GCSP-IMT RESEARCH PAPER – DEVELOPMENT OF A FUEL-CELL SYSTEM FOR AUTOMOTIVE APLICATIONS.

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Abstract. *This paper is aimed at describing the process of designing, building, and operating a Fuel-Cell system for automotive applications. These activities were engaged while fulfilling my individual GCSP Program assignments for the development of technical/creative and multidisciplinary competencies under a GCSP-IMT Scholarship, during the year of 2022. The report also intends to bring some perspective on one Fuel-Cell technology, which may pair suitably with green hydrogen in order to produce an efficient, renewable energy conversion system. Also, it is hoped that the relevance of academic competition activities to the enhancement of the technical and multidisciplinary competencies will become apparent.*

Keywords. Sustainability, Renewable Energy, Electric Vehicle, Fuel-Cell, Multidisciplinary,

Introduction

Renewable energies are one of the most discussed topics in modern engineering because of its effects in our planet on medium and long term, with the potential to alleviate or revert the anthropogenic green-house effects, now globally addressed by the Paris Protocol and other COPs of the UN. This situation and that almost 45% of all the energy consumed on Brazil may be traced back to mobility purposes (Leal & Consoni, 2021).

Through the year, the main technical focus was to study the process of designing, building, and operating a Fuel-cell (FC) system for automotive purposes, which was accomplished through the involvement on the Maua Racing H2 Team. This engagement was productive not only on the technical aspects of the activity since, after being assigned the position of Project Manager and Captain for the Team, it was possible to develop multidisciplinary and human competencies of the program as well.

The choice of a Fuel Cell Electric Vehicle (FCEV) as the main object of research is due to its higher range and smaller time of refuel compared to an Electric Vehicle (EV), and also to the fact of the technology representing a reasonable replacement for Internal Combustion Vehicle (ICV) in light of the Brazilian geopolitical and socioeconomic scenarios.

Objectives

The main goal of these report is to demonstrate the evolution on the development of the GCSP - IMT program competencies in the year of 2022 and convey the results of the research regarding the application of a Fuel-cell in a vehicle.

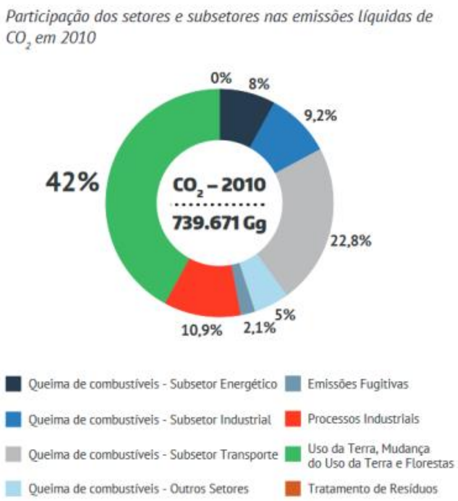
Development

Impact of fossil fuel uses in Brazil and possibilities of EV/FCV applications.

The involvement in Maua Racing H2 Team brought some question to discussion regarding the use of fossil fuels and CO2 emissions of Brazil in comparison to other countries, as well as the shift to EV vehicles, its potential and possible other options with easier application, like the FC vehicles,

According to recent research (Figure 1), the main contributors to the CO2 emissions are the logging with 42% and the vehicle fleet with 32% (CO2 emissions per sector) (Leal & Consoni, 2021).

Figure 1 - CO_2 emissions per sector (Autor, ANO)



It is also important to highlight the participation of the transport sector on the overall percentage of CO2 emissions (Table 1), these is due to the transport sector using mostly diesel engines because its high yield compared to Gas or Ethanol (Leal & Consoni, 2021).

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Energy consumption per transport model, and fuel type percentage per year.

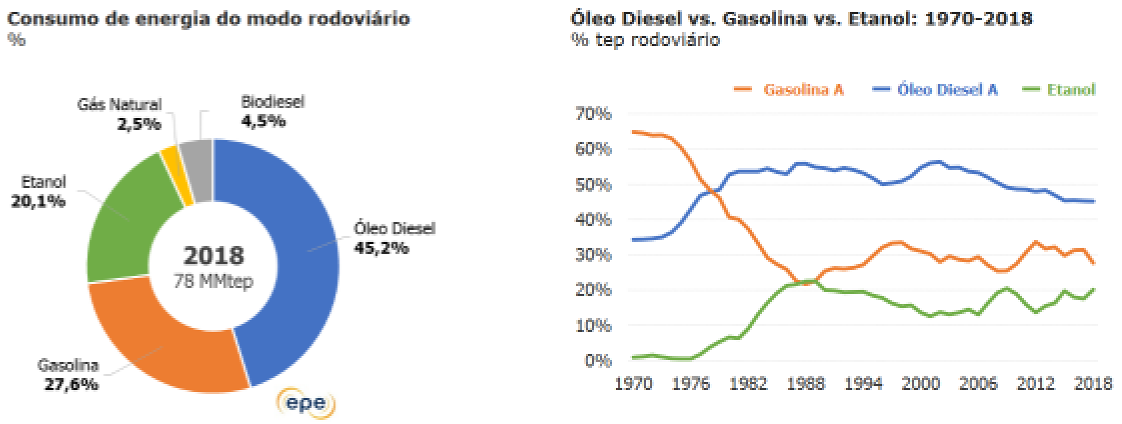

Table 1

Other factor that is important to quote is that Brazil is the second country that produces the most ethanol, with this type of fuel contributing to the neutrality of CO2 emissions (Vidal, 2021) .

Fuel Cell system on the market.

The FCEV system becoming an alternative for EV, due to its longer range, being lighter and less time to refuel. In Brazil, the FCEV, becomes a more reliable option them EV, not only because the energy distribution infrastructure for fossil fuels can be easily avail, but the process of obtaining hydrogen from Ethanol is far more sustainable them the one used in USA or Europe, which is the steam methane reformation (Hernandez & Kafarov, 2007; Leal & Consoni, 2021).

Nowadays there are many manufacturers investing in alternatives for the EVs, which reflects the need of a renewable energy powered vehicles with a longer range compared to EVs, these manufacturers being Toyota, with Toyota Mirai (Figure 1), Honda, with Honda Clarity and Hyundai with Hyundai Nexo and the Type-74 (Figure 2), with the second being a performance model.

Toyota Mirai.

Figure 1

Hyundai Type-74.

Figure 2

But the main focus of FC powered vehicles is for long range transport (Figure 3), with Mercedes-Benz, Scania and other European heavy duty vehicle manufacturers planning to sell only EV and FCEV trucks by the year of 2030 (SAE, 2022).

FC powered truck.

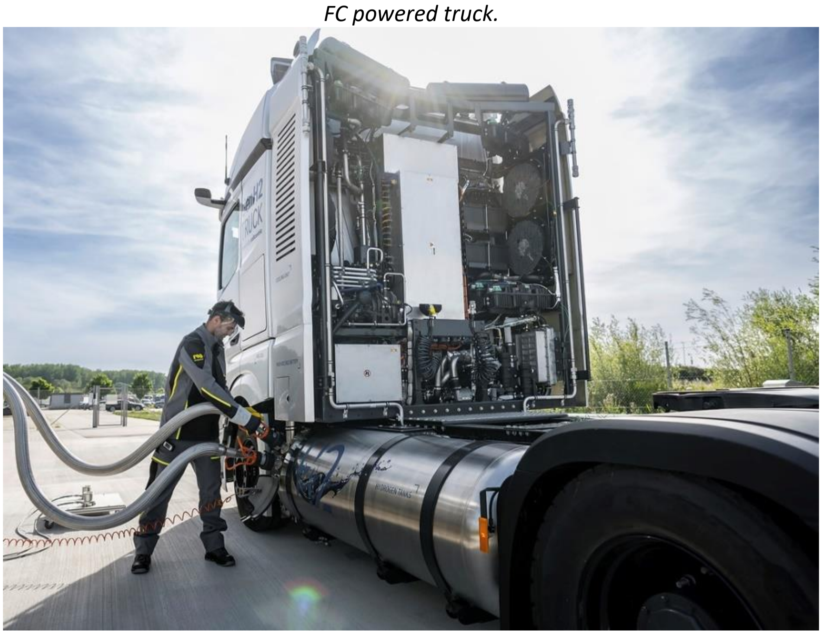

Figure 3

Comparison between, FCEV and EV

Unfortunately, the decision of which powertrain type is more sustainable is not as simple as it seems, for example, according to a recent release from Volvo, comparing the production of Polestar 2, an EV, and the XC40, an ICV, brought a complicated point of analyses, with the production of XC40 releasing 14 Tons of carbon dioxide (CO2), compare to 24 of the Polestar 2, an increase of almost 75% on the production (Wevolver, 2021).

This increase is caused by the production hight capacity Lithium-Ion batteries, that has an average production of 15 to 20 tons of CO2 per pack of 100kWh, and the situation becomes more and more complex if we consider the place where the batteries are manufactured, and where the vehicle will operate, for example, if the vehicle would be manufactured and used in Norway, the total amount of emissions would be only a product of the process of extracting the raw materials necessary to manufacture the car, because in Norway 97% of the energy comes from hydropower plants (Wevolver, 2021; Statista, 2021).

But, if we take a vehicle manufactured in China or India, that circulates in the USA, the situation became much different, with only 12% of the energy matrix in USA being renewable, and the process of manufacturing the vehicle in Asia being much more harmful to the environment than any other place in the world, the following chart shows the comparison between the carbon footprint of Tesla's battery plant in Texas (Table 2) and the new plant in Asia (Table 3) (Wevolver, 2021; Adiministration, 2021).

CO2 emissions per kilometer US battery .

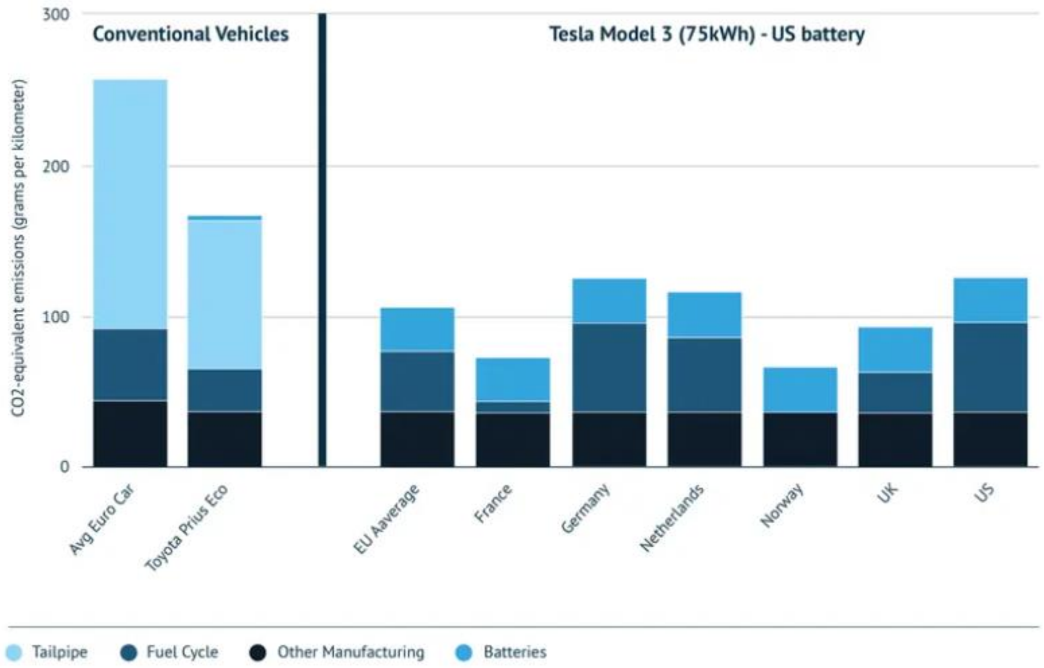

Table 2

CO_2 emissions per kilometer Asia battery.

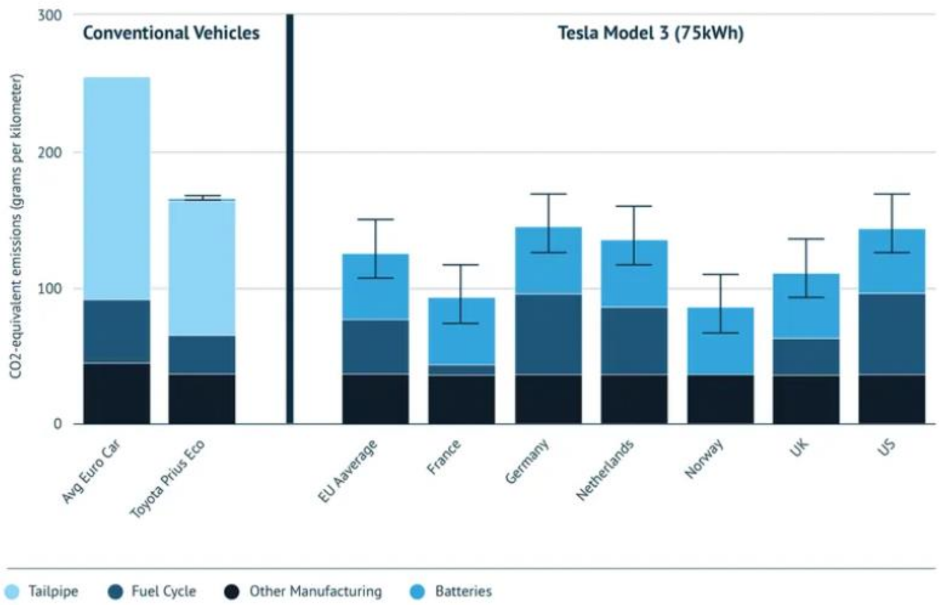

Table 3

The FCEV have also its fair share of CO2 production during the manufacturing process, but compared to an EV, it produces 20% to 25% less CO2 emissions compared to the normal EV, this reduction is caused because the FC vehicles operates in an hybrid basis, using low capacity batteries that are far less harmful for the environment them the ones used on EVs.

But the real benefits of FCEVs reside at its longer range when compared to the EVs, the ease conversion from the usual oil distribution mesh to a hydrogen distribution mesh, and the hight efficiency of the PEM FC, which is reaching 98% of efficiency (Ballard, 2019) .

It is important to highlight that, as well as EVs, the carbon footprint of the FCEVs will variate according to the county and place of manufacture, with not enough research that can provide an exact number comparing different effects in each country or continent.

Nowadays, Brazil and Europe are leading the FCEV research process, focusing on developing a renewable source of green hydrogen, via the Ethanol, the Soy and some other natural source (SAE, 2022).

Fuel-Cell Workflow

The Fuel-Cell (FC) discussed in this article have the designation of Proton Exchange Membrane (PEM), it consists in a semi-permeable membrane that retain one of the electrons from the hydrogen, and with the flow of oxygen, it produces water as a subproduct of the reaction (Figure 4).

Functioning of a PEM Fuel-Cell.

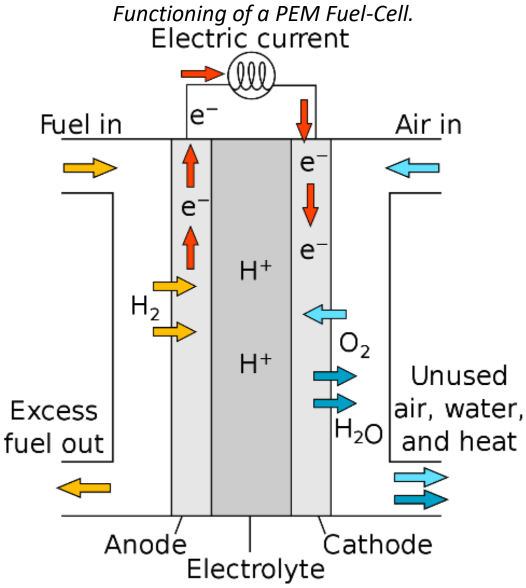

Figure 4

The electron that had been retained create a flow that create a tension, therefore a current capable of charging the accumulator on the vehicle. It's important to highlight that the FC used on the vehicle works in a range of 30~36V and it is capable of producing 2.1kWh in peak configuration, and although its top power is expressively low compere to market PEM FC that can produce up to 150 kWh, its operation logic is the same.

The Basic components of the FC system are the high-pressure tank, operating at 300 PSI, the hight pressure shutoff valve, the pressure regulator, that takes the hydrogen at 300 PSI and transforms to the FC operating pressure of 10~15 PSI, the solenoid 1, responsible for controlling the hydrogen entering the FC, the FC, and the solenoid 2 responsible for purging the hydrogen (Figure 5).

Hydrogen system workflow.

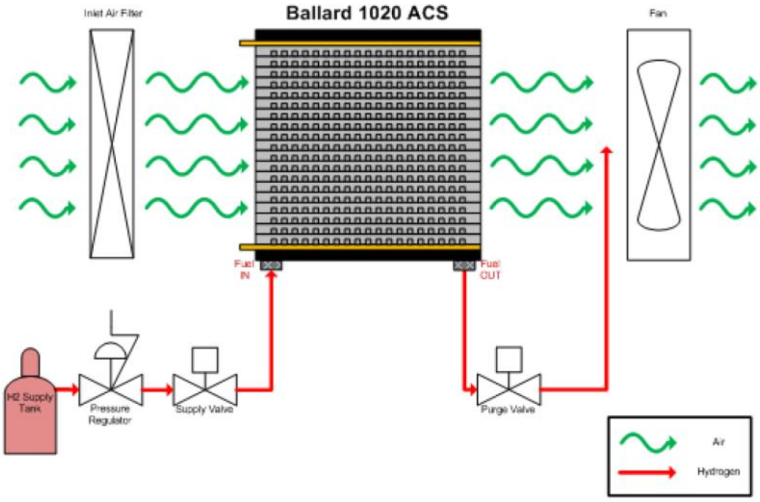

Figure 5

A FC have some control parameters, with these parameters being the temperature, hydrogen intake, hydrogen exhaust, and the tension requested from the FC. Because the FC operates at 36V and the accumulator end motor operates at 48V there had to be designed a DCDC capable of doing a step up from 36V to 48V at 2.1kWh (Figure 6).

Electric system workflow.

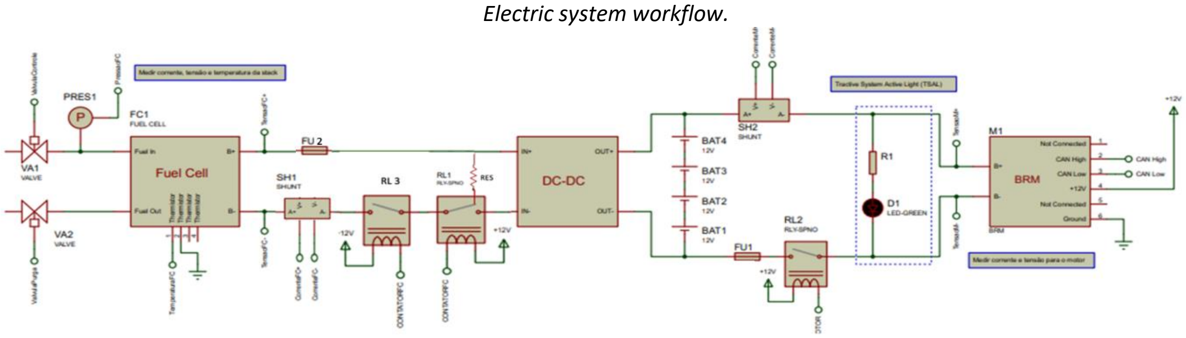

Figure 6

It is important to highlight that the FC in this case operate in floating, which means that the FC produces power according to the demand from the driver, but, in market cars, the FC operates as a range extender, which mean that the FC will only actuate recharging the accumulator, not delivering power directly to the motor.

These change in the control methodology causes gain in efficiency, because the FC has a curve of performance, similar to a internal combustion engine, having an optimal yield at a given flow of hydrogen, tension and temperature (Ballard, 2020; Ballard, 2019).

Room for Development

Although most of the system essentials for the vehicle are already develop by the time that this article is being written, there are many aspects that can be optimize regarding the hybrid powertrain, like, a way to monitor the degradation of the FC, a study for a lighter and smaller DCDC, application of a Lithium-Ion accumulator (which would be lighter than the acid lead that is currently being used) and the study of the cooling of the FC.

With the cooling study being the last thing that would be needed to have 100% control over the yield of the FC, with the heat that it generates being the direct attached for the degradation of the membrane, and the levels of energy produced.

A study of the FC cooling would involve the design of a intake and exhaust structure optimized to the flow of air, as well as a control of the fan that forces air through the FC.

Results

As the main focus of this paper was to demonstrate the results of a research regarding the functioning of FCEVs, and why these types of vehicles are more suitable for the Brazilian social economical and geopolitical scenario over the EVs, there are not much results to comment apart from the obtained on the Maua Racing H2 Team.

Thanks to the technical research, it was possible to deeply understand all the processes involved in the design and operation of a FCEV, therefore the Maua Racing H2 Team achieved a great success on the first FCEV academic competition, acquiring the second place on the overall ranking of the competition, on its first edition and accomplishing the design and manufacturing process of the MRH2-22 (Figure 7).

MRH2-22 first FCEV designed and manufactured on the Mauá Institute of Technology.

Figure 7

Conclusion

The technical aspects in these last 10 months were very developed, with a great base build to enter the next year focusing on the design of the cooling system for the FC

Through the process of research of this paper, it was possible to deeply foresee the major factors involved in the choice between FCEVs and EVs, regarding the environmental, geopolitical, and socioeconomic aspects.

It was also possible to understand the types of FCs available on the market and its applications, therefore, selecting the PEM FC for this study, as this type of technology was the most presented one during the research.

Concluding, the FC vehicles scenario on Brazil have all the favourable conditions to grow, with great distances to cover, a very well-developed basis to base of distribution and an easy access to renewable sources of energy, only lacking in development to turn the technology in a more safe, reliable, and easy to access.

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