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Performance of Green Hydrogen: Fuel Cell Improvement for the Energy Obtention Process

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Abstract— **In this work, relevant information about fuel cells - used to transform hydrogen to electrical energy- is analyzed along with their possible improvements which can be made with the aim of increasing overall performance and lowering operating costs. Special focus has been laid on PEMFC and SOFC cells and their technical aspects to be improved. Renewable sources and this type of technologies are essential to think of a sustainable future which includes the usage of clean energy such as green hydrogen.**

Resumen— **Este trabajo analiza información relevante acerca de las celdas de combustible usadas para transformar hidrógeno en energía eléctrica, así como sus posibles mejoras a fin de aumentar el desempeño y reducir el costo operativo. Se hizo especial enfoque en las celdas PEM y SOFC y en sus aspectos técnicos a mejorar. Las fuentes renovables y tecnología de este tipo son indispensables para pensar un futuro sostenible el cual incluye el uso de energías limpias como lo es el hidrógeno verde.**

I. Introduction

Nowadays the society is facing global issues regarding the environment. People are becoming conscious about the fact that it has to be taken care of in order to preserve life as we know it. The energy field is not an exception when it comes to preserving our planet. Since non-renewable sources do not meet the standards because of the pollution impact they generate, it is evident that clean renewable energy sources should become more widely available for a better future.

Bearing this need in mind, the United Nations Sustainable Development Goals (SDG) Report aims to ensure access to affordable, reliable, sustainable, and modern energy for everyone [1]. In this respect, green hydrogen as a source of energy could accomplish that goal. However, there are still some disadvantages in terms of efficiency because of the lack of mass production and scientific development in the field of green hydrogen obtention. The purpose of this paper is to describe the current cells efficiency and potential changes that can be made in their design to obtain higher amounts of power.

To achieve this aim, this paper is organized as it follows. Firstly, the technical aspect section details the components and functioning of the cell for the improvement on its efficiency. Secondly, the economic aspects section evaluates the regular cost of green hydrogen and the way it can be improved.

II. Fuel Cells Characteristics

A. General aspects

To understand fuel cells, it is necessary to analyze the electrolyse process used to produce hydrogen. In this process a current is applied through a water container. The water molecules split as shown in the reaction in Eq. (1):

$$2H_2O \rightarrow 2H + O_2 \tag{1}$$

The water is made conductive by applying an electrolyte that can be acid or basic. It also requires a catalyst to accelerate the process.

The current passes through the cathode to the anode and the anode collects the oxygen while the cathode collects the hydrogen, which can be seen in Fig. 1. [2]

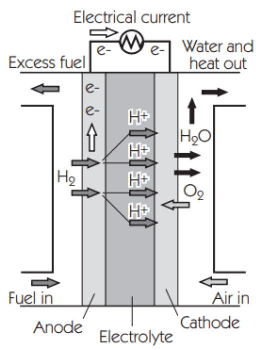

Fig. 1. The Fuel Cell. [2]

This being explained, it should be mentioned that fuel cells are devices capable of doing the reverse electrolysis process. In simple words, the compressed hydrogen passes through a membrane where it combines to oxygen forming water, as it can be seen in Eq. (2).

$$2H + O_2 \rightarrow 2H_2O \tag{2}$$

This reaction generates an electric current capable of powering buildings, cars, spacecraft – as seen in Fig. 2, amongst others [2]. A great advantage is that it is easily stored as small volumes produce a great amount of energy compared to other energy sources.

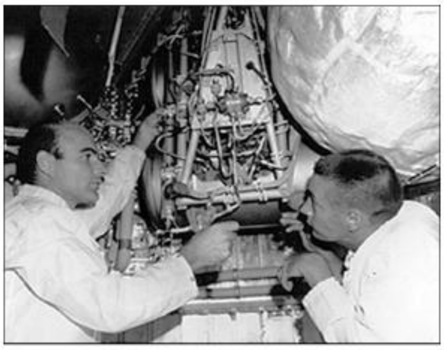

Fig. 2. Spacecraft fuel cell for Gemini missions. [2]

B. *Main Structure of a Fuel Cell*

A fuel cell is an electromechanical system which converts the energy from the chemical reaction between the fuel and the oxidant directly into electrical energy.

In a conventional cell, the fuel (Hydrogen) continuously enters the anode (negative electrode) and the oxidant (oxygen) also continuously enters the cathode (positive electrode). Electrochemical reactions occur between the electrodes and produce an electric current [3], as shown in Fig. 3. This cell can be of different types, as it will be seen in the following section.

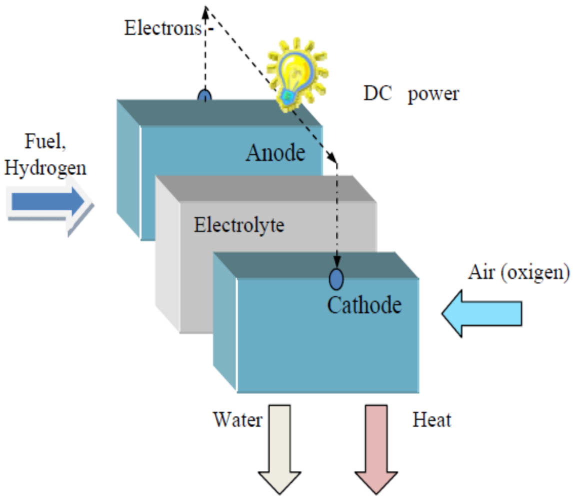

Fig. 3. Fuel Cell Components. [3]

C. *Types of Fuel Cells*

There are five types of fuel cells, which are characterized by the following attributes. Such properties are their operating temperature range, types of fuel used, type of catalyst used and energy conversion efficiency. All these aspects have a direct impact on the efficiency of each type of fuel cell to be developed. Each of these fuel cell technologies available are:

- Polymeric Electrolyte Membrane Fuel Cells (PEMFC).
- Direct Methanol Fuel Cells (DMFC)
- Alkaline Fuel Cells (AFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Molten Carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)

At the beginning of the next page, a table (Table I) with synthetic information on the different fuel cell technologies is presented. The table lists and quantifies the main characteristics that define fuel cells regarding its technical aspects which are the working temperature range, the type of electrolyte, the capacity to deliver power and its most outstanding applications. [3]

The previous list gives general information to the readers about the types of technologies available. However, this paper focuses mainly on PEM and SOFC technologies. The choice made will be subsequently explained.

TABLE I
THE DIFFERENT FUEL CELLS THAT ARE CURRENTLY IN USE AND UNDER DEVELOPMENT

	AFC Alkaline	PEMFC Polymer Electrolyte Membrane	DMFC Direct Methanol	PAFC Phosphoric Acid	MCFC Molten Carbonate	SOFC Solid Oxide
Operating temp. (ºC)	<100	60-120	60-120	160-220	600-800	800-1000
Electrolyte	KOH	Perfluoro sulfonic acid (Nafion membrane)	Perfluoro sulfonic acid (Nafion membrane)	H_3PO_4 immobilized in SiC matrix	Li_2CO_3-K_2CO_3 eutectic mixture immobilized in γ-$LiAlO_2$	YSZ (yttria stabilized zirconia)
Electrode materials	Anode: Ni Cathode: Ag	Anode: Pt, PtRu Cathode: Pt	Anode: Pt, PtRu Cathode: Pt	Anode: Pt, PtRu Cathode: Pt	Anode: Ni-5Cr Cathode: NiO(Li)	Anode: Ni-YSZ Cathode: lanthanum strontium manganite (LSM)
Applications	Transportation Space, Military Energy storage systems			Combined heat and power for decentralized stationary power systems	Combined heat and power for stationary decentralized systems and for transportation (trains, boats etc.)	
Realised Power	Small-medium sized plants 50 kW-11 MW	Small plants 0,5-400 kW modular	Small plants < 5 kW	Medium sized plants >11MW	Small power plants 100 kW-2MW	Small power plants 100-250 kW
Lifetime	Not available	60,000-80,000 h	1,000 h	30,000 – 60,000 h	20,000 – 30,000 h	90,000 h
Investment Cost [€]	200-700/kW	3000-4000/kW	>10000/kW	4000-5000/kW	4000-6000/kW	3000-4000/kW

Table I. Main characteristics for each type of fuel cells [3, 4, 5]

In the table all available technologies are described to give a general field description. The solutions to be presented will be applicable to PEM and SOFC technologies since both of them have more backup investigation, they are more versatile and are massively produced and sold to the market than their competitors, as shown in Fig. 4.

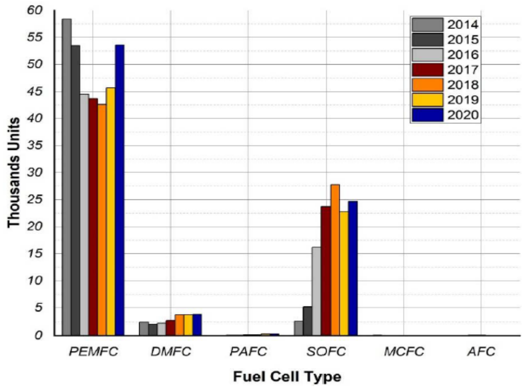

Fig. 4. Fuel cells available in the market. [6]

III. PARAMETERS THAT IMPACT ECONOMICALLY

The main aspects that have a direct impact on the cost of these technologies are the operating cost, the maintenance cost and the durability. The advantages and disadvantages of both fuel cells will be presented to the aim of finding solutions to the disadvantages so that the improvements on the efficiency can be made.

A. PEMFC (Polymer/Proton Electrolyte Membrane)

PEMFC, which stands for Polymer Electrolyte Membrane Fuel Cells, are devices capable of delivering high amounts of power densities. They also present a good durability and are mostly used on the automotive industry. As a disadvantage, they do not tolerate carbon monoxide, which is why they must operate in high temperature ranges. Also, the catalyst used to accelerate the process is expensive.

Fuel Cell Type	Advantages	Disadvantages
Proton Exchange Membrane (PEMFC)	High power densities, proven long operating life, adoption by automakers.	Lack of CO tolerance, water and heat management, expensive catalyst.

Table II. PEMFC advantages and disadvantages. [7]

B. SOFC (Solid Oxid Fuel Cell)

The SOFC, which stands for Solid Oxid Fuel Cells are devices of high efficiency, good internal fuel processing, and dissipates heat on an efficient way. Some of the disadvantages of it are the high operating temperatures that harm the materials affecting the overall durability of the cells and the cost of them.

Fuel Cell Type	Advantages	Disadvantages
Solid Oxide (SOFC)	high efficiency, internal fuel processing, high grade waste heat.	High operating temperature (materials), High cost.

Table III. SOFC advantages and disadvantages [7]

IV. POTENTIAL FOR COST REDUCTION

As stated above, the two main technologies that have the highest potential for improvement in terms of increased performance and reduced costs are PEMFC and SOFC. Both technologies are solutions to deeply decarbonize the stationary sector.

Next, the most technically feasible strategies for developing and increasing performance while reducing equipment operating cost will be presented.

A. Cost Reduction Potential for PEMFC

The following aspects can be considered to optimize these devices.

- Catalyst Cost Reduction

Catalyst cost can be reduced by deploying alloy catalyst such as PtCo and PtNi. Another alternative is the use of a hybrid cathode catalyst (HCC), which contains a Carbon support doped with electrochemically active Nitrogen with Pt catalyst.

With this type of catalyst, better performance, greater tolerance to CO and reduction in material cost are achieved [8].

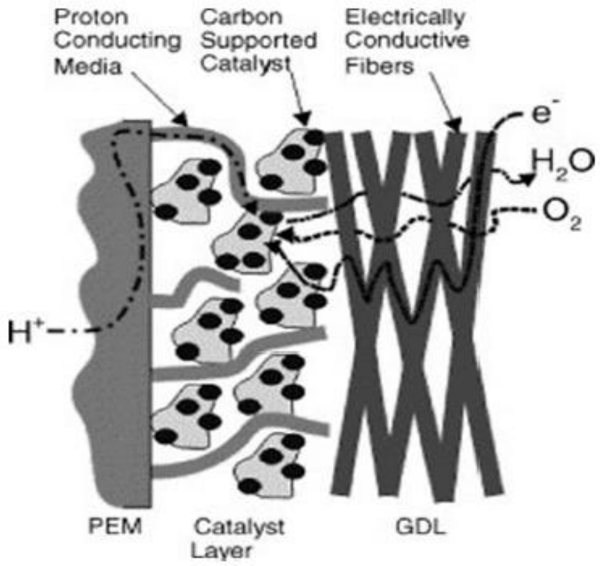

Fig. 5. Cross section of PEMFC showing flow-through catalyst layer. [8]

- Cell Temperature Range Control

The cell must be thermally managed for a temperature range between 0 ºC and 80 ºC. PEM cells have been shown to perform better at temperatures below 80 ºC and above 0 ºC to prevent freezing and equipment degradation. [9]

- New Developments in the Low Temperature PEMs

Low-temperature PEMs are considered those operate below 100 ºC. They generally show high proton conductivity, high limiting current density and power. However, they have low mechanical strength.

The performance of these cells can be enhanced in two ways. They are sulfonation of aromatic polymer and cross-linking of the membrane. If the degree of sulfonation and cross-linking increases, then performance also increases; however, they could also lead to deformation in mechanical properties. Therefore, this aspect must also be taken into account. [9]

B. Cost Reduction Potential for SOFC

To improve the performance of these devices, the following aspects can be considered.

- Pore Size Optimization in Anodes

While larger pore sizes reduce diffusion resistance, smaller pores result in higher reaction rates. An optimal pore-size is therefore found in the mid-range (a porosity of 0.2). [10]

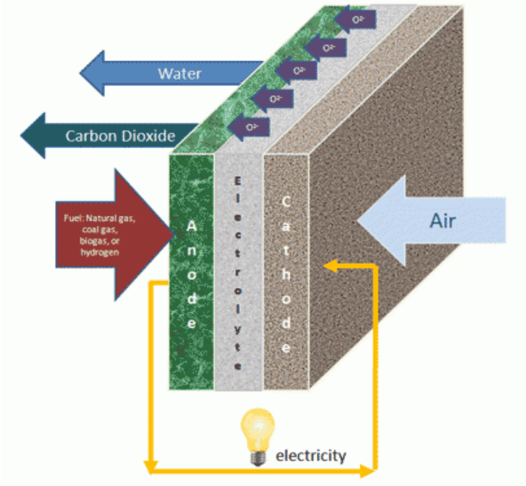

Fig.4. Pore size should be the optimal in the anode since the fuel combines there. [11]

- Planar SOFC Thermal Management

Analyzing the thermal behaviour of SOFCs is essential to formulate good management plans. Effective thermal management leads to minimizing thermal gradients and heat points in the cell during various modes of operation, resulting in increased cell durability. [10]

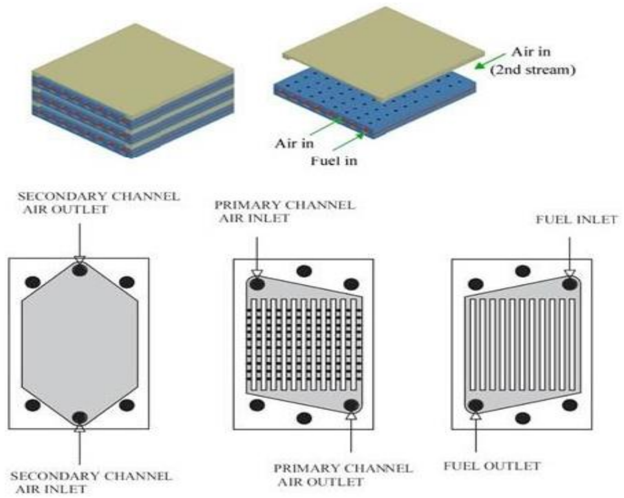

Fig.5. Proposed interconnected and manifolded designs for thermal management. [10]

- New Materials

Development must also be made in terms of materials to improve the cell performance. The use of new materials should result in smaller, more compact fuel cells and more robust SOFC stacks, and the replacement of expensive materials with more economical ones wherever possible. [10]

V. Conclusion

The efficiency improvement of fuel cells is key on its role to be the next source of power for future generations. The improvement of it involves the analysis of the advantages and disadvantages of each of the cells. By working on the weak aspects of each device it is possible to define the solutions for them to be improved. Some of the solutions presented on this paper were related to temperature, materials, and catalysts. These changes could make hydrogen devices good competitors of electrical devices.

As well as this, the world needs to upgrade its energy sources in order to ensure our survival, life quality, and a healthy planet. In line with the United Nations' SDG report, green hydrogen may therefore help ensure access to sustainable energy for all the population.

Acknowledgment

We wish to acknowledge the institution we are part of, this is our beloved University, our teachers that were key on the whole process and our families that encourage us to study and improve professionally.

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The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar