BOILING HYDROGEN ENERGY: EXPLORING THE ENERGY POTENTIAL OF SANTA CATARINA'S PIG FARMING FOR DESCARBONIZATION AND ENERGY TRANSITION

Fernando H. C. Rodella[1], Sofia M. de Almeida[1], Bianca G. Teixeira[1], Sofia K. de Souza[1],

Rodrigo de Almeida Mohedano[1], Nelson Libardi Junior [1] & Paulo Belli Filho[1]

[1]Sanitary and Environmental Engineering/ Technological Center/Sanitary and Environmental Engineering Department/Federal University of Santa Catarina/Florianopolis, Brazil.

** Corresponding author's email address: nelson.libardi@ufsc.com*

ABSTRACT

The constant crises in the energy sector, in parallel with the unequivocal recent manifestations of global warming, have driven research into more efficient technologies that use renewable resources as raw materials. In this scenario, the hydrogen production chain receives special attention as it is a fuel with high energy capacity and minimal environmental impact, presenting itself as an energy vector with the potential to replace fossil fuels and promote efforts towards decarbonization. This study presents technical aspects of hydrogen production from routes that involve hydrocarbon reforming, such as biogas, or biomass from swine waste as a biological source to produce synthesis gas. Santa Catarina, the largest pig producer in Brazil, has a significant economic activity in pig farming. However, the waste generated represents a major environmental problem, generating liabilities for producers and degrading the natural environment. In this way, this study proposes that the integration of hydrogen production with the waste produced represents an innovative and viable approach, aligned with socio-environmental sustainability objectives and with significant potential to add to the contribution of an energy sector linked to contemporary aspirations.

Keywords: Hydrogen. Pig farming. Decarbonization.

1 INTRODUCTION

Biofuels have emerged as a promising solution to meet energy demands and mitigate Greenhouse Gas (GHG) emissions. Among the various biofuel options available, hydrogen (H_2) stands out as an attractive future vehicle for energy production, due to its high conversion efficiency into useful energy, low or non-existent generation of pollutants and high energy density (HALLENBECK; GHOSH, 2009). Based on these premises, this study focused on understanding through broad bibliographical research about the production of H_2, technological routes that involve the reforming of hydrocarbons, such as biogas and biomethane from anaerobic digestion, or the adoption of biomass from pig waste as a biological source to produce synthesis gas. Biogas and biomass from biological waste generated on pig farms in Santa Catarina represent abundant and renewable resources, being an attractive way to generate this energy carrier. Considering the high potential to produce biological waste due to the economic importance of pig farming in Santa Catarina, understanding the potential of this region to produce H_2 is fundamental for the development of strategies aimed at the energy transition.

2 MATERIAL & METHODS

The bibliographical research covered the years between 2000 and 2023, in the scientific databases such as Science Direct and Scielo. The research focused on the energy produced by H_2, especially which produced via biogas, biomethane and biomass from swine waste. So, these terms were used in the searches including title, keywords and abstract.

3 RESULTS & DISCUSSION

The H_2 economy and its role in the energy transition

H_2 is recognized for its remarkable ability to store energy. Calculations have shown that the energy contained in 1 kg of hydrogen is twice that of most conventional fuels (ABE et al., 2019). The energy load of H_2 for the highest heating value is 141.8 MJ/kg at 298 K, which is much higher than that of most fuels, such as conventional gasoline. However, its production continues to be even more costly than current production routes from fossil fuels, and storage and transportation to end users are also more challenging and expensive (ŁUKAJTIS et al., 2018). Among the main GHGs that livestock farming is responsible for producing, CH_4 stands out, which has a global warming potential 25 times greater than CO_2 and a lifespan in the atmosphere of 9 to 15 years (MACHADO et al., 2011). In 2020, the agricultural sector was responsible for emitting a total of 14.54 million tons of CH_4, representing 71.8% of national emissions. The composition of renewable sources in the electrical matrix together with the reduced costs in energy generation via wind and solar photovoltaics, position Brazil in international projections for the economic production of H_2 with low carbon emissions, with the lowest associated costs in the world.

When we turn our attention to the state of Santa Catarina, the H_2 economy presents promising perspectives, benefiting from available natural resources and innovative potential of the state. Santa Catarina plays a crucial role in the agricultural sector, being considered the largest pork exporter in relation to other federative units in Brazil, contributing 54.64% of all national pig production (ABPA, 2023). Through strategic investments and implementation of adequate public policies, Santa Catarina has the potential to stand out as a center of excellence in the production and application of H_2, playing a crucial role in the transition towards a green economy.

Processes and technological routes for obtaining H_2

Steam methane reforming (SMR): Steam reforming of hydrocarbons to obtain synthesis gas is currently the most used process at an industrial level for the synthesis of H_2 due to its high efficiency, technological maturity and low cost of operation and production of synthesis gas. Featuring a conversion efficiency of between 74% and 85%, either due to its high efficiency in terms of the abundance of CH_4 available from natural gas or biogas reserves. It is important to highlight that the process requires environmental and safety precautions, especially in relation to the management of reaction products and CO_2 emissions, which is an unwanted by-product of this process. From an environmental perspective, the full effective use of H_2 produced through SMR is intrinsically linked to the capture of CO_2 produced in reactions, through carbon capture and storage systems (CCS), complemented by monitoring and verification systems to ensure the maximum effectiveness.

Partial oxidation (POX) and catalytic partial oxidation (CPOX): The technological route for producing H_2 through reforming by partial oxidation (POX) and catalytic partial oxidation (CPOX) are efficient methods and were designed with the intention of being used in vehicle fuel cells and in some smaller-scale commercial applications, especially in applications where heat generation is also desired. Advantages of POX are: i) the reaction system is more compact; ii) it can use gaseous, liquid hydrocarbons and coal as raw material; iii) does not generate sulfur (SOx) and nitrogen (NOx) oxides due to operational factors. However, the process has disadvantages: i) greater energy consumption; ii) high operating temperatures can lead to coking, hotspots and sintering of the catalyst; iii) O_2 production and purification units increase process installation and operation costs. The gas mixture formed by POX contains CO, CO_2, H_2, H_2O, CH_4, hydrogen sulfide (H_2S) and carbon oxysulfide (COS). The investments required to carry out the oxygen installation and cover additional costs related to the desulphurization stages mean that this installation requires a high initial investment. Catalytic partial oxidation (CPOX) uses a catalyst to increase the efficiency and reduce energy consumption of the process. Due to the characteristics of the fuel and oxidizer mixture, it is necessary, for safety reasons, to limit the reaction temperature, especially at high pressures.

Compared to SMR, the POX and CPOX process produces a more significant amount of CO, which needs to be subsequently converted into H_2 and CO_2. The fact that it has a lower thermal conversion efficiency compared to other methods, ranging between 60% and 75%, and the operation at high temperatures makes it difficult to apply in compact and smaller reformers.

Autothermal reforming (ATR): Autothermal reforming (ATR) uses ammonia synthesis, combining two processes in a single reactor. This technological route involves the introduction of steam into the CPOX process, causing the reforming and oxidation reactions to occur simultaneously, thus allowing adjustments in the H_2/CO ratio, changing the H_2O/O_2 ratio in the feed and reducing the ATR's energy needs. The resulting reactor is more compact, making it attractive for fuel cell applications. On the other hand, when reactions take place in distinct sections, such as POX followed by SMR, these systems are more appropriate to produce liquid fuels.

Production of H_2 from renewable sources such as biomass: Thermochemical technology involves the processes of pyrolysis, gasification, combustion and liquefaction, with greater emphasis on the first two methods mentioned. Both processes produce, among other gaseous products, CO and CH_4, which can be processed to produce more H_2 through steam reforming and WGS reaction.

Biological processes: The main biological processes used to produce gaseous H_2 are the direct and indirect biophotolysis, dark fermentation and photo-fermentation. These processes result in the production of alcohols, acetone, H_2 and CO_2 in minute quantities. During this process, H_2 is produced by the reduction of molecular nitrogen in the presence of nitrogenase, which also reduces protons to molecular hydrogen. Oxygen, as a nitrogenase inhibitor, is not formed in these conversions. The yield efficiency in the production of H_2 in photo-fermentation is like that observed in the biophotolysis process and is influenced by factors such as type of microorganisms presents and media used, design of the photofermenter and light intensity. In dark fermentation, anaerobic bacteria convert substrates in conditions of absence of light. These microorganisms use electrons from hydrogen oxidation to then produce energy (ŁUKAJTIS et al., 2018). When in the absence of available external electron acceptors, organisms accumulate an excess of electrons generated in metabolic processes, because of the reduction of protons, producing H_2 molecules. These approaches are attractive for biohydrogen production as they utilize waste materials, providing low-cost energy production with simultaneous waste treatment.

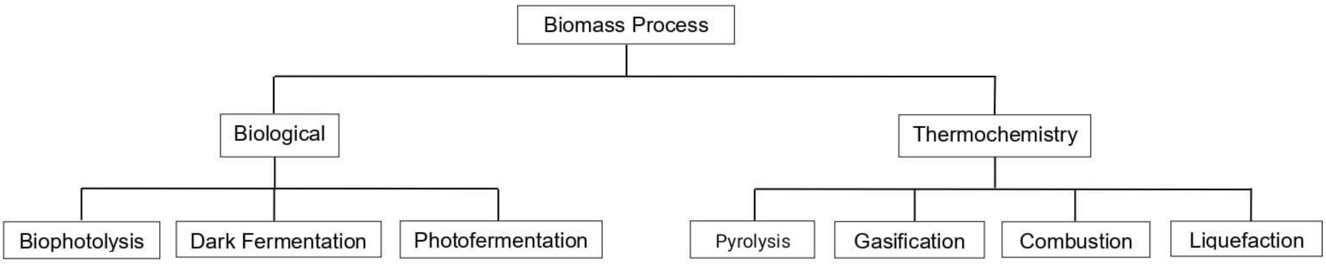

Figure 1 Technology routes for H_2 production based on biomass processes.

4 CONCLUSION

Thermochemical and biological methods are the two main routes for producing H_2 from biomass. Although more beneficial for the environment, they are considered less intensive, as they operate under mild conditions, providing low H_2 yields depending on the raw materials used. On the other hand, thermochemical processes are characterized by being extremely fast, providing higher rates and yields of H_2, with emphasis on gasification, which appears as a promising option based on economic and environmental considerations.

Obtaining H_2 through hydrocarbon reforms, such as biogas, and biomass synthesis, is a key element in the transition to a sustainable energy future, especially for sectors that contribute to GHG emissions. H_2 derived from biogas can be an environmentally and economically more viable alternative than electrolytic green H_2, as it uses a variety of organic substrates, such as urban and industrial waste, or even waste from agricultural activities, constituting a source of renewable energy. In this context, Santa Catarina sees H_2 as a powerful energy matrix. With an eye toward decarbonization and boosting the green economy, the state is positioning itself to leverage the production of abundantly available H_2.

REFERENCES

[1] ABPA. Associação Brasileira de Proteína Animal. Relatório anual de 2023. Disponível em: Acesso em: 10 abril 2024.
[2] ABE, J. O.; POPOOLA, A. P. I.; AJENIFUJA, E.; POPOOLA, O. M. Hydrogen Energy,Economy and Storage: Review and Recommendation. International Journal of Hydrogen Energy, 2019.
[3] HALLENBECK, P. C.; GHOSH, D. Advances in fermentative biohydrogen production:the way forward? Trends Biotechnol, 2009.
[4] ŁUKAJTIS, R.; HOŁOWACZ, I.; KUCHARSKA, K.; GLINKA, M.; RYBARCZYK, P.; PRZYJAZNY, A.; KAMIŃSKI, M. Hydrogen production from biomass using dark fermentation. Renewable and Sustainable Energy Reviews, 2018.
[5] MACHADO, F. S.; PEREIRA, L. G. R.; GUIMARÃES JR., R.; LOPES, F. C. F.; CARNEIRO, J. C.; CHAVES, A. V.; CAMPOS, M. M.; MORENZ, M. J. F. Juiz de Fora: Embrapa Gado de Leite, 2011.
[6] NIKOLAIDIS, P.; POULLIKKAS, A. A Comparative Overview of Hydrogen Production Processes. Renewable and Sustainable Energy Reviews, 2017.