

COB-2023-1773
**GENERATION OF HYDROGEN BY METALLIC WAY AND ITS
APPLICATIONS FOR THE USE OF RENEWABLE ENERGY**

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Abstract. *With the growing global energy need, the search for a viable, promising and sustainable energy matrix emerges as one of the main focuses of scientific research. In recent years, the role of renewable energies has gained increasing prominence, driving the discussion and approval of various public policies on a global scale. The United Nations (UN) launched the 2030 Agenda, an initiative that encompasses 17 Sustainable Development Goals (SDGs) to be achieved by the year 2030. In support of the 2030 Agenda, a large amount of research is being carried out around the world to develop fuels from clean and sustainable sources. However, developing a green energy matrix poses significant challenges for science and the political-economic sector. Fossil fuels are finite and are also relevant sources of environmental pollution, thus highlighting the preference for renewable sources. Hydrogen appears as a great potential, as it is a fuel with high calorific power and is the simplest and most abundant gaseous element in its chemical structure available in the universe. It can be obtained in several ways, including through processes with metals, such as oxidizing aluminum in an alkaline solution. The use of recyclable metals, such as aluminum, is a promising option for sustainable hydrogen generation processes. However, it is important to identify how the waste from sustainable hydrogen generation behaves, considering factors such as the origin of the reagent (aluminum) and the material of the reactor, so that the impact of the waste can be evaluated and, thus, provide an adequate destination for them. In this context, it is crucial to carry out an in-depth investigation of the industrial and technological applications of the products generated by the hydrogen generation reaction from aluminum, so that there is a guarantee of the proper disposal of waste, being an essential step to complete the energy supply chain in a sustainable way, successfully achieving a green circular economy.*

Keywords: *aluminum; energy matrix; hydrogen; renewable energy; sustainability*

1. INTRODUCTION

Since the first industrial revolution, fossil fuels have stood out for their wide use in a diverse energy range, which has led to the evolution of several areas of Engineering, that is, the evolution of technology, a word that originates from the combination of the terms “*techné*” and “*logos*”, which differentiates simple know-how from doing with reasoning, for SOFFNER (2013), technique characterizes the intervention of human beings in nature, being what distinguishes them from other living beings, therefore, technology is the idealization of projects, dreams and, in view of this, the use of coal followed by oil, provided such massive industrial growth, leading to a strong dependence on these types of fuels (JACOB-FURLAN et. al., 2020).

Only after the first oil crisis in the 1970s, when demand exceeded production, motivating OPEC - Organization of Petroleum Producing Countries to quadruple the price of a barrel, did the discussion begin on different ways of obtaining energy (LORENZI and ANDRADE, 2014), however, one of the main motivators should also be considered the environmental impact of uncontrolled oil extraction, according to the ANP - National Petroleum Agency, in November 2014, there was a production of 3.095 million Barrels per Day, up 8.5% compared to November 2021.

The use of hydrogen as fuel emerged as an alternative to produce energy in a cleaner way. Hydrogen is the simplest and most abundant element in the universe. In addition to the fact that, in gaseous form, it has attractions due to its calorific value and its profitability in relation to applications (BEJAN, 1988).

Even with the countless benefits of using hydrogen, it faces some difficulties, from the production of this fuel – which can be financially expensive via electrolysis or hydrocarbon reform (JACOB-FURLAN et. al., 2020) – to the storage and distribution of the gas because its chemical properties are extremely intrinsic to its reactivity (DA SILVA, 2020).

Recently, the production of hydrogen by the reaction of metals with water has been extensively investigated. When metallic elements belonging to group IA, IIA or IIIA of the periodic table come into contact with water, metal hydroxide and hydrogen form (ATKINS, 2011).

In the search for large-scale production to meet a new global demand for hydrogen, new methods have been developed, in addition to the best known and widespread ones, such as steam reforming and electrolysis. As the production of hydrogen through the reaction of metals with water, because when metallic elements belonging to specific groups of the periodic table come into contact with water, there is formation of metallic hydroxide and hydrogen, thus forming a possible line of study for new ways of obtaining hydrogen, such as, for example, reacting aluminum, sodium hydroxide and water.

An alternative to the use of hydrogen is through fuel cells. Classified as a form of sustainable energy generation, fuel cells are a promising alternative for the production of hydrogen, considering it to be one of the most ecological means of production, due to the low emission of polluting gases into the atmosphere (JÚNIOR, 2019). This residue, for many times, although little, can have a destination, in order to transform the process into a system of maximum use, both energy and economic. It is also worth noting that the residue can indicate the path that the reaction takes, so that it indicates the presence of substances that may not be interesting in the process as a whole.

2. ENERGY MATRIX - A BRIEF APPROACH

The energy matrix is a visual or descriptive representation of the composition of energy sources that a country, region or the world uses to meet its energy needs. This representation shows the proportion or participation of each type of energy source in the total energy supply of a given area. The use and control of energy brought a series of social and economic transformations to the world, providing transformations far beyond comfort, such as: transportation, public safety, industrial production, among other activities in society. It is an extremely important element for the world, playing a fundamental role in defining the balance between society's energy needs, environmental preservation and economic development. The composition of the energy matrix of a country, region or the world as a whole directly influences greenhouse gas emissions and the overall environmental impact (UGARTECHE; DE LEÓN; GARCÍA, 2023).

One of the main reasons for preserving the energy matrix is environmental sustainability. The predominant use of non-renewable energy sources such as coal, oil and natural gas has been associated with a significant increase in CO₂ and other greenhouse gas (GHG) emissions. This increase contributes to global warming and climate change, which have serious consequences for the planet and for human life (CORRÊA et al., 2022).

On the other hand, the adoption and expansion of renewable energy sources, such as solar, wind, hydroelectric, geothermal and biomass energy, is vital to reduce the carbon footprint and mitigate climate change. Renewable sources are considered more attractive as they regenerate naturally and are not depleted with continued use. They have less negative impact on the environment and are essential for preserving natural resources for future generations.

Furthermore, the diversification of the energy matrix is an important strategic measure to increase energy security. A balanced and diverse matrix reduces over-reliance on a single source of energy. This is essential to guarantee a stable energy supply, even in situations of geopolitical instability or problems with a specific source. Economic stability is also a crucial factor associated with the energy matrix. The overreliance on non-renewable energy sources can lead to price

fluctuations and vulnerability to external shocks. Diversifying into renewables and other more stable alternatives can help stabilize energy costs and promote sustainable economic development.

In addition, the search for cleaner and more efficient energy sources drives innovation and technological development. The energy matrix can be a catalyst for new business opportunities, jobs and competitiveness for industries, in addition to improving global energy efficiency. Another relevant aspect of the energy matrix is access to energy. In many parts of the world, there is still a lack of access to modern energy sources. The energy matrix can be a tool to guarantee universal access to electricity and heat, improving quality of life and promoting social and economic development (AGOSTINI et al., 2021).

In short, the energy matrix plays an essential role in the search for balance between humanity's energy needs, environmental protection and economic growth. With growing concern about climate change and the need to reduce greenhouse gas emissions, the transition to a cleaner and more sustainable energy matrix has become a global priority. The energy matrix is essential to guide and monitor this transition, seeking a safer, more sustainable and prosperous future for all (JACOB-FURLAN, et. al., 2022).

According to the IEA - International Energy Agency, in 2019, the world energy matrix was arranged as shown in Figure 1 below:

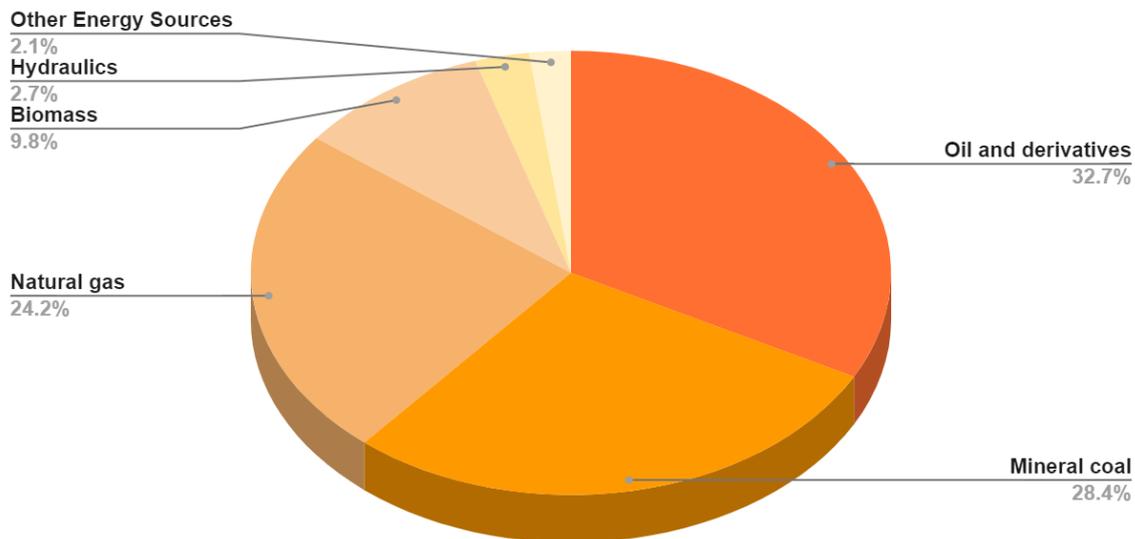


Figure 1. World energy matrix (IEA, 2020)

Given this, it is already possible to conclude that the world's energy matrix is still heavily based on fossil fuels, which in turn generates a significant impact on the environment, such as global warming.

Also, regarding this scenario, the United Nations adopted the Paris Agreement, with the objective of reducing CO₂ emissions, maintaining a low increase in global temperature, and discussing ways to achieve a total of zero emissions by 2050.



Figure 2: 17 UN Sustainable Development Goals to be achieved by the 2030 Agenda. (UN, 2017)

It is possible to note that Figure 2 above reveals the 17 SDGs proposed by the UN and also exalts that changing the energy matrix is a point to be studied for the future, as items 7, 11, 12 and 13 are directly linked.

2.1 RENEWABLE AND NON-RENEWABLE SOURCES

The Energy Matrix basically consists of two types of sources: **renewable** and **non-renewable**.

A non-renewable source of energy is one that makes use of exhaustible natural resources, that is, that will come to an end, whether in a brief reality or in the distant future. This source is usually associated with environmental problems, in addition to territorial disputes, stimulating wars and conflicts.

Renewable energy sources are considered clean, as they emit less greenhouse gases (GHG) than non-renewable sources and, therefore, are achieving a good insertion in the Brazilian and world market. The energy sources that belong to this group are considered inexhaustible, as their amounts are constantly renewed when used.

The Table 1 below shows examples and descriptions of renewable and non-renewable sources in the energy matrix scenario:

Table 1: Energy Matrix - Examples of Renewable and Non-Renewable Energy Sources.

Energy Source Type	Example	Description	References
Renewable Energy	Solar Energy	Generated by capturing sunlight through photovoltaic (PV) panels or solar thermal systems. Provides electricity and heat.	(KUMAR et al., 2023)
	Wind Energy	Generated by harnessing the kinetic energy of wind using wind turbines. Converted to electricity.	(CHANG et al., 2022)
	Hydropower	Generated by utilizing the energy of flowing water in rivers or dams. Converted to electricity.	(GONZALEZ-SALAZAR; ROGER POGANIETZ, 2022)
	Geothermal Energy	Utilizes the heat from the Earth's core to produce electricity or heat buildings.	(BOZGEYIK; ALTAY; HEPBASLI, 2022)
	Biomass Energy	Derived from organic materials like wood, agricultural residues, and organic waste. Can be converted to electricity and heat.	(FURUBAYASHI, 2022)

Non-Renewable Energy	Fossil Fuels (Coal)	Formed from ancient organic matter, primarily plant material. Burned to produce electricity and heat.	(GRAMMELIS; MARGARITIS; KARAMPINIS, 2016)
	Fossil Fuels (Oil - Petroleum)	Derived from ancient marine organisms. Refined into fuels like gasoline, diesel, and heating oil.	(RAJABI; MORADI, 2023)
	Fossil Fuels (Natural Gas)	Composed mainly of methane. Used for electricity generation, heating, and industrial processes.	(SI et al., 2023)
	Nuclear Energy	Generated through nuclear reactions, typically using uranium or plutonium. Produces heat to generate electricity.	(IMRAN et al., 2023)

The use of energy from renewable sources has gained prominence all over the world in recent decades, such as energy: hydroelectric, wind, geothermal, from biomass. They differ from each other in terms of profitability and suitability for use.

The nuclear power plant is highlighted, although not being considered renewable, when they use enriched uranium, they can be considered a clean energy source - however, again they are not considered renewable. Within the exposed theme, the International Energy Agency (IEA) compares that, in 2018, more than 30% of the world's energy was derived from oil and fossil sources, while more than 45% was derived from mineral coal and natural gas, and only 20% came from renewable sources, such as hydroelectric, biomass and nuclear.

One of the major topics currently being studied is the migration of the energy matrix to matrices of more renewable sources, mainly due to the richest deposits of fossil sources and oil wells being located in the Middle East region, which constantly conflicts with the West, mainly with the great North American power, the USA. Such conflicts of political and ideological interests also interfere in the good management and generation of global energy.

3. FUTURE PROSPECTS FOR HYDROGEN

The use of hydrogen as fuel emerged as an alternative to produce energy in a cleaner way. Hydrogen is the simplest and most abundant element in the universe, on planet Earth, it is found in molecular form in abundance in the form of water - H₂O. In addition, in its gaseous form, its calorific value is extremely superior when compared to other fuels, making its use much more profitable in this regard, since smaller amounts of fuel would be required to generate the same energy values (WANGHON, 2018). Added to this, the chemical reaction of hydrogen to generate energy only produces water vapour, thus characterizing it as a totally friendly gas to the environment.

Despite the many benefits that the use of hydrogen as a fuel provides, it presents some difficulties regarding its production and storage. Some of the main ways to produce this fuel are through electrolysis, a process that requires high energy and financial expenditure, or by reforming hydrocarbons, a process that emits greenhouse gases such as CO₂ (JACOB-FURLAN et al., 2020).

However, with regard to one of the major challenges for the storage and distribution of this type of fuel, is the fact that hydrogen is not very dense and has a low boiling temperature, which makes its storage difficult (DA SILVA, 2020). To store it, then, high pressure and continuous monitoring are required, as it is a highly reactive gas. High pressure cylinders are usually used for storage, or materials where H₂ can form metal hydride and gradually be released.

In this scenario, hydrogen presents itself as a very promising alternative in discussions about changes in energy matrices. Despite the scientific and technological difficulties, different ways of producing hydrogen in a clean and sustainable way can be explored, and the mathematical modeling of such methods will complement existing fuel cell models (DOS SANTOS, 2019; VARGAS et al., 2004; VARGAS and BEJAN, 2004).

3.1 HYDROGEN GENERATION USING RECYCLED ALUMINUM

Aluminum is considered one of the most popular metals on the face of the Earth, and stands out for being present in most human activities (GREENWOOD, 1997). Although it makes up only about 1% of the Earth's mass, it is the most abundant in the Earth's crust, which partly explains its popularity.

In antiquity, it was seen for many years as a precious metal, being alongside gold and silver, at many gala dinners, in front of nobility and royalty, until the process of obtaining it via metallurgy was discovered in 1888, which made it popular. Aluminum metallurgy was an economic landmark for the 19th century (MARTIN, 2011).

Currently, in Brazil, aluminum has great relevance in the sphere of recycling, evidencing its economic, social and environmental role (CONSTANTINO et al., 2001). Industrialized beverage cans have 99% aluminum in their composition. The wide use of aluminum and the fact that its recycling process is well known and applied worldwide (CASSANELLI, 2016), make it possible for the aluminum used in the chemical reaction to produce hydrogen to be obtained from reuse, promoting sustainability and making the process attractive (REINERT et al., 2021).

The hydrogen production reaction from aluminum consists of reacting aluminum in strips, from industrialized beverage cans, with sodium hydroxide (NaOH) in a kitassato (BOLT, 2020). The reaction happens spontaneously and has an exothermic character, so it must always be controlled. As a reaction product, we have the generation of hydrogen in its gaseous phase, and of sodium aluminate. Inside the reactor, aluminum undergoes a redox reaction with the alkaline solution (HSIEH; HER; CHEN, 2012), and from that, generates the products mentioned above, according to Eq. (1) below demonstrates:



4. CONCLUSION

There are countless efforts to make the world's energy matrix more sustainable, and ways to produce renewable energy stand out. Among such a need, hydrogen is categorized as an excellent alternative carrier of energy and fuel for renewable purposes, mainly taking into account its high calorific value and the multiplicity of ways for its generation.

However, it is still clear that there are still several mishaps regarding the storage of H₂ fuel, however, when scientifically mastered, the future will be promising. Even when one observes the political and economic progress of some potentials around the world, it is analyzed that a change in the energy matrix is urgent so that the environment is no longer harmed by fossil fuels.

Thus, investing in the production of hydrogen by alternative means is of extreme scientific and economic interest, since the impact of this investment will fall on society, motivating the search for energy sustainability.

5. ACKNOWLEDGEMENTS

To the Brazilian National Council of Scientific and Technological Development - (CNPq) - [projects 407198/2013-0, 403560/2013-6, 407204/2013-0, 430986/2016-5, 443823/2018-9, 313646/2020-1, 310708/2017-6, 308460/2020-0, 446787/2020-5, no. 25/2021, 405864/2022-1, 408073/2021-7, 408080/2022-1, and to project 300093/2022]; CAPES; Ministry of Education (MEC), Brazil - (projects 062/14 and CAPES-PRINT-UFPR-88881.311981/2018-01); Araucaria Foundation of Parana, Brazil (project 115/2018, no. 50.579 – PRONEX), to FUNDEP, Renault and UFPR for the funding and the development of the project called “ROTA 2030”.

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