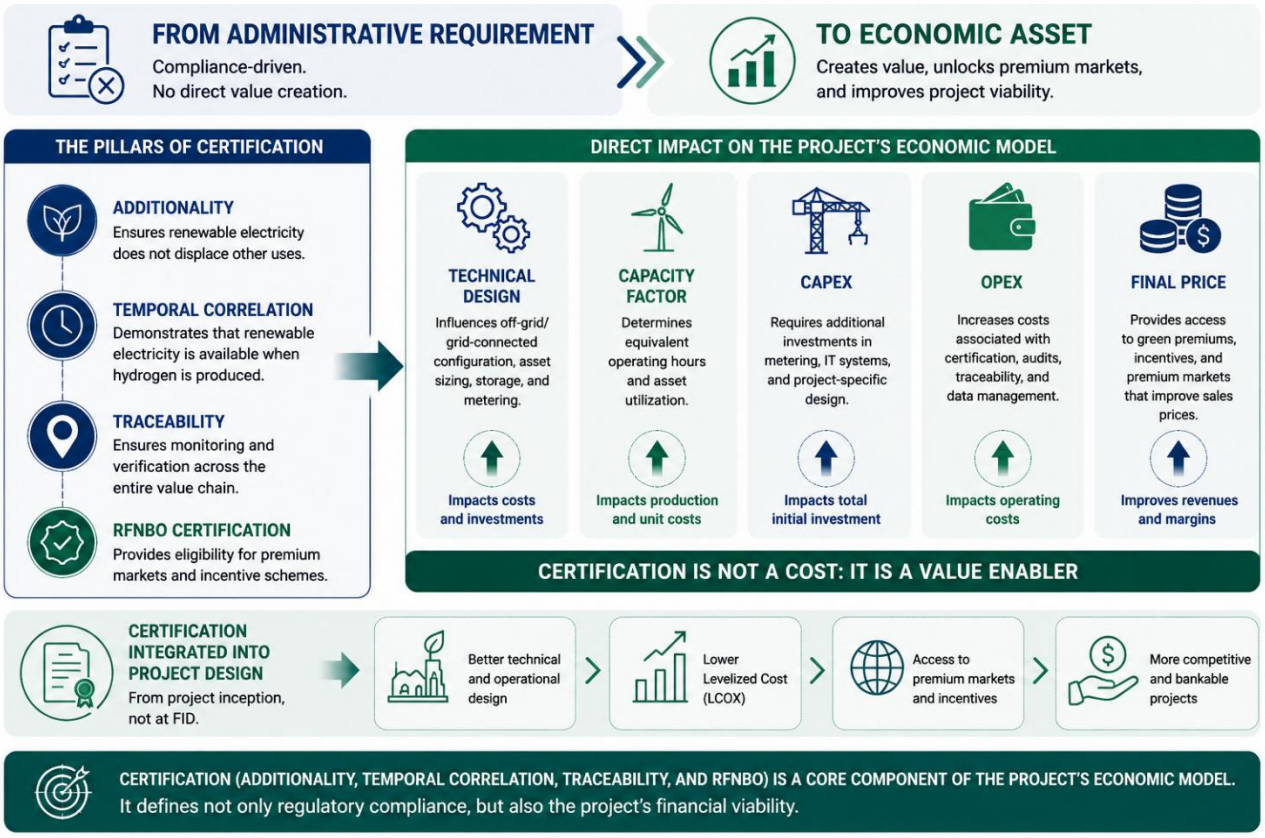
Although the three schemes pursue similar emissions-reduction objectives, they present relevant differences in calculation methodologies, levels of stringency and verification mechanisms. Among them, RFNBO currently constitutes the most stringent and detailed standard, which is why it is frequently used as a design reference for projects oriented to export. [14][15][23][24][25][26]

Design strategy

Designing the project under the most stringent requirements from the early stages allows for maximizing future commercial flexibility, facilitating simultaneous access to Europe and Asia and reducing risks associated with regulatory changes. This approach may increase design and operating costs, but significantly improves eligibility for premium markets and support mechanisms.

Figure 11. Certification as an economic asset rather than an administrative requirement.

Source: own elaboration, Óptima Consultores (2026).



International experience shows that certification directly influences fundamental project variables, including electrical configuration, electrolysis utilization factors, traceability requirements, investment costs and operating costs. Consequently, certification standards must be understood as an integral part of the project's economic and commercial model, and not as a subsequent regulatory compliance stage. [14][15]

International markets are experiencing a shift from voluntary decarbonization commitments toward regulatory compliance obligations. This shift is relevant to the project's commercial structuring because only legally binding demand provides sufficient stability to support bankable long-term supply agreements. However, not all instruments referenced in this context have the same legal nature or immediate effects. It is therefore necessary to distinguish between two categories.

The first category comprises directly applicable instruments that already impose effective obligations on operators without the need for additional national legislation. Regulation (EU) 2023/1805 (FuelEU Maritime) [28] imposes mandatory standards for reducing the emissions intensity of maritime transport, creating commercial opportunities for e-methanol and green ammonia from its entry into force. Delegated Regulation (EU) 2023/1184 [15] establishes the technical criteria for a fuel to qualify as an RFNBO, a prerequisite for accessing European regulatory premiums. Regulation (EU) 2023/956 (CBAM) [23]

progressively increases the cost of importing carbon-intensive products into the European Union, improving the relative competitiveness of derivatives with a verifiable low carbon footprint.

The second category includes obligations whose implementation depends on the transposition of the RED III Directive [14] into the national legislation of each Member State. Renewable hydrogen uptake quotas in industry and transport, which account for a significant share of projected European demand, fall into this second category. Given that transposition is still ongoing in several key countries, the volumes associated with these quotas should be treated with greater caution in the demand analysis.

In South Korea, the K-ETS creates direct economic incentives for industrial buyers to favor inputs with lower carbon intensity, while the clean hydrogen bidding program (HBM) provides contracts with predictable price signals. In Japan, the Green Transformation (GX) strategy combines a carbon tax with contracts-for-difference mechanisms administered by JOGMEC, with an allocation of approximately USD 19.2 billion over 15 years. [14][15][23][28]

Access to premium markets

The ability to access premium markets will depend less and less on producing renewable molecules, and increasingly on demonstrating, through verifiable certification and traceability mechanisms, that those molecules comply with the standards required by the destination markets.

9.3 Regulatory instruments that generate demand

One of the most relevant changes observed in international markets is the transition from voluntary decarbonization mechanisms to mandatory regulatory obligations. In this context, several regulatory instruments are transforming the demand for renewable derivatives into a structural need for certain economic sectors, creating market signals that are more stable and predictable than those traditionally observed in emerging energy markets. From the Project Finance perspective, this regulated demand constitutes one of the main enablers for the structuring of bankable long-term contracts. [27]

- FuelEU Maritime establishes a mandatory standard of progressive reduction of GHG emissions intensity for vessels above 5,000 GT, under a Well-to-Wake approach. It applies to 100% of the energy consumed on intra-EU voyages and to 50% on intercontinental routes, which extends the regulation to Colombia–Europe routes. The targets are progressive, starting in 2025 until reaching an 80% reduction in 2050, with financial penalties for non-compliance. For AkuaippaHy, this mechanism converts the certified carbon intensity of e-methanol or ammonia into a direct financial variable, since a fuel with a lower footprint avoids penalties, generates tradable compliance surpluses under the pooling scheme and impacts the operator's OPEX (Operating Expenditure). The value proposition for the maritime buyer, beyond the molecule itself, is verifiable regulatory compliance. In addition, FuelEU Maritime transforms the fuel's environmental attribute into a tangible economic variable for shipping companies and maritime operators, generating a willingness to pay associated with regulatory compliance and not solely with the energy value of the molecule. [28]

- ReFuelEU Aviation establishes mandatory quantitative mandates for the incorporation of SAF (Sustainable Aviation Fuels) at European airports, from 2% in 2025 to 70% in 2050. It includes a specific sub-quota for RFNBO synthetic fuels, which grows from 0.7% in 2030 to 35% in 2050. This sub-quota is strategic because it prevents the obligation from being met entirely with advanced biofuels, reserving a growing market for electrolysis-derived e-fuels. The mechanism transforms the "green premium" into a mandatory compliance cost for the airport supplier, strengthening the structuring of long-term supply contracts. The existence of a specific sub-quota for RFNBO synthetic fuels guarantees that a growing portion of the regulatory obligation will need to be covered through electrolysis-derived fuels, creating a structural long-term demand for these products. [14]

The status of transposition varies significantly across the project's priority markets. Germany approved its transposition of RED III for the transport sector in the Bundestag on April 23, 2026, establishing an RFNBO trajectory starting at 0.1% in 2026 and reaching 5% in 2035 and 10% in 2040, with a non-compliance penalty of EUR 14/kg, the highest in the European Union. The industrial quota, however, has yet to be transposed into German law. The Netherlands approved its transport quota in March 2026, with a target of 1.8% by 2030; the industrial quota is progressing through parliament but has not yet completed the legislative process. Spain approved a Royal Decree in July 2026 establishing RFNBO quotas for road transport from 2028, with a target of 2.5% by 2030 and 11% by 2040; specific non-compliance penalties had not been confirmed as of the closing date of this study.

Industrial quotas face widespread delays across the European Union, as Member States have shown reluctance to impose significant obligations on the industrial sector due to competitiveness concerns arising from higher energy prices. According to BloombergNEF, only 12 of the 27 Member States had enacted RFNBO quotas into law nearly one year after the May 2025 deadline; in most countries, the established penalties are below the threshold of approximately EUR 10/kg at which non-compliance becomes economically unattractive compared with actual compliance. This situation has a direct implication for AkuaippaHy's commercial strategy: the most predictable and bankable regulated demand over the 2027–2030 horizon is emerging from the transport sector, where quotas and penalties are more advanced across the three countries, and from the directly applicable instruments already in force, rather than from the RED III industrial quotas, whose transposition remains incomplete. [14][15][37][38][39]

- In South Korea, the K-ETS operates as a cap-and-trade scheme that covers 79% of national emissions, with historical carbon prices between USD 10 and 30/tCO_2e. It is not a direct border tax on imported ammonia or methanol, but industrial buyers subject to the system have direct economic incentives to prefer lower carbon-intensity inputs, since this reduces their exposure to the allowance market. Phase 4 (2026-2030) will progressively tighten free allocations, increasing the carbon price signal and strengthening the structural demand for low-emissions inputs. In other words, the Korean Emissions Trading System (K-ETS) introduces growing economic incentives for the adoption of lower carbon-intensity inputs. As free allocations decrease and corporate exposure to the carbon price increases, demand for low-emissions fuels and raw materials strengthens. [21]

- In Japan, the GX strategy complements the current carbon tax (low: USD 2.2-2.7/tCO_2) with CfD mechanisms administered by JOGMEC, with an allocation of approximately USD 19.2 billion over 15 years to close the cost gap between low-carbon fuels and fossil alternatives. That is, Japan complements its climate objectives through the Green Transformation (GX) strategy, which incorporates CfD-type mechanisms administered by JOGMEC to close the economic gap between conventional fuels and low-carbon alternatives. These instruments reduce commercial uncertainties and facilitate the structuring of long-term supply contracts. [25][26]

Although the regulatory mechanisms analyzed differ in their design, they all share a common feature: they transform environmental compliance into an economic obligation for specific buyers. This evolution is particularly relevant for PtX projects, as it allows part of the uncertainty associated with voluntary markets to be replaced by demand signals backed by regulation. [27][28]

Demand

The main source of growth for green ammonia, e-methanol and other renewable derivatives does not come solely from corporate sustainability commitments. Increasingly, demand is being driven by regulatory instruments that turn decarbonization into an economic obligation for sectors such as maritime transport, aviation, power generation and industry.

The analysis carried out shows that the future competitiveness of PtX projects will depend simultaneously on three elements: preferential market access, the ability to meet certification standards and participation in sectors where demand is being driven by mandatory regulation. The convergence of these factors explains why certification and regulatory compliance have ceased

to be administrative requirements and have become central components of the projects' commercial and financial model. [14][15]

10 Comprehensive Feasibility Assessment: FID and Bankability Perspective

The feasibility assessment of the AkuaippaHy project is structured around five interdependent dimensions: commercial, regulatory, logistical, financial and socio-territorial. Structural weakness in any of these dimensions can prevent financial close, even when the others perform positively. The assessment does not aim to determine the absolute viability of the project, but to identify the conditions that must materialize in order to advance toward a final investment decision (FID) and subsequent financial close.

10.1 Commercial feasibility

In Project Finance terms, commercial viability is not equivalent to "sales capacity", but to the ability to generate stable, predictable and contractually protected cash flows over a horizon equivalent to the debt tenor. The relevant question, beyond whether potential demand exists or not, is whether that demand can be transformed into long-term contracts capable of supporting Project Finance financing processes.

The central distinction is between voluntary demand and regulated demand. While the former depends mainly on corporate decisions and can be affected by economic cycles, the latter arises from regulatory obligations whose non-compliance generates direct economic consequences. From a financial perspective, regulated demand offers a significantly more robust basis for structuring bankable long-term contracts. AkuaippaHy's commercial strategy must prioritize buyers exposed to climate regulation and avoid dependence on the conventional ammonia or methanol spot market [14][15][23][24][25][26][27][28].

Commercial viability also depends on the ability to close the structural gap between renewable molecules and fossil alternatives. International experience shows that this objective is achieved through revenue stack schemes that combine the price of the molecule, the value associated with emissions reduction, regulatory premiums and public support mechanisms. In the absence of these complementary revenue sources, short-term economic competitiveness continues to be a challenge for most PtX projects at a global scale. [2][3]

In its current state, the project does not have binding long-term offtake contracts. International practice shows that, to reach FID in comparable projects, between 60% and 70% of capacity must be pre-committed through long-term contracts with solid counterparties. This threshold does not constitute a universal rule, but it is a recurring reference observed in projects that have managed to advance toward construction or financial close. Below that threshold, the project faces severe restrictions in accessing competitive financing. The offtaker's credit quality is as relevant as the price: investment-grade counterparties, with financial strength or state backing, improve debt conditions, extend tenor and reduce spreads. The eventual participation of the offtaker as an equity partner (ACME-IHI model) aligns incentives and strengthens bankability. [29]

From a portfolio perspective, ammonia currently presents greater industrial maturity, greater depth of the global market and a stronger financial track record, with widely consolidated port and logistics infrastructure for its international transport. Renewable methanol shows greater growth potential in the maritime sector, driven by dual-fuel vessels from Maersk, CMA CGM and Cargill, but it introduces additional complexity: sustainable sources of biogenic CO_2 and carbon traceability systems are enabling conditions. For the location in La Guajira, the availability of biogenic biogenic CO_2 is the most relevant constraint for the e-methanol route. For this reason, ammonia emerges as the most mature entry route from a market and bankability perspective. [9]

E-methanol represents an attractive commercial opportunity in the medium term, particularly in the maritime sector, but its development will depend on the consolidation of sustainable carbon supply chains and robust traceability mechanisms. For a location such as La Guajira, the availability of biogenic biogenic CO_2 continues to be one of the main structural restrictions for the expansion of this production route.

Commercial feasibility assessment

- ✓ There is growing international demand for low-emissions ammonia and e-methanol.
- ✓ Target markets have regulatory instruments that strengthen long-term demand.
- ✓ Structuring offtake contracts continues to be a critical requirement to advance toward FID.
- ✓ Economic competitiveness depends on mechanisms that allow closing the gap against fossil alternatives.
- ✓ The e-methanol route requires resolving restrictions associated with the sustainable supply of CO_2.

10.2 Regulatory feasibility

The regulatory feasibility of the project must be understood as the ability to maintain effective access to markets, support mechanisms and sources of demand throughout the project's development and operation horizon. From the FID perspective, regulatory risk can be summarized in three fundamental questions: will the project be eligible to market its products in the target markets when it begins operations? Will it be able to maintain that eligibility in the face of methodological and regulatory changes? And are the destination regulatory frameworks sufficiently robust to support financeable long-term contracts? [14][15]

The comparative analysis of RFNBO, CHCS and the mechanisms associated with the Japanese GX strategy allows the conclusion that certification has evolved from a compliance requirement into an economic and commercial asset. In the markets analyzed, certification constitutes an enabling condition to access support schemes, participate in competitive contracting processes, serve buyers subject to regulatory obligations and capture premiums associated with low-emissions fuels. Future competitiveness will depend increasingly on verifiable carbon intensity and on the ability to demonstrate traceability and regulatory compliance through robust monitoring, reporting and verification (MRV) systems. [14][15][23][24][25][26]

This decision has design and cost implications that should be made explicit. Designing the project to comply with the European RFNBO standard, which is the most stringent, increases CAPEX compared with configurations designed for markets with less demanding requirements. The requirement for strict hourly correlation between renewable generation and electrolysis, which becomes progressively more stringent from 2030 onward, may require oversizing the renewable generation capacity or incorporating energy storage, with a direct impact on the levelized cost of production. This additional cost should be understood as the eligibility premium required to access European markets and the associated support mechanisms.

The rationale behind this trade-off is not one-sided. If the project is designed to meet the RFNBO standard and the product is ultimately sold into a less demanding market, the additional capacity or infrastructure may prove unnecessary. Conversely, the opposite scenario is equally costly: if the project is designed for a less demanding market and a buyer in a premium market such as Europe is subsequently identified, the technical configuration may need to be redesigned, potentially requiring environmental impact assessments to be repeated, with the possibility of delaying the investment decision by several years. Given that AkuaippaHy's strategic objective is the European market, designing the project to comply with RFNBO requirements from the early stages is consistent with this strategic orientation and reduces the risk of costly subsequent redesigns. This decision, however, requires the project's market orientation to be deliberate and maintained throughout all stages of project structuring. [14][15]

The most robust regulatory strategy consists of designing the project under the most stringent standards currently available, particularly RFNBO. This approach maximizes future commercial flexibility, facilitates simultaneous access to European and Asian markets and reduces risks associated with regulatory changes. However, it also implies greater technical and operational requirements, derived from criteria such as additionality, temporal correlation and energy traceability, whose impacts must be explicitly incorporated into the project's economic and financial analyses. [14][15]

In general terms, the project's regulatory feasibility is favorable. The main target markets have consolidated regulatory frameworks that, in addition to establishing certification criteria, generate structural demand for low-emissions fuels and raw

materials. However, the existence of favorable regulation does not eliminate regulatory risk; it shifts it toward the project's ability to maintain continuous compliance, adapt to eventual regulatory changes and preserve its commercial eligibility throughout the useful life of the assets.

Regulatory feasibility assessment

- ✓ The target markets have consolidated regulatory frameworks and long-term demand signals.
- ✓ AkuaippaHy can be designed to meet the most stringent international standards currently available.
- ✓ Certification constitutes a market-access mechanism, not solely a compliance obligation.
- ✓ Requirements for additionality, temporal correlation and traceability may increase investment and operating costs.
- ✓ Commercial eligibility must be maintained in the face of future regulatory and methodological modifications.

10.3 Logistical feasibility

Logistics constitutes a direct determinant of commercial competitiveness and bankability for export-oriented PtX projects. Beyond representing an operating cost, logistics influences the delivered price at destination (CFR), supply reliability, the ability to comply with long-term contracts and, in some markets, even the certifiable carbon intensity of the molecule. Depending on the product and commercial route, logistics costs may represent between 10% and 25% of the final value delivered to the buyer. [3]

AkuaippaHy's location in the Colombian Caribbean constitutes a relevant logistics advantage compared to other international competitors. Relative proximity to the main European hubs allows for reducing sailing distances and transport costs compared to routes originating from regions such as Magallanes (Chile), Australia or the Middle East. From this perspective, the project's location contributes favorably to the competitiveness of ammonia and e-methanol destined for European markets. For Asian markets, the situation is different. The greater transport distances and dependence on the Panama Canal introduce additional costs and greater exposure to operational risks, which requires incorporating these differentials from the project's commercial and financial structuring stages. [9]

Before FID, the project must have clear definitions regarding four critical elements: access to specialized port infrastructure, maritime transport contracting strategy, management of risks associated with strategic logistics corridors (particularly the Panama Canal) and compatibility between the logistics configuration and the carbon certification requirements imposed by the destination markets. [3]

In general terms, the project's logistics feasibility is favorable. The combination of Caribbean access, relative proximity to Europe, availability of existing port infrastructure and potential to integrate with international maritime corridors constitutes a relevant competitive advantage for AkuaippaHy. However, the materialization of this advantage will depend on the ability to secure port and logistics solutions compatible with the project's future scale and to adequately manage the risks associated with long-haul export routes.

Logistics feasibility assessment

- ✓ Strategic location in the Colombian Caribbean with access to the main international maritime corridors.
- ✓ Relative advantage compared to competitors farther from European markets.
- ✓ Possibility of integrating with international import hubs for ammonia and e-methanol.
- ✓ Need to secure port infrastructure and logistics capabilities compatible with the project's commercial scale.
- ✓ Exposure to risks associated with the Panama Canal and the evolution of maritime transport costs.
- ✓ Need to maintain consistency among logistics, traceability and carbon certification.

10.4 Financial feasibility

AkuaippaHy's financial feasibility depends on the ability to combine multiple revenue sources, risk-mitigation mechanisms and specialized capital sources. International experience shows that large-scale PtX projects are rarely financed through a single financial structure, requiring the articulation of commercial instruments, public support, long-term debt and private capital. [3]

From the Project Finance perspective, one of the critical factors is the alignment between the duration of offtake contracts and the debt tenor. Contractual stability allows modeling predictable cash flows and achieving financial metrics compatible with the requirements of international financiers. Consequently, the ability to secure long-term contracts with buyers of high credit quality constitutes one of the main determinants of bankability for the project. [3][29]

At the current stage of development, the most relevant financial instruments for AkuaippaHy are those oriented to project preparation and maturation. Specialized project preparation facilities (PPF), international cooperation and multilateral banking can play an important role in financing FEED (Front-End Engineering Design) studies, contractual structuring, regulatory eligibility analysis and FID preparation. [3]

In later phases, the financing strategy must consider the participation of export credit agencies (ECAs), multilateral banking and other sources of long-term debt. In this context, technology selection and the origin of strategic equipment can directly influence the available financing alternatives and the achievable financial conditions. [3]

From a financial perspective, the project's main challenge goes beyond the potential availability of financing instruments, since it corresponds to the ability to mature the elements that allow access to them, particularly offtake contracts, regulatory compliance, technological definition and comprehensive structuring of the commercial model. [3]

Financial feasibility assessment

- ✓ There is a growing international ecosystem of financial instruments oriented to PtX projects.
- ✓ The project can potentially access support schemes for preparation, structuring and long-term financing.
- ✓ The location, scale and alignment with regulated markets strengthen the potential interest of specialized financiers.
- ✓ The current absence of offtake contracts limits the project's immediate bankability.
- ✓ Regulatory eligibility and commercial structuring continue to be prerequisites for accessing competitive financing.
- ✓ Technological and contractual maturation will be decisive for advancing toward FID and financial close.

11 Risk framework and mitigation strategies

The project's risks were assessed considering simultaneously their probability of occurrence and their potential impact on the final investment decision, financial close and commercial operation. Rather than isolated risks, critical factors were identified whose materialization could compromise the project's ability to reach conditions compatible with Project Finance schemes.

From the perspective of the final investment decision, the critical risks identified are the lack of sufficient supply contracts to support financing, the inability to demonstrate compliance with international certification standards, and the materialization of social, environmental, and land-related contingencies that could affect development schedules or costs. These are the main determinants of bankability observed in comparable international projects. [29][3]

These factors are compounded by regulatory risk in destination markets associated with delays in the transposition of the RED III Directive in several European Union Member States. The renewable hydrogen uptake quotas for industry and transport, which contribute to the European demand projections presented in this study, do not impose effective obligations on buyers until each country incorporates them into its national legislation. If this process extends beyond 2027, some demand

segments that the project's commercial model considers likely in the medium term could be pushed to later horizons, reducing the pool of bankable contracts available in the period preceding the investment decision.

The most direct mitigation of this risk is to prioritize the structuring of agreements with buyers whose obligations are already in force, such as shipping companies subject to FuelEU Maritime mandates, industrial buyers exposed to CBAM, and participants in public procurement mechanisms such as H2Global. These instruments are directly applicable and do not depend on national transposition. [14][15][23][28]

The analysis evidences that the most relevant risks for AkuaippaHy concentrate in the commercial, regulatory and socio-territorial dimensions. Unlike conventional energy infrastructure projects, the main uncertainty factors are not related to the technological maturity of the production processes but to the ability to secure long-term demand, maintain regulatory eligibility and structure conditions compatible with large-scale financing. [3]

From the FID perspective, the critical risks identified correspond to the absence of sufficient offtake contracts to support financing, the inability to demonstrate compliance with international certification standards, and the materialization of socio-territorial contingencies that affect development schedules or costs. These elements constitute the main bankability determinants observed in comparable international projects. [29][3]

Nevertheless, most of the identified risks have known mitigation strategies that are applied internationally. Early structuring of strategic buyers, designing the project under RFNBO criteria, the use of economic-gap closure mechanisms, the involvement of territorial stakeholders from the initial stages and the progressive integration of specialized financial instruments allow for significantly reducing the project's exposure and improving its risk profile to investors and financiers. [3]

Comprehensive risk assessment

- ✓ No technological risks are identified that structurally compromise the project's viability.
- ✓ Internationally proven mitigation mechanisms exist for most of the identified risks.
- ✓ Securing offtakers and commercial structuring continue to be the main challenges to reaching FID.
- ✓ Regulatory compliance and certification must be maintained throughout the project's life cycle.
- ✓ Socio-territorial management will be decisive for meeting schedules and budgets.

Commercial risk – Critical to FID

Absence of firm offtake for 60-70% of capacity (a condition for Project Finance)

Mitigation

Market sounding at Gate 1; prioritize regulated buyers; evaluate offtaker-plus-equity-partner model (ACME-IHI reference)

Commercial risk – critical to FID

Structural cost gap between LCOX and fossil price without contractual closure mechanisms

Mitigation

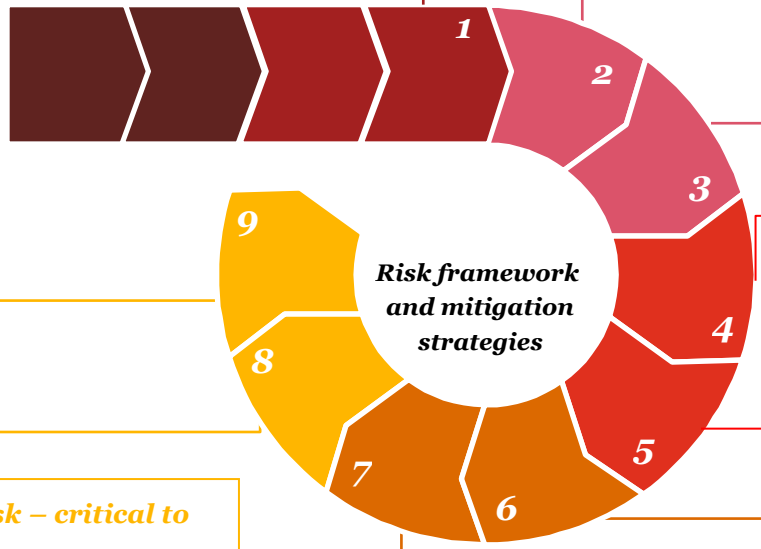
Identify eligibility under H2Global, the Korean CfD or JOGMEC; structure a multi-layer revenue stack

Regulatory risk – high

Changes in RFNBO standards (2030 hourly correlation) that require unforeseen technological adjustments

Mitigation

RFNBO-by-design approach; renewable oversizing or storage from basic engineering



Regulatory risk – critical to FID

Lack of back-to-back alignment between carbon-intensity commitments to the offtaker and the EPC contractor's guarantees

Mitigation

EPC clauses with LDs aligned to regulatory commitments; stacking of technical and environmental guarantees

Financial risk – high

Mismatch between debt tenor and offtake contractual duration

Mitigation

Offtake contracts of 15-20 years aligned with ECA-backed debt

Competitiveness risk – high

Dependence on subsidies not yet awarded in the base financial model

Mitigation

Base model viable without subsidies; subsidies only as a profitability enhancer

Social / territorial risk – critical to FID

Wayúu prior consultation: schedule risks, suspensions and cost overruns in the pre-FID phase

Mitigation

Early territorial engagement (before Gate 0); benefit-sharing mechanisms; proactive management

Logistics risk – medium

Dependence on the Panama Canal for Asian routes; freight volatility

Mitigation

Medium/long-term freight contracts; route diversification; scenario modeling with freight differentials

Technological risk – medium/high

Electrolyzer degradation above the guaranteed level impacts DSCR and certified carbon intensity

Mitigation

Robust technological performance guarantees in the EPC contract; conservative degradation factor in the financial model

A preliminary observation is necessary before describing the applicable regulatory framework. In Colombia, there is no prior institutional experience in the assessment and approval of integrated projects for the industrial-scale production of green ammonia, liquid hydrogen, or e-methanol. The National Authority for Environmental Licenses (ANLA) and the Regional Autonomous Corporations would assess these projects under the general environmental licensing framework applicable to the heavy chemical industry, as compiled in Decree 1076 of 2015, without sector-specific precedents or technical guidelines for the PtX value chain.

Nor is there a regulatory framework that recognizes the cross-cutting nature of these projects or a one-stop shop coordinating the concurrent responsibilities of the Ministries of Mines and Energy, Environment, Transport, and Trade, as well as CREG (Energy and Gas Regulatory Commission) and DIMAR (General Maritime Directorate). At the legislative level, no ongoing initiatives have been identified that specifically seek to expedite the assessment of strategic PtX projects, unlike in Brazil, where the National Hydrogen Program (PNH2) includes interinstitutional coordination measures, or in Chile, where the environmental authority has developed specific protocols for hydrogen projects as part of the environmental impact assessment process.

This situation does not constitute a prohibitive barrier, but it does imply higher structuring costs, greater uncertainty regarding environmental licensing timelines, and a higher perception of institutional risk among international financiers assessing these projects against benchmarks from other jurisdictions. [4][11]

12 Enabling Conditions for the Development of PtX Projects in Colombia

The local regulatory analysis starts from the structural observation that Colombia does not have an integrated regulatory framework specifically designed for large-scale Power-to-X (PtX) projects. In practice, the project's regulatory feasibility results from the concurrent and frequently uncoordinated application of electrical, environmental, industrial, safety and land-use regulations that were not designed to operate jointly in projects of this nature. This regulatory fragmentation is not a prohibitive barrier to the development of PtX projects, but it is a factor that increases structuring complexity, extends licensing horizons and raises due diligence costs for financiers and investors. It also implies greater requirements for institutional coordination, early structuring and regulatory management during the project's maturation phases. Consequently, Colombia's future competitiveness will depend on the availability of renewable resources, but also on its ability to consolidate enabling conditions that allow natural advantages to be transformed into bankable projects and effective exports of renewable molecules. [4]

12.1 Land-use planning and access to land

The development of an integrated hydrogen-and-derivatives project requires significant land areas that must simultaneously accommodate energy, industrial and logistics infrastructure. In La Guajira, this dimension acquires additional complexity due to the convergence of high renewable potential, the presence of collective indigenous territories of the Wayúu people, multiple land-use planning instruments and environmental restrictions. The project's preliminary configurations (460 MW wind and 540 MWp solar) constitute a conceptual reference that must be validated and optimized during subsequent engineering and structuring stages.

The regulatory basis is Law 388 of 1997 and the municipal Land-Use Plans (POT). The industrial complex is classified as a high-impact industrial use, which may limit location options to previously delineated industrial or port zones. For this reason, compatibility between technical design and land-use planning must be evaluated from the early stages of the project, avoiding urban or environmental restrictions that may generate subsequent design rework.

The presence of Wayúu communities implies that certain components will require prior consultation processes in accordance with ILO (International Labour Organisation) Convention 169 and Colombian regulations, which introduces time requirements and schedule risks that must be incorporated into the project's planning and financial viability analyses. The

recent experience of renewable energy projects in La Guajira demonstrates that the early management of territorial engagement is a decisive factor for compliance with schedules and the reduction of development risks.

Multiple levels of government intervene in land access: municipalities (POT), departmental governments (supramunicipal coordination), and Regional Autonomous Corporations (CAR) and ANLA (environmental restrictions). Land access, rather than an administrative requirement, is a process of territorial governance that conditions the environmental, social and regulatory viability of the industrial complex.

Implication for AkuaippaHy

Physical land availability does not appear as a structural restriction for the project. However, coordination between land-use planning, environmental management and community engagement constitutes a critical enabling condition that must be addressed from the earliest stages of maturation in order to reduce risks to schedule, cost and bankability.

12.2 Enabling energy infrastructure and electrolysis

The configuration of the energy system constitutes a strategic decision for PtX projects, since it simultaneously affects economic competitiveness, operational performance and compliance with the certification standards required by international markets. For AkuaippaHy, the analysis developed identifies fully off-grid configurations with dedicated renewable generation as the most robust alternative to meet the additionality, temporal correlation and geographic correlation requirements established by the European Union's RFNBO scheme.

Although configurations connected to the National Interconnected System (SIN) could offer operational advantages in certain scenarios, they present relevant challenges from the perspective of energy traceability and demonstration of renewable attributes. The absence of fully implemented mechanisms for temporal granularity and energy certification compatible with international standards currently limits the ability to robustly demonstrate compliance with the requirements imposed by premium markets.

Electrolysis constitutes the industrial core of the project and the main point of integration between electrical, industrial, environmental and safety regulation. Colombia does not have a specific regulatory framework for this technology, so its development depends on the concurrent application of standards associated with electrical connection, industrial facilities, process safety and environmental management.

From the project development perspective, the most relevant aspects correspond to the availability of energy infrastructure, connection or self-generation requirements, industrial risk management and sustainable water supply. The latter aspect acquires special relevance in La Guajira, where water-stress conditions make it foreseeable that desalination systems will be incorporated as an integral part of the technological solution.

Finally, environmental licensing emerges as one of the main determinants of the schedule toward FID. The absence of regulatory precedents for large-scale PtX complexes implies that the authorities will have to evaluate novel industrial configurations that integrate renewable generation, electrolysis, derivatives production and logistics facilities within a single value chain.

Implication for AkuaippaHy

The enabling of energy infrastructure and electrolysis does not appear as an insurmountable regulatory barrier to the project's development. However, the early adoption of an architecture compatible with RFNBO standards, the proper management of water resources and the anticipated planning of licensing processes constitute enabling conditions to reduce schedule risks and preserve the project's commercial eligibility.

12.3 Production and transformation of renewable molecules

The production of derivatives introduces a substantial change in the project's regulatory complexity, transforming a generation-and-electrolysis facility into an industrial chemical-processing complex. This transition implies greater requirements in terms of environmental, industrial safety, risk management and territorial engagement, bringing the project closer to the regulatory standards applicable to the large-scale chemical industry.

In the case of ammonia, the main regulatory implication is associated with the handling of hazardous substances and the need to incorporate advanced process-safety criteria from the initial design stages. Although Colombia does not have a specific regime for green ammonia, there is a sufficient regulatory framework for its development based on environmental, industrial and risk-management standards complemented by international standards widely used by the global chemical industry.

E-methanol introduces additional complexity by incorporating the carbon dimension into the project's regulatory and commercial model. Beyond conventional environmental and industrial requirements, access to international markets depends on the ability to demonstrate the origin, traceability and carbon intensity of the CO_2 used during the synthesis. In this context, biogenic CO_2 sources currently present the route of lowest regulatory risk and greatest acceptance in the international certification schemes.
The growing importance of standards such as RFNBO implies that the production of e-methanol must be designed from a comprehensive carbon-accounting perspective, incorporating life-cycle analysis methodologies, monitoring, reporting and verification (MRV) systems, and traceability mechanisms compatible with the requirements of destination markets. Consequently, carbon management ceases to be a complementary environmental aspect and becomes a central component of the project's commercial and regulatory strategy.

Implication for AkuaippaHy

From a regulatory perspective, ammonia currently represents the most mature development route and the one with the lowest implementation complexity. E-methanol offers a particularly attractive commercial opportunity in premium markets, but requires the robust resolution of issues associated with the sustainable supply of CO_2, carbon traceability and compliance with international certification standards

12.4 Logistics and port infrastructure

Logistics infrastructure is an enabling element for the international competitiveness of export-oriented PtX projects. Although Colombia does not currently have a specific regulatory framework for large-scale storage and handling of hydrogen and derivatives, there is a set of environmental, industrial, transport and safety regulations that allows for structuring this type of project under standards equivalent to those used internationally.

The logistics management of ammonia, methanol and hydrogen requires the adoption of technical and safety standards comparable to those of the international petrochemical industry, both for storage and for land and maritime transport. In practice, compliance with international standards constitutes a requirement of insurers, certifiers, buyers and financiers, regardless of the existence of specific regulatory requirements in national regulation.

From a territorial perspective, proximity to port infrastructure acquires special relevance for export projects. The need to mobilize large product volumes, as well as the requirements associated with specialized storage and hazardous-substance handling, favor integrated configurations between industrial production and port facilities. In this context, strategic assets such as Puerto Bolívar and Puerto Brisa represent a relevant advantage for the development of PtX projects in La Guajira.

In addition, access to international markets requires compliance with global maritime standards and the assurance of robust chain-of-custody and traceability mechanisms. The preservation of certified environmental attributes throughout the entire

logistics chain becomes an indispensable requirement to maintain the commercial eligibility of the molecules in regulated markets.

Implication for AkuaippaHy

Logistics and port infrastructure does not currently constitute a structural barrier to the project's development. On the contrary, the strategic location of La Guajira and the existence of international-scale port infrastructure represent a relevant competitive advantage. However, the early integration of industrial design, logistics strategy and traceability systems will be fundamental to preserving the project's competitiveness and commercial eligibility in international markets.

12.5 Incentives and promotion mechanisms

Tax incentives currently constitute the main public-policy instrument available in Colombia to promote low-emissions hydrogen and derivatives projects. Unlike other markets that have developed specific mechanisms for demand creation or economic-gap closure — such as H2Global in Germany, CHCS in South Korea or CfD schemes in Japan — the Colombian model has focused mainly on reducing investment costs through tax and customs benefits.

The current framework, developed from Law 1715 of 2014 and expanded by Law 2099 of 2021, allows access to benefits such as a special income-tax deduction, accelerated depreciation of assets, VAT (Value-Added Tax) exclusion and tariff exemption for eligible equipment and technologies. These instruments can contribute significantly to CAPEX reduction and to the improvement of financial indicators during the project's initial stages.

However, effective access to these benefits depends on the eligibility certification issued by UPME (Mining and Energy Planning Unit) and on the ability to demonstrate that the equipment and components form part of a project aligned with the energy transition objectives defined by the current regulation. In integrated PtX projects, this assessment may be particularly relevant for components associated with electrolysis, derivatives synthesis, auxiliary systems and certain support infrastructure.

Table 8. Tax incentives contemplated in Colombian public policy, regulation and normative framework

Source: Law 2099 of 2021 [31]; Decree 895 of 2022 [32]; UPME Resolutions 135 and 736 of 2025.

Instrument	Description	Implication for AkuaippaHy
Special income-tax deduction	Deduction of up to 50% of the value of the investment in eligible assets, distributed over a maximum of 15 years, capped at 50% of net taxable income per taxable period.	Requires generating sufficient net taxable income in Colombia. Conditions the design of the investment vehicle and the location of revenues. May require specific structures for its effective use.
Accelerated depreciation of assets	Reduction of the fiscal useful life of eligible equipment. Accelerates the recognition of the depreciation expense, reducing the taxable base in the early years.	Direct impact on after-tax cash flow in the early years — the most sensitive for debt repayment in Project Finance.
VAT exclusion	Exclusion of value-added tax on goods and services necessary for the implementation of the project.	Immediate impact on CAPEX. Relevant for electrolyzers, turbines, reactors and auxiliary systems, which are mostly imported and of high unit value.
Tariff exemption	Exemption from customs duties for the import of equipment, machinery and materials not produced in the country, subject to demonstration of the absence of equivalent domestic production and prior certification by UPME.	Cumulative effect with the VAT exclusion on CAPEX reduction. Strategic given that the AkuaippaHy supply chain depends largely on imported technology.

From AkuaippaHy's perspective, tax incentives represent a positive element within the project's financial structure, but they do not replace the need for long-term contracts, international certification and mechanisms that allow closing the economic

gap against fossil alternatives. Their main contribution is to improve the competitiveness of the investment and to facilitate financial structuring during the development and construction stages.

Implication for AkuaippaHy

Colombia has a favorable tax-incentive framework for PtX projects, capable of reducing investment costs and improving financial indicators. However, a gap still exists with respect to markets that have developed specific mechanisms for demand creation and commercial-risk mitigation, so the project's competitiveness will continue to depend mainly on its ability to access regulated international markets and structure bankable long-term contracts.

12.6 Structural regulatory gaps

The analysis carried out shows that Colombia has favorable conditions for the development of PtX projects from the perspective of renewable resources, market access and tax incentives. However, certain regulatory and institutional gaps persist that may affect the speed of maturation, the international competitiveness and the bankability of export-oriented projects such as AkuaippaHy. The main gaps identified are:

- Absence of a consolidated national system for renewable-attribute certification interoperable with international standards such as RFNBO, CHCS or the mechanisms associated with the Japanese GX strategy.
- Limited maturity of energy-traceability and carbon-accounting mechanisms, particularly in aspects related to temporal granularity, chain of custody and verification of environmental attributes.
- Still incipient institutional experience in evaluating and supporting large-scale export-oriented PtX projects.
- Absence of an integrated regulatory framework that recognizes the cross-cutting nature of PtX projects, located at the intersection of the energy, industrial, environmental, logistics and trade sectors.
- Need to strengthen coordination among entities with concurrent competences, including the Ministry of Mines and Energy, UPME, CREG, the Ministry of Environment, ANLA, the Ministry of Trade and DNP (National Planning Department).

Nevertheless, these gaps should be interpreted as institutional-maturation challenges rather than as structural barriers to the project's development. Similar situations have been observed in countries that currently lead the development of hydrogen and derivatives, including Chile, Brazil, Morocco, Namibia and Egypt. International experience shows that the consolidation of certification, traceability and institutional-coordination mechanisms typically occurs in parallel with the development of the first large-scale projects.

Implication for AkuaippaHy

The main regulatory gap identified is not associated with the production of hydrogen or derivatives, but with the ability to demonstrate and robustly certify the renewable attributes of the molecules produced. In this sense, the strengthening of certification, traceability and institutional-governance mechanisms constitutes one of the main opportunities to consolidate Colombia as an export platform for renewable fuels and raw materials.

13 Maturation roadmap to FID

International experience demonstrates that successful PtX projects advance through progressive processes of reducing commercial, regulatory, technical and financial uncertainty. Consequently, the final investment decision (FID) must be understood as the result of a structured sequence of validations that allow a market opportunity to be transformed into a financeable asset.

Table 9. Roadmap to the final investment decision

Source: Óptima Consultores (2026). Market Study and Regulatory Analysis of the AkuaippaHy Project – Volume III [3].

Gate	Horizon	Key actions	Progress criteria
Gate 0 – Minimum viable structural definition	2026-2027	Define the priority molecule (ammonia vs. methanol) under bankability criteria. Realistic preliminary sizing. Electrical configuration (dedicated, hybrid, grid). Carbon-intensity modeling under RFNBO. Identification of the port and base logistics scheme. Preliminary financial modeling.	Product defined under a technical-financial rationale. LCOX modeled with structural sensitivity. Conservatively estimated carbon intensity. Validated preliminary logistics route. Formal decision to advance to advanced pre-feasibility.
Gate 1 – Commercial validation and preliminary structuring	2027-2028	Market sounding with utilities and regulated offtakers. Signing of NDAs and non-binding MoUs. Comparative assessment of EU vs. Asia. Analysis of viable contractual structure. ECA eligibility assessment. Preliminary back-to-back EPC–offtake analysis.	Formal interest from ≥1-2 anchor buyers. Confirmation of eligibility in the priority market. Defensible target price in the regulated market. Confirmed ECA or multilateral appetite. Decision to launch a financed FEED.
Gate 2 – Financeable FEED and pre-FID structuring	2028-2029	Execution of detailed FEED. Technically closed CAPEX. Advanced negotiation of offtake contracts (HPA). Formal structuring with ECAs. Validation of DSCR under conservative scenarios. Closure of the definitive logistics scheme.	≥60% of capacity committed under firm contracts. EPC contract with performance and carbon-intensity guarantees. Approved ECA structure. DSCR ≥1.6-1.7x in a downside scenario. CAPEX within a bankable range. Critical risks mitigated or insured.
Gate 3 – Construction (post-FID)	2030 onward	Definitive EPC closure with LDs. Technical-financial PMO. Independent technical supervision (Owner's Engineer). Management of interfaces between subsystems. Progressive validation of projected carbon intensity.	Physical completion in line with schedule. Technical performance tests (PAC). Verification of guaranteed specific efficiency. Initial validation of carbon intensity. Formal activation of offtake contracts.
Gate 4 – Operation and preservation of bankability	Post-COD	Continuous MRV. Periodic carbon-intensity audits. Active contractual management with offtakers. Monitoring of the evolution of regulatory frameworks. Global competitive monitoring. Technical-financial evaluation for a Phase 2 expansion.	Sustained technical performance ≥24 months. Actual DSCR aligned with or superior to the modeled level. Confirmed regulatory eligibility without reclassifications. Contractual compliance without material disputes.

- **Minimum conditions to advance toward FID**

The integrated analysis carried out in this study concludes that the evolution of AkuaippaHy toward a final investment decision will depend on meeting five enabling conditions:

1. **Validation of demand and strategic buyers**
   Securing buyers with financial capacity and exposure to regulated markets, capable of supporting long-term contracts compatible with Project Finance schemes.

2. **Confirmation of regulatory eligibility**
   Demonstrating the feasibility of compliance with international certification standards, particularly RFNBO, including additionality, traceability, MRV and chain of custody.

3. **Consolidation of the commercial strategy**

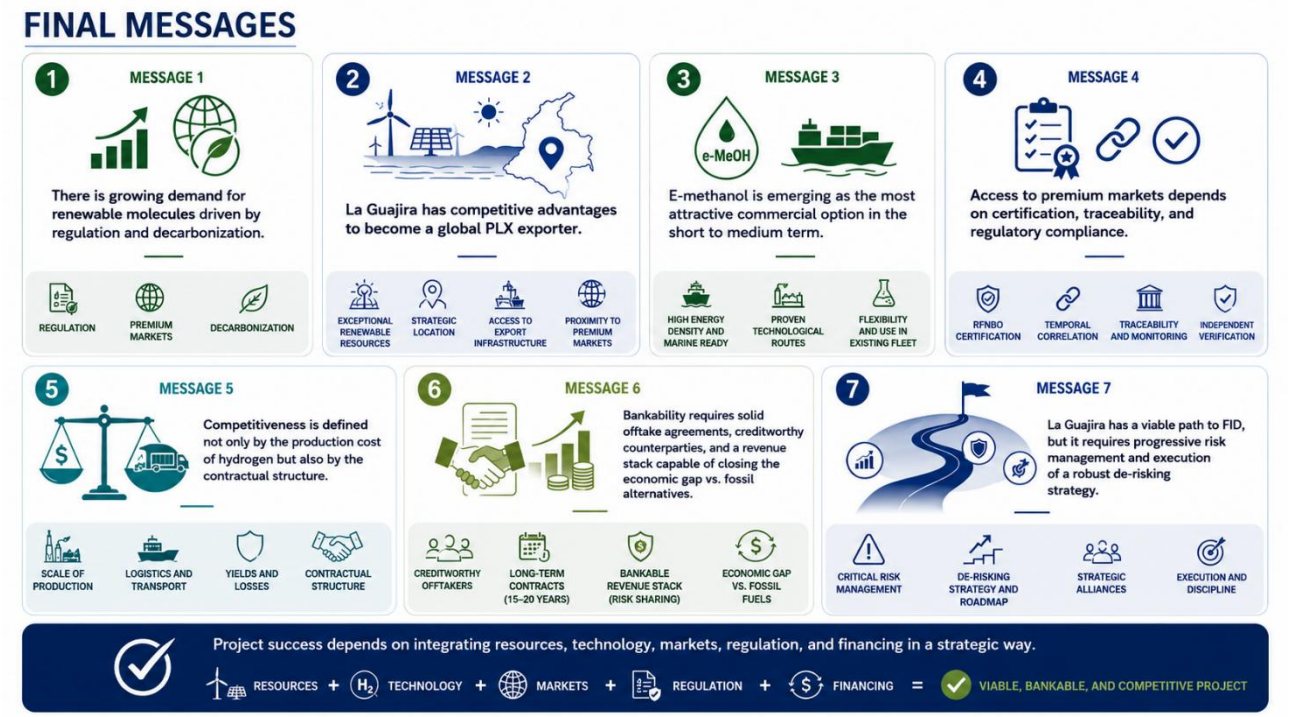
Defining target molecules, priority markets, contractual structure and economic-gap closure mechanisms compatible with the revenue stack required by the project.

4. **Technical and logistical maturation**
   Completing FEED studies, technological definition, carbon-sourcing strategy, logistics infrastructure and port solutions required for export.

5. **Financial structuring**
   Aligning contracts, certification, risks and commercial strategy with the requirements of financiers, export credit agencies and potential investors.

Figure 12. Critical success factors.

Source: own elaboration, Óptima Consultores (2026).



The integrated analysis of market, regulation, competitiveness, infrastructure, bankability and risks allows the conclusion that AkuaippaHy is aligned with the main trends currently driving the development of PtX projects at a global level. The existence of regulated demand for renewable molecules, the competitive advantages of La Guajira as an export platform and the growing consolidation of premium markets for ammonia and e-methanol configure a real opportunity for Colombia's insertion into the international supply chains of low-emissions fuels and raw materials.

However, international experience demonstrates that the availability of renewable resources and technological viability constitute only the starting point. The materialization of projects of this scale depends on the ability to transform comparative advantages into competitive advantages through certification, commercial structuring, risk management and access to financing mechanisms compatible with Project Finance schemes.

Consequently, the next step consists of identifying the priority actions that allow reducing uncertainties, strengthening the project's value proposition and accelerating its transition from a market opportunity to a final investment decision.

14 Regulatory and institutional strengthening agenda to consolidate Colombia as a PtX export platform

The analysis carried out evidences that Colombia has relevant competitive advantages to participate in the international markets for renewable molecules. However, taking advantage of this opportunity will depend on the ability to strengthen certain enabling conditions that allow reducing regulatory uncertainties, facilitating access to international markets and improving the bankability of projects. The following agenda proposes actions prioritized by time horizon.

Table 10. Prioritization of actions for institutional strengthening[4]

Source: Óptima Consultores (2026). Market Study and Regulatory Analysis of the AkuaippaHy Project – Volume IV [4].

Horizon	Strengthening line	Strategic objective	Lead actors
Short term	National MRV, traceability and interoperable certification system	Develop mechanisms compatible with RFNBO, CHCS and international schemes that allow demonstrating verifiable renewable attributes for hydrogen and PtX derivatives.	Ministry of Environment, IDEAM
	Additionality, temporality and energy traceability	Establish regulatory and contractual guidelines for dedicated PPAs, environmental attributes and temporal granularity compatible with international markets.	Ministry of Mines and Energy, CREG, UPME
	Preparation tools for international bankability	Develop contractual models, risk allocation and capabilities for interaction with ECAs, multilateral banking and international investors.	Ministry of Finance, FDN
Medium term	Logistics and port infrastructure for PtX export	Strengthen national capabilities for the storage, handling and export of ammonia, e-methanol and hydrogen under international standards.	Ministry of Transport, DIMAR, Port Authorities
	Industrial safety technical framework for renewable molecules	Develop technical guidelines and regulatory criteria for export-oriented hydrogen, ammonia and methanol facilities.	Ministry of Environment, ANLA
Long term	Foreign trade facilitation and rules of origin	Consolidate institutional capabilities for chain of custody, documentary certification and compliance with international trade requirements.	Ministry of Trade, DIAN
	PtX governance and institutional coordination	Strengthen the articulation among energy, environmental, industrial, port and commercial entities to reduce regulatory frictions and accelerate the development of projects.	MME, MinAmbiente, MinComercio, UPME, CREG, ANLA, DNP

The main institutional-strengthening opportunity for Colombia is to consolidate certification, traceability, regulatory-coordination and market-access capabilities that allow capturing the economic value associated with renewable molecules.

[4] IDEAM: Instituto de Hidrología, Meteorología y Estudios Ambientales.
FDN: Financiera de Desarrollo Nacional.
DIAN: Dirección de Impuestos y Aduanas Nacionales
MME: Ministerio de Minas y Energía
MinComercio: Ministerio de Comercio

International experience demonstrates that the countries that will lead the PtX economy will be those able to convert competitive renewable resources into certified, financeable and globally tradable products.

15 Conclusions

The integrated analysis carried out allows the identification of the main messages for the AkuaippaHy project's decision-making process. These elements summarize the factors that will determine its competitiveness, market access, bankability and evolution toward a final investment decision (FID).

The central question is no longer whether AkuaippaHy can produce renewable molecules, but under what conditions it can commercialize them, finance them, and transform them into a bankable project. The following messages summarize the key considerations for investment decisions.

MARKET
There is structural demand for green ammonia and e-methanol driven by climate regulation and industrial decarbonization.

BANKABILITY
The main challenge is not technological—it is securing demand, contracts, and financing structures compatible with project finance.

LOGISTICS
La Guajira combines world-class renewable resources, port access, and strategic export logistics.



DESTINATIONS
Europe represents the natural entry market, while Asia offers the largest long-term growth opportunity.

MOLECULES
Ammonia provides the most mature market pathway, while e-methanol offers the strongest long-term commercial upside.

CERTIFICATION
RFNBO should be incorporated as a project design parameter rather than a post-development regulatory requirement.

7 KEY MESSAGES FOR DECISION-MAKING

1 STRUCTURAL DEMAND
International demand for renewable molecules is growing, driven by climate policies and decarbonization targets.

2 LA GUAJIRA IS COMPETITIVE
Its combination of world-class renewable resources, port infrastructure, and strategic location positions Colombia as a competitive export platform.

3 AMMONIA IS THE ENTRY ROUTE
Ammonia is currently the most mature technological, logistical, and commercial pathway for early project monetization.

4 THE BOTTLENECK IS COMMERCIAL AND FINANCIAL
The primary challenge is not technology, but rather securing long-term demand and bankable financial structures.

5 RFNBO MUST BE A DESIGN STANDARD
Certification and eligibility criteria should be integrated from project inception to access premium markets and support mechanisms.

6 OFFTAKE IS CRITICAL FOR FID
Long-term agreements with anchor buyers are essential to reach FID and ensure bankability.

7 WINDOW OF OPPORTUNITY
Colombia has a real opportunity to become a leading exporter of renewable molecules, but success requires closing regulatory gaps and strengthening institutional capabilities.

Project success depends on integrating resources, technology, markets, regulation, and financing in a strategic way.

RESOURCES + TECHNOLOGY + MARKETS + REGULATION + FINANCING = VIABLE, BANKABLE AND COMPETITIVE PROJECT

Key messages for decision-making

1. Structural international demand exists for renewable molecules.
Demand for green ammonia, e-methanol and other derivatives is being driven by binding regulation, carbon-pricing mechanisms and industrial and maritime decarbonization objectives in Europe and Asia

2. La Guajira possesses competitive conditions to become an international-scale PtX export hub.
The combination of world-class renewable resources, strategic port infrastructure and relative proximity to European markets positions Colombia favorably against other emerging competitors.

3. Ammonia represents the most mature entry route for the first phase of development.
Technological availability, market depth, existing logistics infrastructure and lower dependence on carbon sources make ammonia the alternative with the lowest implementation complexity in the short term.

4. E-methanol emerges as the main medium-term commercial opportunity.
The growing demand associated with maritime decarbonization generates a relevant opportunity for certified molecules, although its development will depend on the sustainable and traceable availability of CO_2.

5. Certification must be understood as a component of the economic model and not as an administrative requirement.
RFNBO eligibility and other equivalent schemes determine market access, price premiums, support mechanisms and contracting conditions, directly affecting the project's competitiveness and bankability.

6. The main challenge is no longer technological, but commercial and financial.
International experience demonstrates that PtX projects reach FID when they manage to secure long-term demand, structure bankable contracts and reduce the economic gap against fossil alternatives.

7. Offtake constitutes the critical condition to reach FID.
The ability to secure anchor buyers, with credit strength and exposure to regulated markets, will be the main determinant of the project's financial viability.

8. Colombia has a real window of opportunity, but it requires strengthening certification, traceability and institutional-coordination capabilities.
The consolidation of these enabling conditions will be decisive for transforming natural advantages into sustainable international-scale exports of renewable molecules.

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