Integrating Bioeconomy and Energy Transition through Green Ammonia Valorization: A Competitive Intelligence Perspective in Quebec, Canada

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Abstract. This study analyses the strategic positioning of green ammonia within Quebec's and Canada's energy transition frameworks, emphasizing its role as a hydrogen carrier for storage, transportation, and industrial decarbonization. Building on the Hydrogen Strategy for Canada and Quebec's Green Hydrogen and Bioenergy Strategy, the research identifies a key gap: the absence of an integrated, decision-oriented framework linking regional energy demand with potential green ammonia supply sources**.** Using a competitive intelligence (CI) approach, the study triangulates data from institutional, industrial, and academic sources to map demand and supply ecosystems. Results reveal four priority demand sectors, renewable energy storage, agriculture, maritime transport, and off-grid communities, and three major supply categories: industrial infrastructure, renewable-powered production, and emerging bio-based technologies. By integrating technical, economic, and environmental indicators into a sectoral intelligence dashboard, this research contributes a novel analytical framework supporting both policy design and strategic investment decisions in the energy transition.

1 Introduction

The global urgency of climate action, reaffirmed by the 2015 Paris Agreement, has intensified national efforts toward deep decarbonization and carbon neutrality by 2050 [1], [2]. As the energy sector accounts for more than 70% of global CO_2 emissions [3], [4], it remains central to mitigation strategies worldwide. In this context, Canada's Hydrogen Strategy [5] and Quebec's Green Hydrogen and Bioenergy Strategy (SQHVB) [6] seek to structure a low-carbon economy by promoting innovative energy vectors, among which green ammonia is increasingly recognized for its strategic potential.

Green ammonia, synthesized from renewable hydrogen and atmospheric nitrogen, offers major logistical advantages, notably its liquid state under moderate pressure and its

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compatibility with existing storage and transportation infrastructures [8], [9]. These characteristics make it particularly suitable for large-scale energy storage and long-distance transport. However, its large-scale deployment remains constrained by several challenges, including the high energy intensity of conventional Haber–Bosch synthesis, technological immaturity of alternative routes, and substantial capital investment requirements [10]. Although emerging low-temperature electrochemical processes show promising potential [11], they are still at an early stage of development.

In Quebec, multiple perspectives intersect regional circular economy models, the *Decarbonization Challenge Program* [12], and research initiatives in electrochemical synthesis. Despite these advances, structured data on energy needs, production capacities, and strategic positioning of green ammonia within decarbonized energy mixes remain scarce. The research gap lies in the absence of an integrated framework connecting actual energy needs with existing or potential green ammonia sources at the regional and national scales. Existing studies mainly emphasize technical and environmental aspects [13], [14], while the strategic structuring of markets, actors, and territorial ecosystems remains insufficiently addressed**.** This study therefore aims to identify and qualify the needs and potential sources of green ammonia in Quebec, Canada, and internationally, using competitive and business intelligence tools [15].

Accordingly, this study aims to identify and qualify the current and potential needs and sources of green ammonia in Quebec, Canada, and internationally, with the goal of developing a sectoral dashboard supported by competitive and business intelligence tools [15]. The research is guided by the following questions:

1. What are the current and future energy needs that could be addressed by green ammonia within regional ecosystems?
2. What are the main industrial, technological, or bio-based sources capable of supporting sustainable and localized green ammonia production?

Ultimately, this approach seeks to provide a decision-support framework to guide public policies and industrial strategies toward a responsible and competitive energy transition.

2 Literature review

2.1 Global Energy Transition and the Role of Hydrogen

The Paris Agreement and IPCC scenarios have accelerated the global shift toward renewable energy and carbon neutrality [1], [3]. Hydrogen has emerged as a cornerstone of this transition, offering high energy density and zero-emission potential. Canada's Hydrogen Strategy projects a 45 Mt CO_2 reduction by 2030 through tax incentives and clean fuel regulations [16]. The integration of hydrogen into national frameworks requires harmonized certification systems based on life-cycle emissions rather than color classifications [17].

2.2 Green Ammonia as a Strategic Energy Vector

Green ammonia (NH_3), produced via renewable-powered electrolysis of hydrogen and nitrogen fixation, is increasingly recognized as a viable hydrogen carrier [18]. Conventional ammonia synthesis accounts for 1–2% of global energy consumption, making its decarbonization critical [10]. Studies suggest renewable-based systems integrating carbon capture and solar PV could reduce production costs to around $749 per tonne by 2035 [19].

Additionally, small-scale and modular production units operating under mild conditions open new regional opportunities [13].

Ammonia's logistical advantages—its liquid state under mild pressure, existing global infrastructure, and 17.8% hydrogen content—make it an efficient medium for energy storage and transport [20]. It also serves as a potential fuel for maritime transport and distributed generation [21]. However, adoption is constrained by safety concerns and public perception [22], [23].

2.3 Emerging Pathways and Market Niches

Innovative routes such as bio-based production and photocatalytic or electrochemical synthesis could transform the ammonia industry [24], [25]. These approaches enable localized, flexible production suited to specific market needs [26]. Economic studies show that while green ammonia is currently costlier than gray alternatives, rising carbon prices and natural-gas volatility will enhance competitiveness [14]. Its potential spans agriculture, heavy industry, maritime transport, and remote communities, particularly in regions like Quebec with abundant hydropower.

3 Methodology

This study applied a competitive intelligence (CI) approach as a structured and ethical method for data collection and analysis. CI involves systematically gathering, analyzing, and synthesizing external information to support strategic decision-making in dynamic environments [27], [28]. In this project, CI was used to map the needs and potential sources of green ammonia across Quebec, Canada, and international contexts. Data triangulation combined multiple based on certain selection criteria such as relevance to the study, access to information and compatibility: scientific databases; institutional and governmental reports; academic research centers; industry and consulting firms; and energy data platforms. Information was synthesized and visualized using business-intelligence tools such as Power BI and FusionCharts to identify correlations between energy needs, supply sources, and strategic niches.

4 Results

The analysis of the collected data led to the development of a comprehensive mapping of green ammonia demand and supply ecosystems within the Quebec and Canadian contexts. By cross-referencing institutional, industrial, and academic sources through the competitive intelligence process, cross-analysis highlights four distinct priority domains for demand-side integration. These domains represent strategic vectors for the regional and national energy transition, beginning with renewable-energy storage, where ammonia serves as a long-term and high-density medium to mitigate the intermittency of solar and wind assets. In the agricultural sector, a shift toward localized production loops was brought out, which facilitate the decarbonization of fertilizer supply chains and reduce systemic reliance on imported ammonia. Furthermore, the analytical results position maritime transport as a critical demand driver, where ammonia can act as a low-carbon fuel alternative leveraging port infrastructure and contributing to the decarbonization of shipping routes. This is complemented by the potential for energy autonomy in remote and off-grid northern communities, where ammonia-based power systems offer a path toward low-emission, decentralized generation.

On the supply side, the data categorizes the production landscape into three primary archetypes defined by technological and regional infrastructure. The first category comprises industrial and repurposed infrastructure, exemplified by Alberta's hydrogen hubs and other industrial facilities capable of conversion to blue or green ammonia production. This is paralleled by renewable-powered production facilities, taking advantage of hydroelectric and wind resources in regions like Quebec and Atlantic Canada to produce hydrogen and ammonia with minimal carbon intensity. Finally, the analysis distinguishes an emerging class of technological solutions, including bio-based and modular electrochemical systems designed for small-scale, decentralized ammonia synthesis under mild operating conditions.

Figure 1 illustrates a relational data model to capture key metrics for each ammonia source.

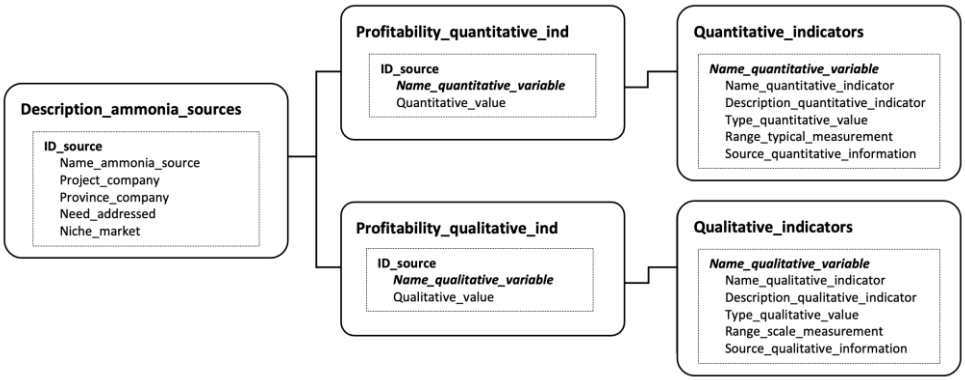

Figure 1. Relational data model for ammonia sources.

Then, Figure 2 shows an example of data structure and content for an ammonia source: fossil fuels, including the need addressed, niche market and both quantitative and qualitative indicators to measure.

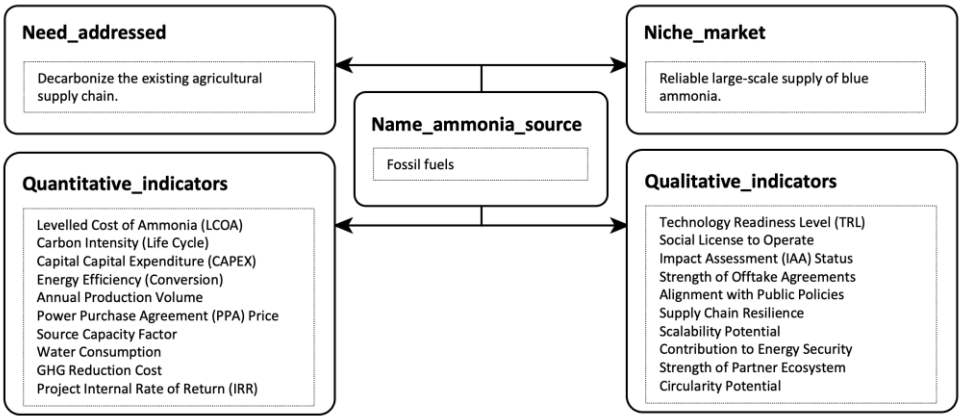

Figure 2. Example of data structure for an ammonia source.

5 Analysis consolidation according to literature

The findings highlight the strategic complementarity between renewable potential and infrastructure readiness in Quebec. Hydroelectricity offers a stable, low-emission energy base supporting ammonia synthesis at competitive costs, particularly for maritime and industrial uses. These results align with prior work on ammonia's dual role as an energy carrier and decarbonization agent [13], [7]. The use of competitive intelligence proved effective in synthesizing dispersed data into actionable insights, extending the methodological proposals of previous studies [28], [29]. The analysis also suggests that Quebec's advantage lies in combining renewable generation capacity with data-driven industrial decarbonization.

6 Theoretical and managerial contributions

This research integrates competitive intelligence within energy-transition analytics, proposing a conceptual model linking ammonia sources, infrastructure, and performance indicators. It enriches understanding of how data-driven intelligence frameworks can support policy alignment and technology deployment. From a managerial standpoint, the study delivers a decision-support dashboard enabling assessment of the feasibility and strategic value of green-ammonia projects, identifying optimal niches such as maritime fueling, fertilizer decarbonization, and regional energy storage.

7 Conclusions, limitations and avenues of research

The study structured the main needs and sources of green ammonia in Quebec and Canada, providing a first analytical framework for energy intelligence. Results confirm ammonia's potential as a flexible vector linking industrial decarbonization and regional self-sufficiency. Limitations include reliance on secondary data and an exploratory dashboard requiring validation through techno-economic modeling. Future research should integrate life-cycle assessment and AI-driven forecasting to simulate market evolution and infrastructure planning, strengthening collaboration among academia, government, and industry.

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