OFFSHORE PRODUCTION OF GREEN HYDROGEN BY ELECTROLYSIS OF SEA WATER ON THE BRAZILIAN COAST

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ABSTRACT

The production of *Green* H_2 on a large scale is a challenge for Brazil to play a leading role in this segment. In this article, it is proposed the use of offshore installations for the electrolysis of seawater, using power from wind and hydro-kinetic farms located offshore. The “state of the art” of H_2 production in Brazil and in the world was established. The electrolysis processes focused on seawater as an input were studied. The potential for generating electricity from renewable sources along the Brazilian coast was surveyed and regions with greater suitability to house the proposed facilities were identified. Offshore installations for the production of *Green* H_2 can place Brazil in a prominent position in the emerging, and very promising, "Green Labeled" H_2 market. Therefore, it is imperative that the country immediately initiate incentives and investment in this sector.

Keywords: Energy Transition, *Green* H_2 from sea water, Offshore installations, Sustainability.

Introduction

Hydrogen gas (H_2) is seen as a vector for the energy transition aiming at a new energy generation model to meet global demand if the concentration of greenhouse gases (GHG) in the atmosphere increases. A great growth of the world demand for this gas is expected as the technologies for its use mature. Some countries are able to be self-sufficient in the production of H_2, others are not. This will give rise to a global market for this product, which will become a commodity, with strong growth in the coming decades.

Scope and methodology

The objective of this research was to evaluate the scenario for the production of H_2, by electrolysis of sea water, in Brazil. Analyzing Brazil’s particular conditions in this scenario, identifying the country’s competitive advantages and its ’weak points’ that can be a specil for its highlight in the *Green* H_2 futures market.

To achieve this objective, a review of the academic and industrial literature was first carried out to establish the ’state of the art’ of H_2 production in Brazil and worldwide. Among the various production processes, this work is focused only on those that result in *Green* H_2, that is, using material and energy inputs from renewable sources, in particular: electrolysis processes. The structure for energy generation in Brazil from renewable sources was identified, specifically *offshore* installations, as well as the characteristics of these installations. The Brazilian offshore potential for generating electricity from wind and sea currents along the Brazilian ocean coast was raised. Identified Brazil’s strengths and weaknesses as a player in the global scenario of energy transition, as a producer and exporter of *Green* H_2.

Hydrogen Production

Several technologies are in use for the production of H_2; the main ones are Natural Gas Reform, with or without Carbon Capture and Storage (CCS), resulting the so called *gray and blue hydrogen*; Coal gasification (with or without CCS); Biomass gasification; Ethanol reforming, Other processes, less frequently used, are: reaction of simple exchange of acids with metals, reaction of hydrates with water, pyrolysis (thermal decomposition of hydrocarbons by the action of heat) etc. This article analyzes the production of *Green Hydrogen* from seawater electrolysis.

DOI: 10.55592/ISE.2023.8204555

Results and discussion

A. Global consumption of H_2

Currently, H_2 supplies about 4% of global primary energy demand. The 2021 annual H_2 production in the world was around 94 million tons [1] . 98% of said H_2 production was of fossil origin, using conventional carbon-intensive production technologies. 75% of the total H_2 production was from Natural Gas reforming, and 23% was from Mineral Coal reforming. The carbon footprint of these production processes vary between 9 and 20 $kg\ CO_2/kg\ H_2$, depending on the fuel used and the efficiency of the applied technology [1] . Only 2% of global H_2 production is based on electrolysis, the share of emission-free *Green* H_2 in the market is a measly 0.1% of global production. A growth of 600% of this market in the next 3 decades is expected. Solarplaza projected a world demand of around 400 to 450 million tons of H_2 in 2050 based on Fusion Fuel expectations [1].

B. Green H_2 production park

Green H_2 production park is a electro-hydro industrial facility to produce *Green* H_2 on a large scale. Production parks can be placed onshore or offshore. Logistics from offshore *Green* H_2 production parks using pipelines require an infrastructure not yet available. The use of ships is a current response to the offshore *Green* H_2 production.

C. Electrolysis

Electrolysis is the process of breaking water into its constituent elements H_2 and oxygen gas (O_2) consuming electrical power. The advantage of the process is that it provides a very clean H_2, free of carbon and sulfur impurities. The disadvantage is that the process is expensive compared to steam reforming of natural gas, due to the cost of the electrical energy needed to drive the process. The electrolysis of 9 kg of water results in 8 kg of O_2 and 1 kg of H_2. Electrolysis requires the theoretical energy of 40 kWh for 1 kg of H_2. According to the Hydrogen Analysis Resource Center (HYARC) [2] the yields of electrolysis is circa 67%. Therefore, a typical effective consumption in the range of 55 to 75 $kWh/kg\ H_2$ is considered for the electrolysis. It is an energy-intensive process, which can make it expensive.

a) Sea water electrolysis

One option that is not dependent on the water cycle or the availability of water in rivers is to use seawater. Seawater must be collected, filtered, and purified before being introduced into the electrolyzer. The reverse osmosis system for purifying seawater is the most widespread and commonly used method today. After electrolysis, the captured H_2 needs to be conditioned to the requirements for its transportation, either by cryogenic liquefaction or compression. The compressed H_2 pressure is approximately 70 MPa. Specific and high-power compressors are required to achieve this pressure. This step is energetically demanding, with a similar energy requirement to electrolysis. The overall energy consumption of the process, including water treatment, electrolysis, and compression, is approximately 100 $kWh/kg\ H_2$.

b) The importance of the location

There are a variety of methods for storing and transporting H_2. It can be stored as a compressed gas, liquefied, converted to ammonia or other liquid organic substances, each with its own advantages and disadvantages in terms of energy consumption, safety, and ease of use. H_2 transportation can be done through pipelines, on roads or railways, or by ships. Optimizing logistics and selecting the technologies that best suit each specific project is a key factor in determining the price of H_2. The goal is to minimize the costs of the entire logistics chain. The location of the *Green* H_2 production facility is a factor of very significant importance for the competitive pricing of the product at the final destination.

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c) Electrolyzers

Electrolyzers for H_2 production can be divided into two main categories: alkaline liquid electrolyte (ALE) and solid polymer (SP). SP electrolyzers are also known as proton exchange membrane (PEM) electrolyzers. There is a third class of electrolyzers that use solid oxide membranes, called (SOEC) or high temperature electrolysers (HTEL). The different technologies also define the scale of application: ALE units can be scaled up for high volume production, while SP technology is better suited for small volume production.

SOEC technology is still few and very expensive. Solid oxide membranes are not abundant in the market, which makes it difficult to spread this more efficient technology in large-scale plants. However, industrial units are more prepared to deal with high temperature processes. Capital expenditures (CAPEX) currently range between 3,000 € and 10,000 € per Nm^3/h. There is a forecast of a CAPEX reduction of 50% in the coming decades [3].

D. Brazil's panorama

a) Electricity and water

A significant part of Brazil's electricity matrix comes from hydroelectric power plants (HPPs). Hydropower accounted for 12.5% of Brazil's domestic energy supply in 2022 [4]. According to the Generation Information System (SIGA) of the Brazilian Electricity Regulatory Agency's (ANEEL), there are 215 HPPs, with a rated capacity of 103 GW, in operation [5]. Electricity consumption in Brazil totaled 690 TWh in 2022. HPPs account for 61.9% of Brazilian power [4]. This large availability of renewable energy favors the implementation of large *Green* H_2 production parks to meet domestic demand and export this commodity.

89 HPPs, including Itaipu Binacional and Belo Monte HPP, among the largest in the world, are run-of-the-river type [6]. These HPPs are rain-dependent and have seasonal production. As an example, Belo Monte HPP, on the Xingu River, has a rated power of 11,233 MW but its average generation is 4,571 MW [7]. From January to June, the Xingu River has abundance of water and Belo Monte HPP is able to produce a large amount of cheap energy during this period. This condition is ideal for the installation of a large *Green* H_2 production park that operates according to the HPP's seasonality.

Some companies have already signed letters of intent for the development of H_2 plants next to port terminals to simplify logistics, aiming at exporting the product. These plants are budgeted at more than USD 200 billion and consider immediate start [8]. Porto de Pecém in Ceará, Porto de Suape in Pernambuco and Porto do Açu in Rio de Janeiro already have areas destined for these H_2 projects.

b) The seashore power potential

Brazil has an oceanic coastline of 7,367 km [9]. The Brazilian territorial sea (ZEE), established by the United Nations Convention on the Law of the Sea (UNCLOS), extends for up to 200 nautical miles.

A rough estimate of the offshore wind power potential, according to the distance from the coast, is as follows: 0-10 km=57 GW; 10-50 km=202 GW; 50-100 km=255 GW and, 100-200 km=1,266 GW [10].

The Energy Research Company (EPE) linked to the Ministry of Mines and Energy (MME) estimated the offshore wind potential, exploitable with current technologies, for areas that can be considered attractive with speed above 7 m/s and heights of up to 100 m), at around 700 GW in places with depths of up to 50 m [11]. Exploring this tremendous potential would allow the generation of 6.150 TWh/y [12].

The Brazilian oceanic coast also has the potential to generate electricity from waves and tides. In contrast to the unpredictability of the winds, the predictability of the generation of tides and currents is high, since daily, biweekly, monthly, and even annual cycles can be predicted [13]. The north coast, where tides predominate, stands out, with an estimated potential for power generation of 27 GW. In total, considering the entire coastline, the potential is 117 GW [13]. Exploring all this potential with tidal power plants would allow the generation of 1,000 TWh of energy per year from waves and tides. This tremendous offshore potential is still untapped.

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Offshore Installations

Brazil has extensive experience in offshore installations, gained through the activities of Petrobras' oil & gas exploration. This expertise can be used for other offshore activities in the open sea, including the installation of wind farms, hydrokinetic farms, and *Green* H_2 production parks. The logistical difficulties of building, installing, operating and maintaining those installation in the Brazilian territorial sea (ZEE) can be overcome using the Petrobras' technological framework.

The transmission of power produced offshore to consumption centers on land requires the use of submarine cables, and the long distances involved are an obstacle to the integration of offshore parks into the transmission network. The local use of this power to produce hydrogen by the electrolysis of seawater emerges as an interesting and viable technology [14]. Platforms of the most diverse types, and Floating, Production, Storage and Offloading (FPSO) vessels, can be designed (or adapted) for the production of *Green* H_2. The location in the open sea also reduces the risk of any accidents that could affect the lives of surrounding populations.

The export of *Green* H_2 to overseas consumer markets is also facilitated because cargo operations can be carried out in the open sea without the need for these ships to dock at ports. This reduces costs and time, as it eliminates competition with other cargo ships for mooring berths. This operation also dispenses the need to build hydrogen storage facilities on land and piping networks to the cargo terminals at the ports.

Despite having a strong synergy with offshore O&G technology, offshore wind farm projects are only just getting started and are dependent on complex and partially undefined licensing processes. Hydro-kinetic farms have not yet even been considered.

Conclusion

The H_2 and *Green* H_2 economy presents great opportunities and immense challenges for Brazil in all areas, and it requires courageous decisions from the strategists who shape the country's economic policy.

The National Plan of Energy (PNE 2050), H_2 included as a disruptive technology [15]. The Ten-Years Plan for Energy Expansion (PDE 2031) has a chapter dedicated exclusively to H_2, demonstrating the importance of this fuel for the country [16]. The Hydrogen Program - (PNH2), a study carried out in cooperation with several Ministries and with the technical support of EPE, was issued in August 2021 [17].

However, a more solid legal framework is lacking. Three bills referring to *Green* H_2 are being discussed in the National Congress: PL 725/2022 (Establishes parameters for the sustainable use of hydrogen); PL 1878/2022 (Creates the Policy to regulate the production and uses of Green Hydrogen for energy purposes); and PL 2308/2023 (Creates the Policy to regulate the production and uses of Green Hydrogen for energy purposes). Efforts are needed to move forward and pass these bills to create a legal basis for *Green* H_2 in Brazil.

When it comes to offshore projects, things move at a snail's pace. In March 2023 offshore wind projects worth 182.9 GW were in the licensing process at the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA). The processes have stalled, among other reasons, due to the lack of a legal framework. No environmental license has been granted. Some of these processes are for areas that overlap each other, meaning that the same area is being claimed by different projects. It is imperative to speed up this licensing process and to have clear licensing rules and documentation requirements. It is necessary to adopt a one-stop-shop procedure, where all interested parties have access to each incoming process, avoiding queues, duplication, and delays.

Commitment to research is needed to improve technologies for producing *Green* H_2 from seawater, making use of renewable energy sources available to actively participate in this emerging market. This market is new and brings immense challenges. It requires risky, non-refundable investments to overcome these challenges and move on to bigger projects with less uncertainty.

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Brazil has very favorable conditions to be a protagonist in this market. However, if the necessary investments are not made, it may lose this competitive advantage.

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