CASE STUDY

BUSINESS MODELS FOR GREEN HYDROGEN IN LATIN AMERICA

3. GREEN AMMONIA PRODUCTION IN MAGALLANES CHILE

H2GO

This publication is part of the activities of the project "Advancing a Regional Approach to the Green Hydrogen Economy in Latin America and the Caribbean" (H2 ¡Vamos! / H2 Go!), an initiative led by the United Nations Environment Programme (UNEP) and funded by the Green Climate Fund. The project aims to strengthen regional capacities to promote a just, inclusive, and sustainable green hydrogen economy.

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1. EXECUTIVE SUMMARY

In 2024, Chile reaffirmed its leadership in the green hydrogen economy with the development of the HNH Energy Project, located in the Magallanes Region. This project, led by AustriaEnergy, Ökowind, and Copenhagen Infrastructure Partners (CIP), aims to produce 1.3 million tons of green ammonia annually using hydrogen generated from wind energy and water obtained through seawater desalination [1], [2]. With an estimated investment of USD 11 billion in its first phase, the project seeks to meet the growing global demand for sustainable chemical products, particularly in markets such as Europe and Asia [2]. This effort combines exceptional natural resources, advanced technologies, and a favorable political environment, positioning Chile as a global benchmark in industrial decarbonization [3].

2. BACKGROUND AND CONTEXT

Conventional ammonia production is responsible for 2% of global CO_2 emissions due to the intensive use of natural gas as an energy input. In the face of this challenge, green hydrogen emerges as a sustainable and effective alternative to decarbonize this sector. Chile, with its exceptional potential for renewable energy generation—particularly wind—is in a privileged position to lead this transition. The Magallanes and Chilean Antarctic Region, in particular, offers unique conditions, such as consistent winds with average speeds exceeding 10 m/s, making it an ideal site for projects of this magnitude.

In this context, the project is framed within Chile's National Green Hydrogen Strategy, adopted in 2020, which sets clear goals to position the country as one of the world's leading exporters of green hydrogen [3], [4].

3. PROJECT DESCRIPTION

The HNH Energy project is located in the commune of San Gregorio, 120 km north of the city of Punta Arenas, in the Magallanes Region. It centers on the construction of a 1.4 GW wind farm to power advanced electrolysis systems and meet the energy needs of the project under an off-grid scheme. These electrolyzers will generate green hydrogen, which will be synthesized into ammonia using the Haber-Bosch process.

With a total estimated investment of USD 11 billion in its initial stage, the project aspires to become one of the largest producers of green ammonia globally. After completing both development phases, it is expected to reach a production capacity of 1.3 million tons of green ammonia per year. The products are primarily intended for international markets, especially in Europe and Asia, where demand for sustainable inputs is high [1], [2].

4. USE OF TECHNOLOGY

The HNH Energy project harnesses high-efficiency wind energy generated in the Magallanes Region to produce green hydrogen through electrolysis. This hydrogen is then converted into green ammonia, a key input for the decarbonization of chemical, agricultural, power generation, and maritime industries. The process involves the following stages:

GREEN HYDROGEN PRODUCTION

1. **Renewable Energy Generation:**

   - The project features a 1.4 GW wind farm, strategically located in the commune of San Gregorio, Magallanes and Chilean Antarctic Region, where average wind speeds exceed 10 m/s. This location ensures a stable and reliable supply of clean electricity.
   - The wind turbines are designed to operate under the extreme weather conditions of the region, equipped with advanced systems that maximize energy generation in highly variable climates [1], [2].

2. Water Purification and Preparation:

- Before electrolysis, the water is treated through reverse osmosis and electrodeionization (EDI) systems to remove impurities.
- The desalination plant associated with the project will produce 175 liters per second of desalinated water, the amount required for the process.

3. Electrolysis:

- The alkaline electrolyzers, with a total initial capacity of 1,000 MW, split water into hydrogen and oxygen using electricity.
- This system operates with an efficiency of 70–75%, generating approximately 850 tons of green hydrogen per day [1].

4. Hydrogen Purification:

- The hydrogen produced is purified using DeOxo catalysts and advanced separation systems, ensuring the removal of oxygen traces, water, and other elements.
- This step is essential to meet the technical specifications required for ammonia synthesis.

GREEN AMMONIA SYNTHESIS AND PRODUCTION

1. Nitrogen Capture:

- The nitrogen required for ammonia production is extracted from the air using cryogenic and pressure swing adsorption systems, achieving 99.9% purity.
- These systems are fully integrated into the subsequent synthesis processes, ensuring process sustainability.

2. Haber-Bosch Reaction:

- The green hydrogen and purified nitrogen are combined in Haber-Bosch reactors designed to operate with hydrogen produced by electrolysis.
- The reactors operate at 150–200 bar pressure and around 400 °C, using modified iron catalysts.
- Unconverted gases are recycled in each cycle using advanced compressors, optimizing efficiency and minimizing losses [1].

3. Storage and Transportation:

- The resulting ammonia is stored in cryogenic tanks designed to maintain -33 °C at atmospheric pressure, ensuring the product remains in liquid form.
- The HNH Energy project includes the development of a private port terminal, open to public use, with automated loading systems to facilitate the export of green ammonia to international markets such as Europe and Asia [1], [2].

OPERATIONAL AND ENVIRONMENTAL BENEFITS

1. Emission Reduction:

- Replacing natural gas with green hydrogen will eliminate up to 1.5 million tons of CO_2 annually in conventional ammonia production.

2. Energy Efficiency:

- The integration of wind energy produced in Magallanes ensures competitive costs and a sustainable supply.

3. Scalability:

- The modular infrastructure under which the HNH Energy project is designed allows for future expansion of production capacity by adding 2 GW of electrolysis and 2 million tons of green ammonia per year.

KEY INNOVATIONS IN THE PROJECT

1. **Advanced Digital Control:**
   - Real-time sensors and monitoring systems optimize energy efficiency and ensure compliance with quality standards.

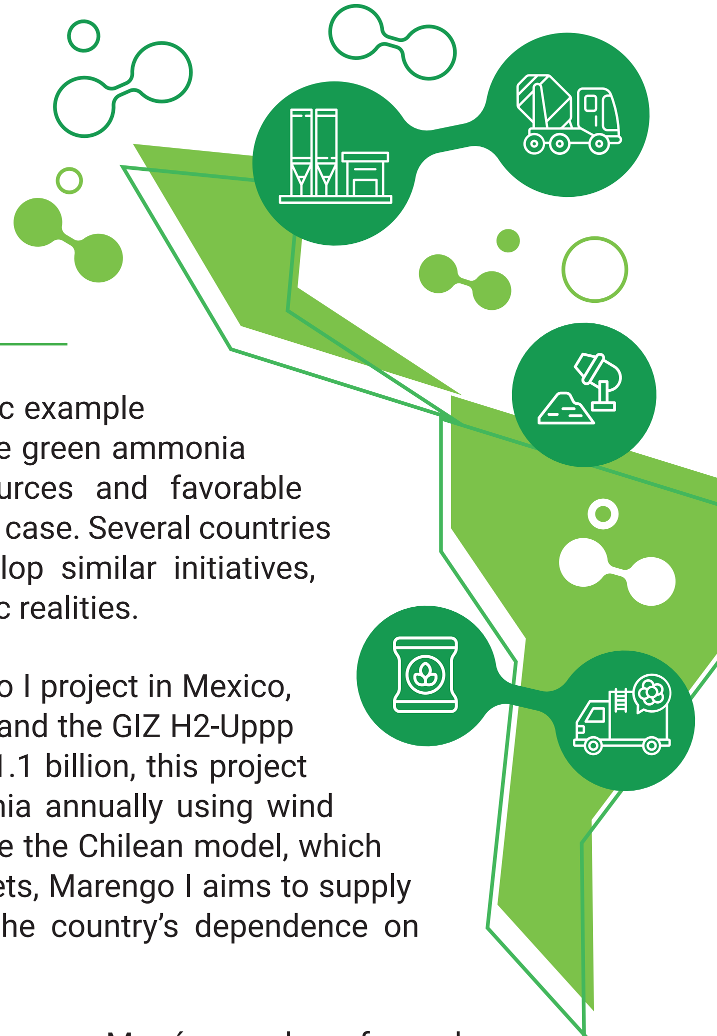
2. **Integration with Renewable Energy:**
   - The electricity generated by the wind farm is connected directly to the electrolysis systems, eliminating intermediaries and maximizing sustainability. The project is designed for off-grid operation, where all the energy used is 100% renewable and generated by the project itself.

3. **Regulatory Compliance:**
   - The project is proposed in line with the highest quality standards and international norms, facilitating acceptance in regulated markets. As a new industry, various markets are developing specific regulations for green ammonia, which are being considered and adopted in the project's development.

5. VALUE PROPOSITION

The HNH Energy project directly contributes to positioning Chile as a global leader in the decarbonization of the chemical industry by offering green ammonia that reduces CO_2 emissions by 90% compared to conventional production. This project not only contributes to the global emission reduction targets established by the Paris Agreement, but also meets the growing international demand for sustainable chemical inputs, particularly in Europe and Asia, where environmental regulations are strict [3], [4].

Moreover, the project seeks to foster regional economic development by generating approximately 4,000 direct jobs during the construction phase and around 1,000 jobs during operation. The integration of local wind energy ensures long-term competitive costs, strengthening Chile's position as a competitive exporter of sustainable products. Finally, the modular infrastructure allows for efficient scalability, ensuring the project can expand to meet future global market demand [1], [2].



6. SIMILAR PROJECTS IN LATIN AMERICA AND REGIONAL ADAPTATION

The HNH Energy project stands as an emblematic example of Latin America's capacity to develop large-scale green ammonia projects, leveraging abundant renewable resources and favorable geographic conditions. However, it is not a unique case. Several countries in the region have begun to explore and develop similar initiatives, adapted to their respective markets and economic realities.

One of the most notable examples is the Marengo I project in Mexico, developed by Hy2gen in partnership with MexCo and the GIZ H2-Uppp program. With an estimated investment of USD 1.1 billion, this project plans to produce 170,000 tons of green ammonia annually using wind and solar energy in the state of Campeche. Unlike the Chilean model, which focuses on exports to Asian and European markets, Marengo I aims to supply Mexico's domestic fertilizer industry, reducing the country's dependence on imported agricultural inputs [5].

In Colombia, the District of Barranquilla and the company Monómeros have formed an alliance to produce green ammonia with the goal of decarbonizing fertilizer production and strengthening the agricultural sector. Although the project is still in a preliminary stage, it highlights the growing demand for sustainable solutions in the Latin American market [6].

In addition to HNH Energy, Chile hosts other initiatives that reinforce its position in the green hydrogen and ammonia sector. These include the green hydrogen and ammonia project by MAE, and the partnership between Glenfarne Energy Transition and Samsung Engineering, both aiming to consolidate Chile as a key supplier of sustainable fuels and chemicals. Likewise, Statkraft Chile has secured co-financing for green hydrogen and ammonia studies, demonstrating the country's ongoing advancement in its decarbonization strategy [1].

These examples show that green ammonia development in Latin America is not limited to large-scale export projects like HNH Energy. There are opportunities to adapt these models to various scales, from massive initiatives aimed at export, to smaller local developments supplying national or regional industries, particularly in the agricultural and energy sectors.

In countries such as Honduras or El Salvador, where energy infrastructure and investment capacity are more limited, a feasible approach could involve the development of modular green hydrogen and ammonia production plants, scalable based on local demand. These types of projects could be supported by government incentives and international financing, similar to the schemes implemented in Chile and Mexico.

> ***Analyzing these projects across Latin America reveals replication and scalability opportunities for the HNH Energy model, promoting green hydrogen as a viable alternative for the chemical, agricultural, and energy industries in the region. At the same time, it emphasizes the need to adapt these developments to the economic, energy, and logistical conditions of each country to ensure long-term viability and sustainability.***

7. MARKET SEGMENT

The target market for the HNH Energy project includes a combination of local and international clients, focused on key sectors that require green ammonia to decarbonize their operations. The main market segments are described below:

1. **Chemical Industries:**
   - Europe and Asia represent the main international markets due to their high demand for sustainable chemical products such as fertilizers and chemical precursors for the agricultural and manufacturing industries.
   - Companies seeking low-carbon alternatives to comply with strict environmental regulations, such as the European Union's Carbon Border Adjustment Mechanism (CBAM), are a priority customer base [3], [4].

2. **Agriculture:**
   - Green ammonia is a key input for the production of sustainable fertilizers, highly demanded in agricultural markets across Europe, Asia, and North America.
   - Locally, the project can supply Chilean agribusinesses, promoting sustainable agricultural practices and reducing the environmental footprint of the national agricultural sector.

3. Mining Sector in Chile:

- Local mining companies, which are a priority sector for decarbonization, could benefit from the use of green ammonia and other hydrogen-derived products to reduce their carbon footprint.
- However, the HNH Energy project's location in Magallanes poses logistical challenges in supplying the mining region of Antofagasta, where most of Chile's mining activity is concentrated. This distance implies additional transportation and storage costs compared to green hydrogen producers located closer to the country's northern operations.

4. Carbon Certificates:

- Beyond direct sales of green ammonia, the project will generate additional income through the commercialization of carbon certificates in international markets, particularly in Europe, where carbon prices are steadily increasing [4].

5. Diversification of Green Ammonia Uses:

- In the medium term, the green ammonia produced by the project could also be used as marine fuel for cargo ships. This emerging market has the potential to significantly reduce emissions in the maritime sector, further consolidating Magallanes as a global hub for green energy.

8. KEY ACTIVITIES

The success of the HNH Energy project is based on strategic planning and the execution of key activities, ranging from preliminary engineering studies, the development of robust environmental baselines, to the implementation of infrastructure and operational optimization. The project has already secured approval for the necessary maritime concessions for the import/export port and the desalination plant. However, one of the major challenges the project faces is the environmental approval process. Below are the project's phases and critical activities:

PHASE 1: FEASIBILITY STUDIES AND PLANNING (2020–2024)

1. Environmental Impact Assessment (EIA):

- The project submitted its EIA in July 2024, receiving 1,700 comments from the Chilean environmental authority and the public. These include requests for clarifications and additional information regarding impacts on local biodiversity, water resource use, and effects on nearby communities.
- The company is working to address these concerns by clarifying the EIA content, proposing additional mitigation measures, and reinforcing its environmental sustainability approach.
- The strategic location in Magallanes takes advantage of high-quality wind resources, but also entails logistical and environmental challenges due to sensitive biodiversity and proximity to protected areas.
- Specific environmental baseline studies have been conducted to ensure the project does not affect priority conservation areas, with adjustments made to the location of project facilities and infrastructure to align development with local environmental conditions [1], [2].

2. Technical and Economic Analysis:

- Validation of technologies such as pressurized alkaline electrolyzers and Haber-Bosch reactors.
- The project considers the implementation of its own export port in the San Gregorio area for HNH and third-party projects [1].

3. Strategic Partnership Development:

- Agreements with international and local partners to ensure offtake agreements, financing, advanced technology supply, and integration with international markets.

PHASE 2: INFRASTRUCTURE CONSTRUCTION (2027–2031)

1. **Wind Farms:**
   - Initial installation of turbines with a total capacity of 1.4 GW, specifically designed for extreme Magallanes conditions.
   - Turbine location adjustments based on environmental impact study findings [1].

2. **Electrolyzers and Synthesis Plant:**
   - Installation of electrolysis systems with an initial capacity of 1,000 MW.
   - Installation of ammonia synthesis reactors, designed to optimize energy efficiency.

3. **Logistics Infrastructure:**
   - Development of port terminals and cryogenic tanks for safe storage of ammonia and its subsequent export to international markets.

PHASE 3: TESTING AND INITIAL OPERATION (2031–2032)

1. **System Validation:**
   - Comprehensive testing of the wind generation, electrolysis, ammonia synthesis, and transport logistics systems.
   - Operational process adjustments to optimize efficiency and ensure compliance with environmental regulations.

2. **Personnel Training:**
   - Specialized training for operators and technicians in advanced technologies used in the plant.

PHASE 4: EXPANSION AND SCALING (2032-2036)

1. **Capacity Expansion:**
   - Increase in installed electrolysis capacity to 2 GW, with green ammonia production reaching 1.3 million tons per year.
   - Expansion of wind farms and logistics infrastructure to secure energy supply for the project [2].

2. **New Market Development:**
   - Market diversification, including green ammonia applications as marine fuel, power generation, and in emerging industrial sectors [4].

ENVIRONMENTAL ASSESSMENT PROCESS

The approval of the Environmental Impact Assessment (EIA) is one of the critical challenges for the advancement of the project. The observations made by the environmental authority reflect the complexity and sensitivity of the Magallanes environment [1], [2]. The main issues raised include:

1. **Biodiversity Impact:** The region hosts unique ecosystems that require strict measures to minimize the impact on protected species.

2. **Use of Water Resources:** The availability of demineralized water for electrolysis is a priority issue, especially in a region with limited water resources.

3. **Relationship with Local Communities:** Nearby communities have generally expressed support for the establishment of the industry, which they see as an opportunity for growth and development, along with the creation of opportunities for improved quality of life. At the same time, they have voiced concerns about the project's impact on their environment and way of life, seeking to align project development with sustainable local livelihoods.

Address these concerns, the project has adopted measures such as:

1. **Design Adjustments:** Refining the project's layout, facilities, and access routes to avoid sensitive areas.

2. **Environmental Mitigation:** Implementation of continuous wildlife monitoring programs and the creation of environmental conservation zones to promote the reproduction of vulnerable species.

3. **Community Dialogue:** Establishment of ongoing working groups with local communities to ensure their active participation in the development of the project.

9. KEY PARTNERS

The success of the project depends on strategic collaboration among various key stakeholders, including:

1. **European Consortium:** Led by AustriaEnergy, Oekowind, and Copenhagen Infrastructure Partners, this group is responsible for the project's financing and management [1], [2].

2. **Government of Chile:** In charge of developing enabling infrastructure for industry implementation, providing fiscal incentives, regulatory support, and facilitating the project's integration into the framework of Chile's National Green Hydrogen Strategy [3].

3. **International Organizations:** Entities such as the Inter-American Development Bank (IDB), multilateral credit institutions, the Green Climate Fund, and others have provided initial funding and technical assistance [6].

4. **Technology Providers:** Companies that supply equipment and technology, offering advanced solutions for electrolysis, ammonia synthesis, and other critical systems.

5. **International Clients:** Firms in energy generation, maritime transport, chemical, and agricultural sectors in Europe and Asia, which are expected to sign long-term purchase agreements for the green ammonia produced [4].

10. RESULTS AND BENEFITS

Although the project is still in an early stage of development, it is expected to deliver significant results and impacts across the following areas:

1. Environmental:

- Reduction of 5 million tons of CO_2 annually once operating at full capacity, directly contributing to carbon neutrality targets [1], [4].
- Exclusive use of wind energy, eliminating dependence on fossil fuels.
- Creation of conservation areas for the protection of local biodiversity [2].

2. Economic:

- Estimated annual revenue of USD 500 million from green ammonia exports.
- Attraction of foreign direct investment, with a total estimated amount of USD 11 billion [1], [2].
- Generation of secondary supply chains, fostering the development of local industries in products and services.

3. Social:

- Creation of 4,000 direct jobs during construction and approximately 1,000 jobs during operation [2].
- Training of the local workforce in advanced technologies, increasing regional competitiveness.
- Development of the local supplier ecosystem and support for community development initiatives.

11. COST STRUCTURE

The project is being developed in two implementation stages, aiming to maximize financial and operational efficiency, with the following main components:

INITIAL INVESTMENT (2027–2031) (USD 11 BILLION):

The primary cost components include:

1. **Wind Farms:** Installation of wind turbines with an initial capacity of 1.4 GW.
2. **Electrolyzers:** Implementation of large-scale electrolysis systems.
3. **Ammonia Synthesis Plant:** Includes Haber-Bosch reactors, air separation units for nitrogen production, and gas recycling systems.
4. **Logistics Infrastructure:** Development of port terminals, cryogenic tanks, and transport systems, along with general storage areas [1], [2].

EXPANSION PROJECTION (2031–2036) (USD 2.5 BILLION):

5. Expansion of wind farms to reach a total capacity of 3.5 GW.
6. Increase in green ammonia production capacity to a total of 1.3 million tons per year [2].

12. FINANCING STRUCTURE

El modelo financiero combina diversas fuentes para asegurar la estabilidad económica del proyecto:

1. **Private Investment:** Primarily provided by AustriaEnergy, Oekowind, and Copenhagen Infrastructure Partners, covering the initial development costs of the project [1], [2].
2. **Bank Financing:** Long-term loans from international banks and multilateral organizations, granted at preferential rates under a Project Financing scheme.

13. REVENUE SOURCES

The HNH Energy project is structured to include diversified revenue streams that ensure financial sustainability and debt service. Its primary source of income is the export of green ammonia, complemented by the following:

1. **Export of Green Ammonia:**
   - The green ammonia produced is primarily destined for international markets, with a focus on Europe and Asia, where high demand for this input is projected [2], [4].

2. **Revenue from Logistics Services:**
   - Revenue from Logistics Services: The logistics infrastructure developed in Magallanes — including the construction of dedicated port terminals — will enable the provision of import and export services to third parties, generating additional revenue [1].

14. LESSONS LEARNED

The development of the HNH Energy project has revealed several key lessons that can guide future large-scale green hydrogen projects in Chile and beyond:

1. **Public-Private Collaboration:**

Coordination between the project and national and regional governments, international organizations, and technology partners has been crucial in identifying regulatory, financial, and technical challenges. Aligning national objectives with private sector interests has helped create a favorable environment for project implementation [1], [3].

2. Importance of Land Use Planning

The strategic location in Magallanes offers exceptional wind resources, but also faces environmental challenges. The need to address EIA comments highlights the importance of early planning with a strong environmental and social focus [2].

3. Capacity Building and Workforce Development

Investment in training the local workforce not only strengthens the project's operations but also contributes to regional development and creates a replicable model for other regions.

4. Technological Flexibility and Adaptation

The selection of advanced technologies—such as wind turbines, electrolyzers, and Haber-Bosch reactors—combined with real-time monitoring, enables systems to be adjusted for maximum efficiency and minimal environmental impact [1].

5. Logistical and Competitive Challenges

The lack of existing logistics infrastructure in the region means that HNH had to design its own import/export port. Moreover, the distance from Magallanes to target markets implies higher transport costs, which are offset by low production costs thanks to favorable local conditions [1], [2].

6. Importance of International Markets

Demand for sustainable inputs in markets such as Europe and Asia is a key driver for project viability. However, this also requires compliance with strict international regulations, including certifications and high quality standards [4].

15. CONCLUSIONES

The HNH Energy project represents a significant step forward in Chile's energy transition and in its positioning as a global leader in green hydrogen and ammonia production. This project not only leverages the exceptional wind resources of Magallanes, but also establishes a replicable model of technological innovation, public-private collaboration, and financial sustainability [1], [3].

1. **Environmental Contribution:** With an expected reduction of 5 million tons of CO_2 per year, the project directly contributes to global climate goals and strengthens Chile's role in the fight against climate change [1], [4].

2. **Economic Development:** The USD 11 billion investment and the creation of up to 4,000 direct jobs during the construction phase demonstrate its positive impact on both regional and national economies, attracting international investment and reinforcing Chile's industrial infrastructure [2].

3. **Challenges and Opportunities:** Despite challenges related to land use planning and logistics, the project demonstrates that strategic planning and the early adoption of advanced technologies can overcome these barriers. It also opens the door to new opportunities in international markets and emerging applications of green ammonia [2], [4].

> ***In conclusion, the HNH Energy project lays the foundation for the development of a sustainable economy based on green hydrogen, setting a precedent for future projects in Chile and around the world.***

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