Study of the Potential of the Green Hydrogen Economy in Bahia: A Multiscale Approach

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Given the urgent need to decarbonize global energy sources, this study aims to provide an in-depth understanding of the green hydrogen economy, addressing the challenges, opportunities, and benefits of its development in the Brazilian state of Bahia, which is the fifth largest state in the country. The research focuses on demonstrating the potential of this emerging economy in the state, employing a framework based on a multiscale methodology. This framework is designed to enhance understanding of Bahia's energy and fuel markets. Furthermore, the study explores the technologies and opportunities associated with green hydrogen in Bahia, detailing a framework that maps its potential in various regions, highlighting the primary production hubs and applications. The multiscale methodology plays a pivotal role in achieving these goals.
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The adverse effects of the relentless reliance on fossil fuel-based energy sources are evident, including the consequences of climate change. Transitioning from polluting, carbon-intensive energy to clean, sustainable alternatives, such as green hydrogen, is increasingly essential for achieving sustainable development [1].

Bahia, in particular, possesses numerous opportunities to make Brazil's national energy matrix more sustainable and reduce environmental impacts. One prominent example is solar energy, an area where Bahia excels due to its high potential for photovoltaic generation, which can help meet current and future electricity demands in Brazil [1].

Additionally, the state boasts abundant natural resources and existing infrastructure, making it well-positioned to lead in the production and utilization of green hydrogen (H_2V) and its derivatives [2]. However, one of the major challenges of green hydrogen is achieving accessibility and economic viability compared to traditional production routes. Beyond tax incentives and policy measures, the advancement of basic and applied research into water electrolysis technologies is critical, as renewable, clean, and efficient energy sources are key to sustainable development.

This study adopts a multiscale approach to advance the green hydrogen economy in Bahia. By examining this system at different scales—from microscopic to macroscopic—the research aims to construct a comprehensive framework for developing this economy in Bahia and optimizing its implementation.

Materials and Methods

The method includes a narrative literature review, focusing on articles published between 2020 and 2024, alongside a theoretical multiscale approach to examine green hydrogen production, storage, transport, and applications in different regions of Bahia. The multiscale approach allows for a detailed analysis of the hydrogen production cycle, from the microscopic processes of water electrolysis to large-scale storage, transport, and applications [3].

Main Scales Studied (Figure 1)

Microscopic Scale

Literature review focusing on results from simulations of key water electrolysis technologies,

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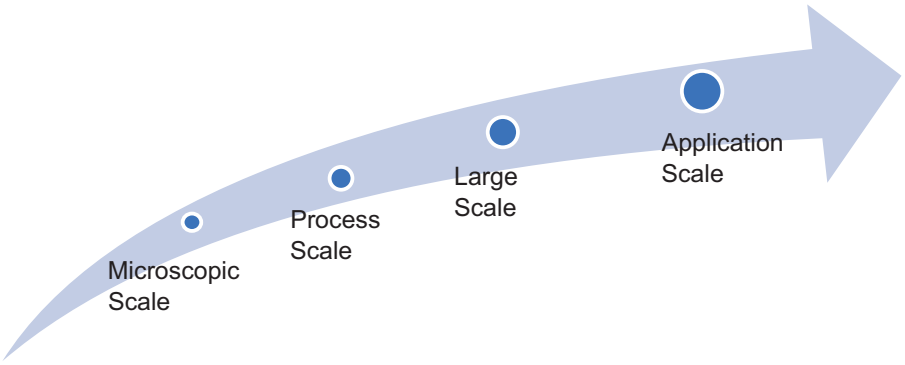
Figure 1. Scales of development of the green hydrogen economy in Bahia.



such as Alkaline and PEM. An example is the study of the PEM structure, which involves a set of cells composed of current collectors, bipolar plates, electrocatalysts, and a polymeric membrane (electrolyte), usually Nafion®, which acts as an ion conductor [4].

Process Scale

Investigation of water and energy sources for electrolysis in Bahia, the primary electrolysis technologies and process otimization. The most suitable water sources are seawater, Rainwater, and treated urban wastewater, regarding the different characteristics of each location [5]. And for the main energy sources, Bahia has a predominantly renewable and diversified electrical matrix composed of wind, solar, water and biomass [2].

Large Scale

Examination of hydrogen storage and transport methods, analyzing the most suitable options for Bahia. The hydrogen supply chain can include diverse echelons, depending on the specifications and needs of each application [6]. Figure 2 presents a hydrogen supply chain.

Application Scale

Exploration of green hydrogen applications as an energy matrix in different regions of the state. Hydrogen utilization technologies involve using hydrogen as a fuel or energy carrier in various applications across different sectors, including transportation, electricity generation, heating, and industry, some common hydrogen utilization technologies include fuel cells, hydrogen combustion, industrial processes, and energy storage and grid balancing [7]. For example, green hydrogen can be used in a plant for ammonia and urea production [8].

By integrating these scales, the study performs a preliminary techno-economic analysis, develops a detailed framework, and enhances understanding of the key steps necessary for developing Bahia's green hydrogen economy.

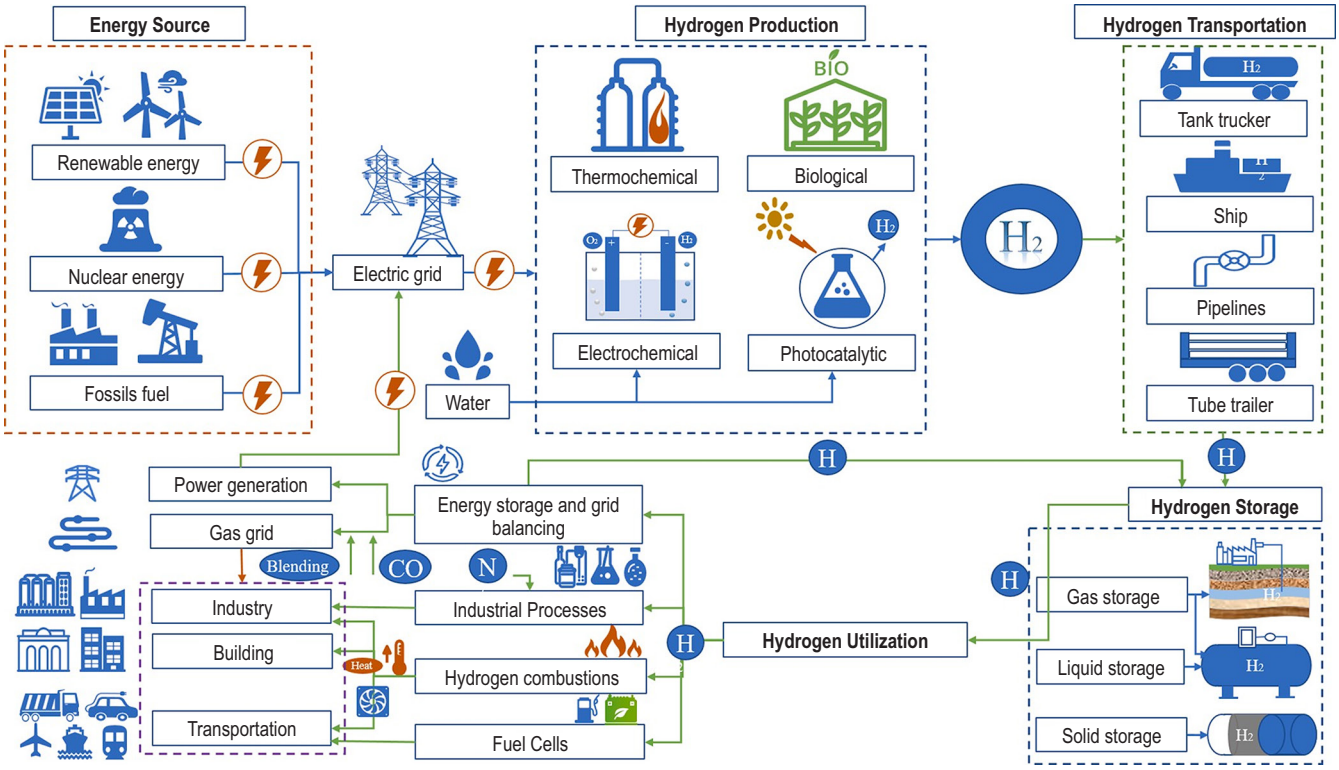
Results and Discussion

Green Hydrogen Production

Hydrogen can be produced by numerous different processes (Figure 3), but green hydrogen is produced via water electrolysis powered by renewable electricity sources [9].

While the green hydrogen process is currently costly and less economically feasible than traditional energy sources, it represents one of the most promising alternatives to decarbonize the economy [9], combat climate change and achieve sustainable development.

Figure 2. An overview of hydrogen production, transportation, storage, and utilization (HPTSU) technologies [7].



Energy Potential in Bahia

Brazil, particularly the Northeast, holds significant competitive advantages in green hydrogen production due to its abundant wind and solar resources, as well as the cost-effectiveness of energy generated by these sources compared to other countries [9]. Bahia's predominantly renewable energy matrix [2] and wealth of natural resources make it an ideal candidate for implementing the green hydrogen economy.

Multiscale Approach

The success of this project hinges on the multiscale approach, which is well-suited for studying complex systems characterized by hierarchical, multi-scale phenomena in space and time. Complex systems involve nonlinear interactions, dissipative structures, and continuous exchanges of energy, matter, and information [10].

Key considerations for the multiscale method include:

- Correlations between phenomena at different scales;
- Trade-offs between dominant mechanisms;
- Combined spatial and temporal structural changes;
- Critical phenomena within complex systems [10].

This approach ensures a comprehensive analysis of green hydrogen's potential, from microscopic processes to macroscopic applications.

Conclusion

This study provides a thorough overview of the green hydrogen economy in Bahia, emphasizing its challenges, opportunities, and potential benefits. The findings underscore the importance of transitioning to clean energy sources to mitigate climate change and foster sustainable and resilient economic development.

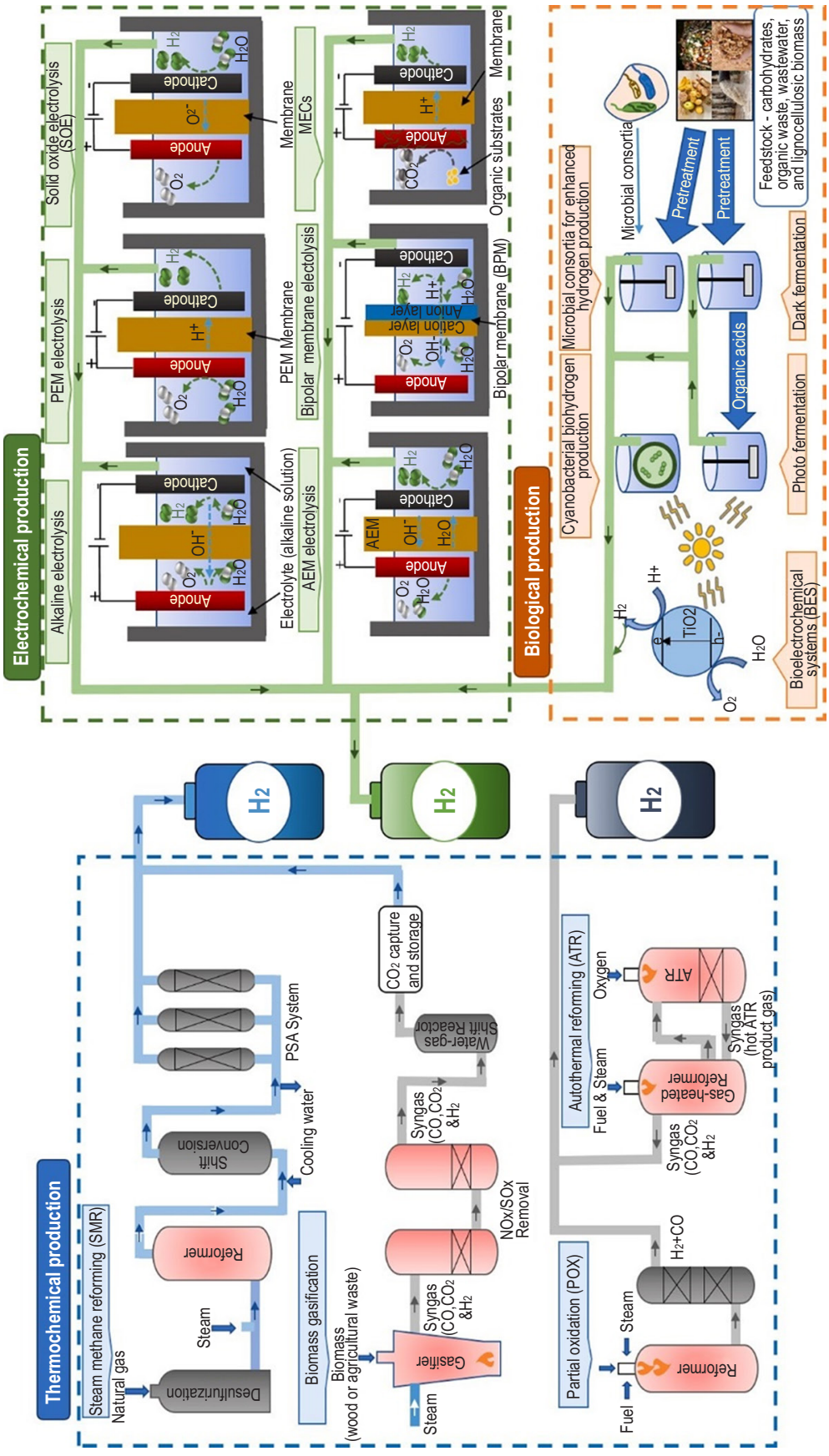


Figure 3. Overview of different hydrogen production technologies [7].

The multiscale method is essential for understanding this complex system, enabling detailed analyses across different levels—from production technologies to the infrastructure required for implementation.

Bahia's favorable conditions, including its renewable energy matrix and abundant solar and wind resources, offer a promising environment for developing the green hydrogen economy. However, investments in research and technology, coupled with public policies and incentives, are necessary to make green hydrogen a viable and competitive alternative to traditional energy sources.

In conclusion, the green hydrogen economy holds significant potential to drive Bahia's transition to a sustainable energy model, reduce greenhouse gas emissions, and build a more inclusive and resilient economy.

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