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LIFE CYCLE ASSESSMENT OF GREEN HYDROGEN PRODUCTION FROM BIOMASS: A REVIEW

SAMUEL ALBERTO OUANA; MÁRCIO MONTAGNANA VICENTE LEME

ABSTRACT
Hydrogen is emerging as a promising alternative to conventional fuels. However, most of the hydrogen (H_2) production is currently derived from fossil sources. In response to this challenge, the production of green hydrogen, obtained from synthesis gas generated from biomass, is emerging as a viable alternative. In this context, it is imperative to carry out a comprehensive analysis of the main bibliographical references that deal with life cycle assessment of hydrogen production technology from steam reforming of natural gas and biomass gasification, covering all stages, from the extraction of raw materials to obtaining hydrogen. Therefore, this article uses Life Cycle Assessment (LCA) to carry out a comparative assessment of the environmental impact of the different production routes, considering parameters such as carbon footprint and energy efficiency. This becomes of critical importance to ensure the genuine sustainability of green hydrogen production and its significant contribution to environmental preservation. An overview of green hydrogen production technology compiled in this article, the authors have thoroughly analyzed the comparison of the main categories of impacts, with regard to quantifying the main total equivalent emissions of carbon dioxide, the environmentally friendly method is biomass gasification technology and blue hydrogen due to the fact that they are associated with photosynthesis and carbon capture and storage technology respectively, resulting in a potential clean energy carrier in the successful decarbonization scenario to respond to the Paris 2015 agreements that foresee a 7.6% reduction in global greenhouse gas (GHG) emissions per year by 2030 to ward off the chance of collapse, stabilizing global warming at 1.5^{O}C.
Keywords: Renewable energy, environmental impact, techno-economic analysis, emissions, carbon storage and capture.

1. INTRODUCTION

The contribution of atmospheric emissions to the environment is predominantly the result of human actions, particularly in the transport and industry sectors. This is often correlated with high population density and economic growth. These factors have contributed to an increase in the concentration of pollutants in the atmosphere and, consequently, global warming (SEIBERT; PINTO; MONTE, 2022).

Climate change issues have been addressed by the Intergovernmental Panel on Climate Change through the creation of public policies that seek new technologies to minimize or eliminate the emission of greenhouse gases into the atmosphere, with sustainable and environmentally friendly industrial solutions and energy plans designed from cradle to grave.

In a world where the climate and the environment are increasingly suffering the negative effects of fossil fuel use, the use of renewable hydrogen has come to be seen as essential for decarbonizing various activities. Renewable hydrogen is yet another essential factor in achieving the goals set at COP27 (27th Conference of the Parties) to accelerate

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decarbonization so that the 2015 Paris Agreement goal of limiting global warming to 1.5 degrees Celsius by the end of the century can be achieved (FERNANDES et al., 2023).

However, today more than 95.0% of the sources used to produce hydrogen are fossil fuels. The main process used is natural gas steam reforming (SMR), which emits an average of 13.7 kg of CO2 for every kg of H2 produced. One of the technological frontiers of greatest interest today is the production of low-carbon hydrogen, especially green hydrogen (Empresa de Pesquisa Energética, 2022).

The production of hydrogen from methane reforming with CO_2 capture and storage, known as blue hydrogen, involves the implementation of a Carbon Capture & Storage (CCS) system, the purpose of which is to separate the CO2 generated in the process for subsequent permanent geological storage. This procedure can be carried out in a Steam Methane Reformer (SMR) or an Autothermal Reformer (ATR). The carbon intensity of the resulting hydrogen varies considerably depending on the CO_2 capture fraction applied (COWNDEN; MULLEN; LUCQUIAUD, 2023).

In this context, global interest in renewable energy has led to an increase in photovoltaic installation capacity and hydrogen demand, which reaches 3802.7 GW and 322.4 Mton of H2, respectively, and research into the environmental impact of green H2 production in different routes is being focused on.

The Life Cycle Assessment (LCA) methodology, established by the International Organisation for Standardisation (ISO), has stood out as an appropriate tool for providing the necessary environmental information to support decision-making related to sustainability, by assessing the environmental impacts of all phases of an industrial activity, from the acquisition of raw materials to their final disposal.

According to the ISO 14040 and 14044 standards, life cycle assessment (LCA) is an environmental management tool that examines the potential environmental impacts between a technical system (technological sphere) and the environment (from the production of raw materials to the end of the life of the process), following the four phases: Definition of objective and scope, Inventory analysis, Impact assessment and Interpretation.

The aim of this article was to analyze the most recent advances in the main reviews that address the Life Cycle Assessment of hydrogen production technology to quantify the carbon footprint of green to quantify the carbon footprint of green hydrogen from biomass gasification, compared to the traditional natural gas steam reforming route.

2. MATERIAL AND METHODS

For this research, scientific publications developed in recent years were consulted in the CAPES journals portal collection in the SCOPUS (Elsevier) and Science Direct list of databases and collections, with the search words in their titles Hydrogen and Green and Cycle and Assessment and Life and Production.

3. RESULTS AND DISCUSSION

Studies related to Life Cycle Assessment (LCA) have been investigated by various researchers in the field of H2 production, using this methodology to analyze the environmental impacts of a product throughout its life cycle.

According to Patel et al. (2024) the production of grey hydrogen results in 13% higher emissions on the liquefied gas (LNG) route, with 13.9 kg CO_2 eq, compared to 12.3 kg CO_2 eq. on the pipeline route. On the other hand, blue hydrogen generates lower emissions than grey hydrogen thanks to the use of CCS, resulting in 7.6 kg CO_2 eq. per kg of H_2 on the pipeline route and 9.3 kg CO2 eq. per kg of H_2 on the LNG route.

According to Hermesmann & Müller, (2022) the impacts on global warming in the two technologies (grey and blue) are mainly due to the supply of natural gas due to its greater

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demand for electricity for heating purposes.

In the study by Cho et al. (2022), the impact of direct emissions on hydrogen production facilities in the United States based on natural gas SMR technology was assessed. The authors concluded that carbon dioxide emissions are dominant among the pollutants evaluated and resulted in an insignificant impact on global warming in terrestrial ecosystems in relation to human health.

On the other hand, the authors Khojasteh Salkuyeh et al., (2017), compared fossil fuel consumption in SMR options with and without the use of carbon capture (CC). They found that the addition of CC resulted in a 39 per cent increase in fossil fuel consumption and a global warming potential (GWP) of 11.7 and 3.5 kg of CO_2 equivalent per kg of H_2.

According to Duval-Dachary et al., (2023) the process of capture, transport and storage in the underground reservoir demands high energy consumption for solvent regeneration, compression and CO_2 injection. Antonini et al., (2020) considered from a life cycle point of view, the addition of CCS with clear benefits about climate change impacts, due to greater CO_2 capture, despite a negative performance about other environmental categories as a result of increased energy consumption.

The two technologies showed the same impacts for the categories of freshwater eutrophication, freshwater ecotoxicity and marine ecotoxicity, which may be due to the fact that they come from the extraction of liquefied petroleum gas (LPG) from fossil fuels that contain compounds such as sulphur that are released into the environment, as described by Zhao et al. (2022), with global warming, acidification and freshwater eutrophication being the most common components in the LCA from a social point of view.

Fossil fuel and biomass gasification technologies have energy and exergy efficiency. The analysis of gasification included energy requirements for biomass fragmentation, transport, energy incorporated into materials, as well as for compression and transport of hydrogen. Thus, biomass gasification is likely to be close to the global energy needs compared to traditional technology, since most do not include hydrogen transport costs, which are close to 40 per cent of global energy needs (BOROLE; GREIG, 2019).

The authors IRIBARREN ET AL. (2014) conducted research covering the initial phase of poplar cultivation through to the purification of the hydrogen obtained through the gasification process. The authors identified that the biomass pre-treatment and synthesis gas cleaning subsystems play a major role in contributing to environmental impacts.

In the study by García et al. (2017), a life cycle assessment was carried out from the seedling production phase to hydrogen production, adopting the "cradle to gate" perspective. The results showed a greater total environmental impact in several of the categories assessed, while the impacts on climate change were less significant.

Xu et al. (2024) compared the damage of the four scenarios (grey hydrogen, blue hydrogen, gasification with CCS and gasification without CCS) throughout the life cycle phases. The greatest environmental impact was found in the grey hydrogen technology, while the lowest was in the gasification with CCS scenario, with a decrease of 17.92%. Implementing carbon capture may cause some environmental damage during the construction phase, but it will contribute to environmental protection during the operational phase. Therefore, gasification causes less damage to the environment than the traditional route.

4. CONCLUSIONS

The review articles thoroughly analyzed all the inputs and outputs involved in each of the grey, blue and biomass gasification hydrogen production processes. The potential impacts of each method were quantified and in terms of total carbon dioxide equivalent emissions, the most environmentally friendly scenario is biomass gasification technology because it is associated with photosynthesis. The other scenarios, due to the fact that they are fossil fuel

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sources, showed greater impacts, with the blue hydrogen scenario showing a reduction in greenhouse gas (GHG) emissions, which is due to the fact that it is associated with CCUS technology, resulting in a potential clean energy carrier in the successful decarbonization scenario to respond to the Paris 2015 agreements, which provide for a 7.6% reduction in global GHG emissions per year by 2030 to ward off the chance of collapse, stabilizing global warming at 1.5^{O}C.

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