HIDROGÊNIO COMO VETOR ENERGÉTICO: EFICIÊNCIA E COMPARAÇÃO ENTRE AS ROTAS DE PRODUÇÃO

Yaeko Yamashita[1] Felipe Azevedo Rios Silva[2] João Vitor Lima Sousa[3] Renato Cabral[4]

[1,2,3]*University of Brasilia, Brasília, Brazil* [4]*Eletrobras and State University of Goiás, Goiânia, Brazil.*
E-mail: [3]*vitor_lima@egresso.ufg.br;* [4]*renatocabral591@gmail.com*

ABSTRACT

Hydrogen is a crucial energy carrier for the global energy transition, with significant potential to decarbonize industrial and transportation sectors. Excessive reliance on fossil fuels can increase vulnerability to price fluctuations and geopolitical issues, making the adoption of a diversified and resilient energy mix necessary. Diversifying pathways by incorporating renewable and green hydrogen not only reduces emissions but also stimulates innovation, creates jobs in emerging sectors, and strengthens collaboration among governments, industries, and research institutions. This approach is important for the development of technologies that integrate different production processes, such as carbon capture and the use of renewable sources, for the transition to a low-carbon economy.

Keywords: Low-carbon hydrogen; Production routes

INTRODUCTION

Hydrogen is widely recognized as a crucial energy carrier for the global energy transition, playing an essential role in the decarbonization of industrial and transportation sectors, which are responsible for a significant portion of global CO_2 emissions. In 2023, these two sectors were responsible for the emission of 290.9 $MtCO_2eq$, accounting for about 68% of Brazil's energy sector emissions (IEA, 2023). The growing demand for sustainable alternatives makes it urgent to analyze and compare the various hydrogen production pathways, which vary widely in terms of energy efficiency, operational costs, and environmental impacts.

Currently, hydrogen accounts for about 2% of global energy demand, and it is estimated that its share could grow to 13% by 2050, according to the International Energy Agency (IEA). However, hydrogen production is still responsible for 830 million tons of CO_2 per year, approximately 2% of global emissions (IEA,2023). These figures highlight the critical need for diversification of production pathways to mitigate the associated environmental impacts. This study examines the main hydrogen production routes, discussing their characteristics, costs, CO_2 emissions, and the importance of a diversified and resilient energy mix for the future.

MATERIALS AND METHODS

The study involves a structured bibliographic research aimed at identifying the different low-carbon hydrogen pathways.

WHAT ARE PRODUCTION ROUTES

Hydrogen production "pathways" are crucial for industry and the transition to a low-carbon economy. They vary in efficiency, cost, and environmental impact, depending on the raw materials and technologies used. The main pathways include: (i) Fossil-based (grey and blue hydrogen); (ii) Renewable (green hydrogen); (iii) Nuclear (pink hydrogen); (iv) Biomass-based (moss hydrogen). This diversity allows different regions and sectors to adopt technologies suited to their needs and resources, contributing to global CO_2 emissions reduction (IEA, 2019).

EFFICIENCY IN HYDROGEN PRODUCTION

The efficiency in hydrogen production, which affects costs and sustainability, is the ratio of the energy of the produced hydrogen to the total energy supplied to the process. For electrolysis, the efficiency is calculated as follows:

$$\eta H_2 = \frac{EH_2}{Eelectrical} \times 100\% \qquad \textit{Eq.}\ (1)$$

where:

ηH_2 is the efficiency of hydrogen production (%); EH_2 is the energy contained in the produced hydrogen (kWh); $Eelectrical$ is the energy supplied to the electrolyzer (kWh).

The efficiency of electrolysis processes varies from 60% to 80%, depending on operational conditions and the type of electrolyzer (Franco & Giovannini, 2023). Recently, a Hysata electrolyzer achieved a record efficiency of 95%, using 41.5 kWh to produce 1 kg of hydrogen, compared to 52.5 kWh for conventional models. For grey hydrogen production via steam methane reforming, the efficiency is typically 70-85% (Ganguli & Bhatt, 2023).

A. CO_2 Emissions

CO_2 emissions associated with hydrogen production vary significantly between different pathways. Grey hydrogen, produced by steam methane reforming, generates about 9 kg of CO_2 per kg of H_2 produced due to the combustion of fossil fuels and the release of CO_2 contained in natural gas. In contrast, green hydrogen produced by electrolysis with 100% renewable electricity results in no direct CO_2 emissions. Blue hydrogen, produced by steam methane reforming with carbon capture and storage (CCUS), reduces emissions by 60-65% compared to grey hydrogen, with about 3-4 kg of CO_2 per kg of H_2 (EPE, 2022).

B. Production Costs

Grey hydrogen is the cheapest, ranging from $1.00 to $2.00 per kg. Blue hydrogen costs between $1.50 and $3.00 per kg, depending on the price of natural gas and the amount of CO_2 captured. Green hydrogen is the most expensive, ranging from $3.00 to $6.00 per kg. Costs depend on the project and business model adopted but are expected to decrease with technological advancements and increased production scale. Innovations such as the Hysata electrolyzer, with 95% efficiency, could significantly reduce these costs.

DIFFERENT HYDROGEN PRODUCTION ROUTES

The pathways, tailored to local needs and resources, help reduce dependence on fossil fuels and combat climate change. Additionally, they foster innovation, create jobs in new sectors, and enhance global energy security. Hydrogen production encompasses various pathways, each with specific characteristics, advantages, and challenges, which can be primarily classified into five main categories: (i) Grey Hydrogen: Mainly produced by steam methane reforming, converting methane into hydrogen and CO_2. This method accounts for about 75% of global hydrogen production but generates large amounts of CO_2. In Brazil, it is estimated that approximately 500,000 tons of grey hydrogen are produced annually (EPE, 2021), and its idle production capacity is around 200,000 tons per year (EPE, 2022); (ii) Blue Hydrogen: Similar to grey hydrogen, but with carbon capture and storage (CCUS), reducing CO_2 emissions and serving as a transition to cleaner technologies; (iii) Green Hydrogen: Produced by electrolysis of water using renewable energy (solar, wind, hydro, etc.), making it the most sustainable method with zero direct CO_2 emissions. Production costs are currently higher but are expected to decrease with technological advancements; (iv) Pink Hydrogen: Generated by electrolysis of water using nuclear energy, combining the efficiency of electrolysis with the low carbon emissions of nuclear power. (v) Moss Hydrogen: Produced from biomass and biofuels, potentially leading to negative emissions by replacing fossil methane with biogas. Costs are not yet well-defined but are expected to become competitive with blue hydrogen as technology evolves. (vi) Waste Hydrogen: Produced from the conversion of organic waste using gasification or pyrolysis. This method aids in waste management and may have a lower carbon footprint, but costs and efficiency are still under development.

Table 1. Comparative Table of Hydrogen Production Pathways

Production Routes	Efficiency (%)	CO_2 emissions (kg/kgH_2)	Energy Source	Production Costs (US$/kg)
Grey hydrogen	70-85	9	Natural gas	1.0-2.0
Blue hydrogen	70-85	3-4	Natural gas + CCS	1.5-3.0
Green hydrogen	60-80	0	Renewable sources	3.0-6.0
Pink hydrogen	60-80	0	Nuclear power	3.0-6.0
Moss Hydrogen	50-70	Variable (negative potential)	Biomass	In development
Hydrogen from waste	Variable	Negative potential	Urban solid waste	In development

Source: EPE (2022), IEA (2019) & IRENA (2020).

CONCLUSION

Diversifying hydrogen production pathways is essential for building a sustainable and resilient energy mix. Excessive dependence on a single energy source, such as natural gas, can increase vulnerability to price fluctuations and geopolitical issues. Moreover, the transition to a low-carbon economy requires innovative solutions that integrate different hydrogen production technologies. Exploring various pathways not only enhances the resilience of the energy mix but also stimulates innovation and creates jobs in emerging sectors. Collaboration among governments, industries, and research institutions is crucial for the effective development of these technologies. While grey hydrogen dominates due to its low cost, renewable and green pathways are gaining relevance in the transition to a low-carbon economy. Carbon capture and the use of renewable sources are critical for reducing emissions associated with hydrogen production. Notably, the production pathways that stand out the most are those with lower greenhouse gas emissions, due to their strong environmental appeal and alignment with global sustainability goals.

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