Hydrogen Fuel Cell Design and Manufacturing Process Used for Public Transportation in Mexico City

G. Luna-Sandoval, G. Urriolagoitia-C, L.H. Hernández, G. Urriolagoitia-S, E. Jiménez

Abstract—**According to the energy crisis that the world faces, the international community requires to offer practical solutions for this problem, hydrogen fuel cells are a promising one like an option to generate clean energy and solve this crisis. During the last few years of the twentieth century, people have enhanced the interest to expand and use the fuel cell technology. Environmental concerns about global warming and the need to reduce carbon dioxide (CO_2) emissions provided the stimulus to seek ways of improving energy conversion efficiency. The Instituto Politécnico Nacional aims through the development of this type of work to be at the forefront of applied knowledge in the design and construction of hydrogen fuel cells. Clean technologies are the technological basis for the design and manufacture of a Proton exchange membrane fuel cell (PEMFC) or hydrogen fuel cell technology that are intended to be applied to public transport in Mexico City. This paper describes the design process and construction of a hydrogen fuel cell for specific applications, in this case, bus public transportation.**

Index Terms—**Design, fuel cell, hydrogen, manufacturing.**

I. Introduction

Environmental pollution problems as well as the future world energy crisis makes think about saving energy. This applied to the transport means:
--Use energy efficiently.
--Improve the quality of the environment.

In order to satisfy this need, in recent years many automotive companies and people in their own workshops have been developing vehicles propelled by electric motors which are powered with energy supplied by the fuel cells, although at present this technology is very expensive, it is thought that decrease in the future with increasing demand.

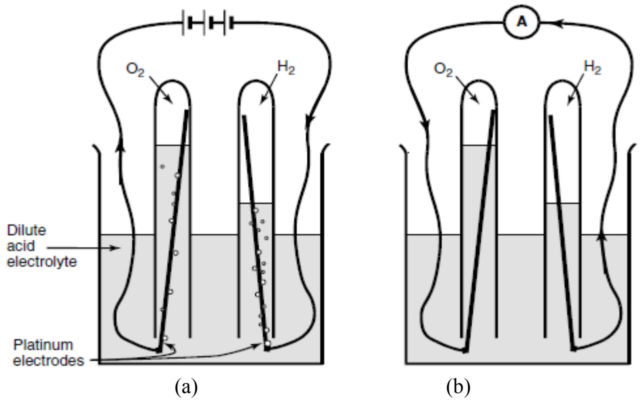
With the growing cost of oil and concern about global warming, people are becoming interested in cleaner, more fuel-efficient vehicle engines powered by bio-fuels or hydrogen, or by alternative energy technologies like batteries, hybrids and fuel cells. And given the rising cost of electricity and reliability issues with the power distribution system, people will soon be demanding cleaner, alternative energy sources to power heat and cool their homes. An ideal technology to do just this is one of the same technologies being developed for cars - fuel cells [12].

Fuel cells run on hydrogen, which can be derived from a variety of fuels ranging from ethanol and methane, to conventional hydrocarbon fuels like propane or natural gas (a reformer is used to extract the hydrogen). A fuel cell can be powered by industrially produced pure hydrogen, a by-product of steam reforming of natural gas. Hydrogen can also be generated from water by electrolysis, decomposing it to oxygen and hydrogen gas, and solar or wind energy can be used to power this electrolytic process [33].

Instituto Politécnico Nacional has taken the challenger to introduce the hydrogen fuel cell design and construction to be used on the public transport of Mexico City.

Some prototypes are currently in testing phase and will most likely be marketed in the first half of next century.

The basic operation of the hydrogen fuel cell is extremely simple. The first demonstration of a fuel cell was by lawyer and scientist William Grove in 1839, using an experiment along the lines of that shown in Figures 1a and 1b. In Figure 1a, water is being electrolyzed into hydrogen and oxygen by passing an electric current through it [1]. In Figure 1b, the power supply has been replaced with an ammeter, and a small current is flowing. The electrolysis is being reversed – the hydrogen (H_2) and oxygen (O_2) are recombining, and an electric current is being produced.



(a) (b)

Fig. 1. (a) The electrolysis of water. The water is separated into hydrogen and oxygen by the passage of an electric current. (b) A small current flows. The oxygen and hydrogen are recombining.

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Another way of looking at the fuel cell is to say that the hydrogen fuel is being ‘burnt’ or combusted in the simple reaction, obtained water (H_2O)

$$2H_2 + O_2 \rightarrow 2H_2O \qquad (1)$$

However, instead of heat energy being liberated, electrical energy is produced.

The experiment shown in Figures 1.1a and 1.1b makes a reasonable demonstration of the basic principle of the fuel cell, but the currents produced are very small. The main reasons for the small current are:

--The low ‘contact area’ between the gas, the electrode, and the electrolyte – basically just a small ring where the electrode emerges from the electrolyte.

--The large distance between the electrodes – the electrolyte resists the flow of electric current.

To overcome these problems, the electrodes are usually made flat, with a thin layer of electrolyte as is in figure 2.

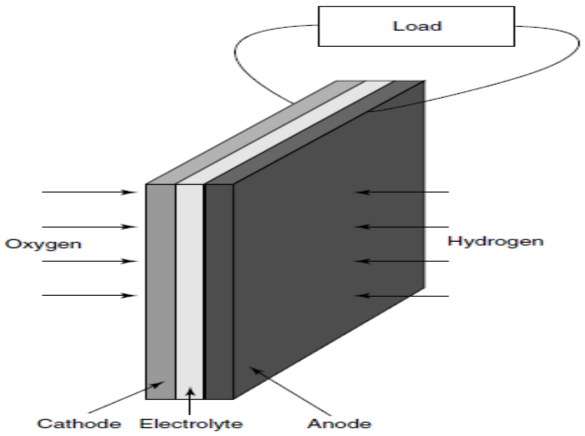

Fig. 2. Basic cathode–electrolyte–anode construction of a fuel cell.

The structure of the electrode is porous so that both the electrolyte from one side and the gas from the other can penetrate it. This is to give the maximum possible contact between the electrode, the electrolyte, and the gas.

However, to understand how the reaction between hydrogen and oxygen produces an electric current, and where the electrons come from, we need to consider the separate reactions taking place at each electrode. These important details vary for different types of fuel cells, but if we start with a cell based around an acid electrolyte, as used by Grove, we shall start with the simplest and still the most common type.

At the anode of an acid electrolyte fuel cell, the hydrogen gas ionises, releasing electrons and creating H^+ ions (or protons).

$$2H_2 \rightarrow 4H^+ + 4e^- \qquad (2)$$

This reaction releases energy. At the cathode, oxygen reacts with electrons taken from
the electrode, and H^+ ions from the electrolyte, to form water.

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_2O \qquad (3)$$

Clearly, for both these reactions to proceed continuously, electrons produced at the anode must pass through an electrical circuit to the cathode. Also, H^+ ions must pass through the electrolyte. An acid is a fluid with free H^+ ions, and so serves this purpose very well.

Certain polymers can also be made to contain mobile H^+ ions. These materials are called *proton exchange membranes*, as an H^+ ion is also a proton.

Comparing equations 2 and 3 we can see that two hydrogen molecules will be needed for each oxygen molecule if the system is to be kept in balance. This is shown in Figure 3. It should be noted that the electrolyte must only allow H^+ ions to pass through it, and not electrons. Otherwise, the electrons would go through the electrolyte, not a round the external circuit, and all would be lost.

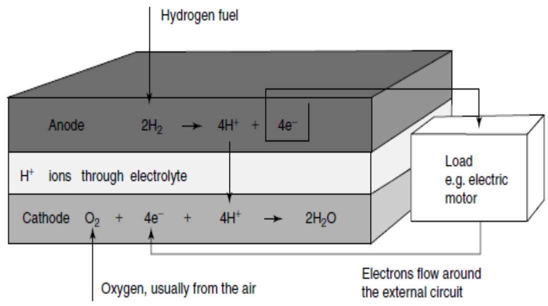

Fig. 3. Electrode reactions and charge flow for an acid electrolyte fuel cell. Note that although the negative electrons flow from anode to cathode, the ‘conventional current’ flows from cathode to anode.

In an alkaline electrolyte fuel cell the overall reaction is the same, but the reactions at each electrode are different. In an alkali, hydroxyl (OH^-) ions are available and mobile. At the anode, these react with hydrogen, releasing energy and electrons, and producing water.

$$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^- \qquad (4)$$

At the cathode, oxygen reacts with electrons taken from the electrode, and water in the electrolyte, forming new OH^- ions.

$$O_2 + 4e^- + 2H_2O \rightarrow 4OH^- \qquad (5)$$

For these reactions to proceed continuously, the OH^- ions must be able to pass through the electrolyte, and there must be an electrical circuit for the electrons to go from the anode to the cathode. Also, comparing equations 4 and 5 we see that, as with the acid electrolyte, twice as much hydrogen is needed as oxygen. This is shown in Figure 4.

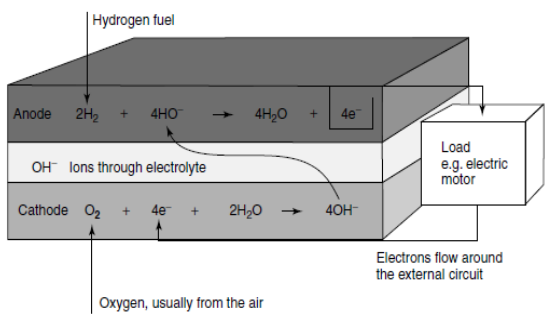

Fig. 4. Electrode reactions and charge flow for an alkaline electrolyte fuel cell. Electrons flow from anode to cathode, but conventional positive current flows from cathode to anode.

Note that although water is consumed at the cathode, it is created twice as fast at the anode.

There are many different fuel cell types, with different electrolytes. The details of the anode and cathode reactions are different in each case [10].

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These are some types of fuel cells: Alkaline fuel cells, Proton Exchange Membrane (PEM) fuel cells, Phosphoric Acid fuel cells (PAFC), Molten Carbonate fuel cells (MCFC), Solid Oxide fuel cells (SOFC), Direct Alcohol fuel cells (DAFCs).

Opportunities are currently available for research on the PEMFC and/or hydrogen fuel cell system at Mexico City. This research may include literature reviews, modelling, control algorithms, testing procedures, hardware design and implementation for specific system components and applications [3].

Current stack technology covers the power range for 100W to 75kW. Applications to date include motor bikes, cars, buses and light aircraft. All applications so far have been configured as fuel cell/battery hybrids vehicles. This combination results in a compact power module with expellant dynamic response and regenerative capability bringing out the best attributes of both the fuel cell system and the battery technology [5, 6].

Fuel cells could dramatically reduce air pollution, when we have a significant population of vehicles using this technology. It could talk about the efficiency increase in which energy is used and a new market demand new jobs as well specialists in the field [27, 28, 32].

The next century hydrogen economy will be part of the country, and that this element used to produce a good portion of electricity for residential use as well as transport. Industrialized countries spend millions of dollars in research for fuel cell development; this technology in 1839, when William Grove developed the first fuel cell was a dream. Today is shaping up not as a dream but as a good solution to satisfy part of the energy demands and environmental future, not far away [21, 22, 23].

The fuel cell has been identified as being particularly suited for mobile power applications because of the high power density and low temperature operation that is attained. The focus of the research is on the fuel cell with the vision to incorporate the hydrogen fuel cell into electric vehicle and portable power applications. For effective use of the fuel cell, a great amount of engineering work is required [24, 31].

When supplying a given load, the external characteristics of the fuel cell must match the demands of the load. This is more challenging when the fuel cell is supplying a variable load, such as an electrical vehicle drive. In most cases, a power electronic converter is required between the fuel cell and the load as an interface. To meet the requirement of dynamic performance, a number of operational variables, such as the fuel injection rate and the operational temperature, of fuel cells can be controlled. Hence a mathematical model is required for system design and performance control [25, 26].

II. Proton Exchange membrane fuel cell Design

The designed and built PEMFC settings are shown in Figure 5 [2].

Following shows in detail each parts of the cell designed and built during this study.

The main function is to serve as the basis structure to assemble the fuel cell. Bases also serve as accommodation for the heaters, which are responsible for maintaining the cell proper operating temperature [4] (between 30 and 100ºC).

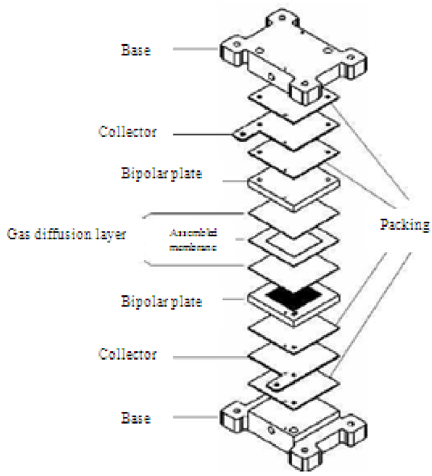

Fig. 5. Schematic of the fuel cell membrane proton exchange designed and manufactured.

The bases were built in aluminum designed 6061. This type of aluminum is characterized by good mechanical strength and corrosion resistance for machining [7, 11], figure 6.

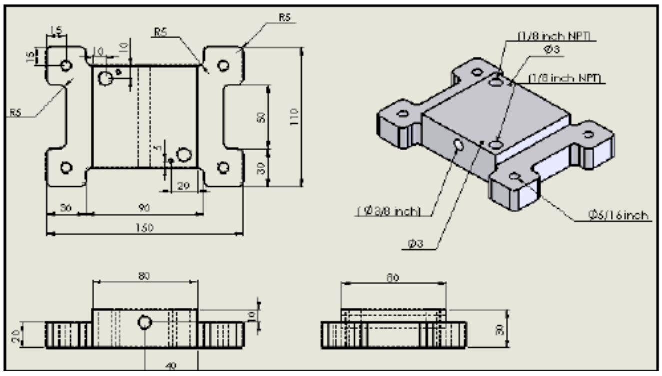

Fig. 6. Construction drawings based cell fuel.

The collector plates are responsible for conducting the generated electrons in the fuel cell to conduce to the charge. The plates were designed constructed of copper. They were then coated with a layer of gold and nickel with the aim of improving its electrical conductivity [9], figure 7.

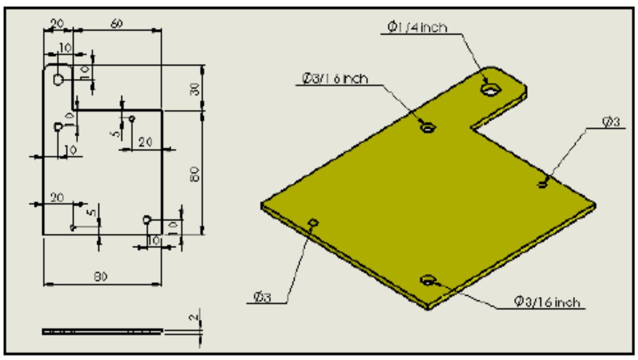

Fig. 7. Construction drawings of the collector plate of the fuel cell.

Basically all the design and construction of the PEMFC or hydrogen fuel cell needs to cover the needs to operate an engine bus as the project of the transport bus in the province of British Columbia, Canada [20]. Show in figure 8.

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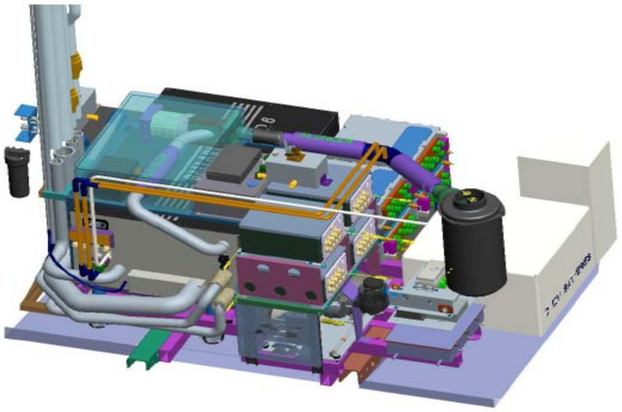

Fig. 8. Drawing of the engine used the hydrogen fuel cell in Canada.

Instituto Politécnico Nacional's Mechanical Engineering Center research and development are working in the design and construction of the PEMFC or hydrogen fuel cell for use in the public transport vehicle with the help of existing journals publications and many universities' research in the world based on this theme.

The hydrogen fuel cell is tested by finite element analysis software to improve its functionality, virtual tests are the best way to verify the fuel cell design before its manufacturing, figure 9 [8, 16, 17].

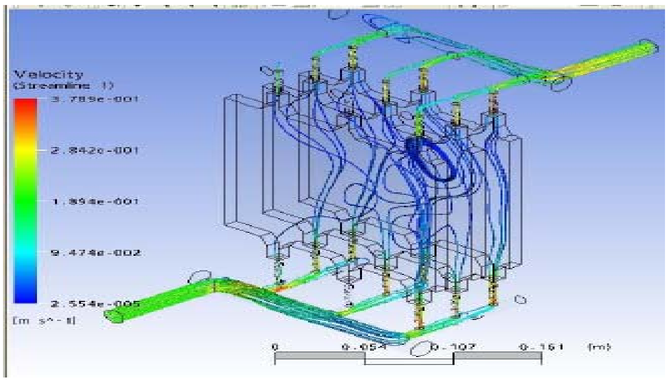

Fig. 9. Finite element analysis applied to the hydrogen fuel cell.

One example of the expected prototype for the public transportation bus for Mexico City is showing on figure 10. But the intention of the research at the Instituto Politécnico Nacional is innovate the PEMFC and/or hydrogen fuel cell using the optimums materials and generate more energy for a specific use.

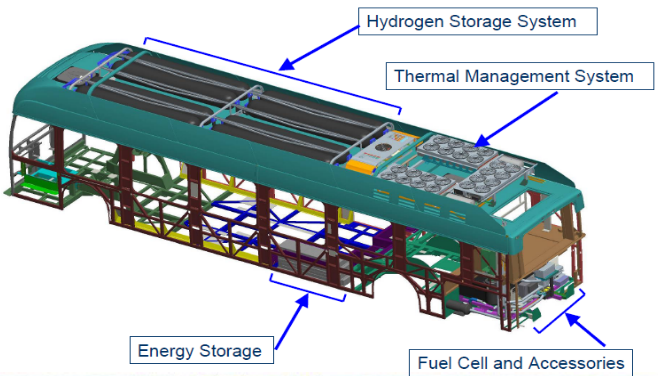

Fig. 10. Schematic of the fuel cell system mounted in the bus transport in Canada.

III. New Advance of the State of Knowledge and Results for Fuel Cell Used in Bus Public Transport in Mexico City

The difference between the hydrogen Canadian bus and the hydrogen Mexican prototype bus is the storage system; Canadian bus use the hydrogen storage system meanwhile the Mexican bus will use water storage system to reduce the risk of fire by accident. Figure 11 shows this peculiarity.

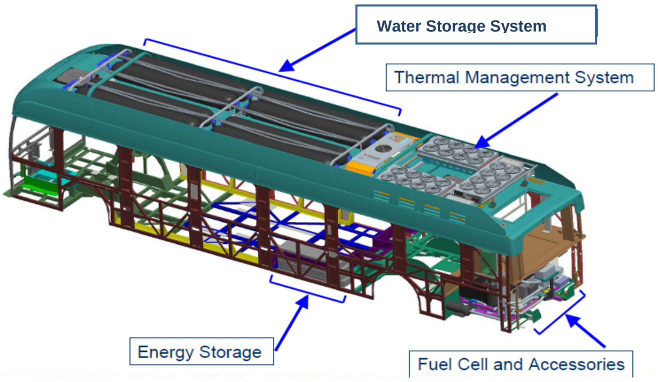

Fig. 11. Schematic of the fuel cell system for the bus transport in Mexico.

With various types of fuel cells that existing in the market, Instituto Politécnico Nacional is designing a new way of hydrogen power supply to use it into the bus public transportation in Mexico City, unlike to the hydrogen buses public transportation used in Canada [20] and another parts of the world.

The fuel cell designed and built to use in vehicles for public transportation in Mexico city transform the water into hydrogen, so the difference with the others countries are the storage system, in this case the bus shall water storage system unlike the hydrogen s system used now days that it is extremely more dangerous for be flammable.

It makes no sense to introduce hydrogen in the transport sector without fuel cells in the long run because of the high electricity to heat ratio and the high overall conversion efficiency of fuel cells powered by hydrogen: today, the efficiency of the fuel cell system for passenger cars is around 40% (in the future maybe 50%) compared to 25–30% for the gasoline/diesel powered internal combustion engine under real driving conditions. Fuel cell systems have a higher efficiency at partial load than full load which also suggests their suitability for application in motor vehicles, which are usually operated at partial load, e.g. during urban driving. In addition, the fuel cells exhaust produces zero emissions when fuelled by hydrogen. Road transport noise in urban areas would also be significantly reduced. Furthermore, fuel cell vehicles could possibly even act as distributed electricity generators when parked at homes and offices and connected to a supplemental fuel supply. From this perspective, the use of hydrogen in internal combustion engines can only be an interim solution.

Today, the powertrain costs of fuel cell vehicles are still far from being cost-competitive. They have the largest influence on the economic efficiency of hydrogen use in the transport sector and the greatest challenge is to drastically reduce fuel cell costs from currently more than US$2000/kW to less than US$100/kW for passenger cars.

On the other hand, fuel cell drive systems offer totally new design opportunities for vehicles: because they have fewer mechanical and hydraulic subsystems compared with combustion engines, they provide greater design flexibility, potentially fewer vehicle platforms and hence more efficient manufacturing approaches which may lead to additional cost reductions. Nevertheless, this cost reduction potential has to be realized first and is in a continuous interplay with the requirements for efficiency and lifetime. This is the major source of uncertainty for the market success of fuel cell vehicles. Additional technical challenges like hydrogen storage and safety issues have to be solved as well.

To achieve a relevant market success, it is essential to meet the fuel cell targets set for costs, lifetime and reliability. These technology developments obviously always take longer than planned by industry. However, preparation for the structural changes in industry is just as important as the technical optimization of fuel cells. Qualified service technicians and skilled workers must be available to ensure that the introduction of fuel cell technology is managed as smoothly as possible. The success of hydrogen in the transport sector will crucially depend on the development and commercialization of competitive fuel cell vehicles [34].

For hydrogen fueling to take place, several steps are required [35], figure 12:

1. The hydrogen must be transported to the fueling station. Although hydrogen could be produced onsite, this module does not deal with onsite production. Fuel cell sites covered by this manual will have the fuel delivered to the site in some manner (truck, train or pipeline).
2. The hydrogen is stored onsite. The hydrogen can be stored as either a gas or liquid on the dispensing facility site.
3. The hydrogen is converted to its final form. The storage of the hydrogen may be in a different form than required for the final distribution and may be converted onsite. In the case study (included in this module), the fuel is converted from liquid to gas for final distribution to the vehicles.
4. The hydrogen is distributed to vehicles.

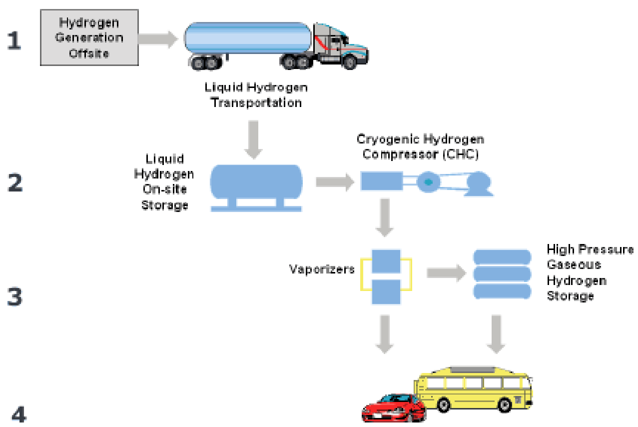

Fig. 12. Hydrogen dispensing facility overview.

The first prototype showing in figure 13 is under strict test applying finite element analysis [13, 14, 15], generated energy, temperature, pressure with special instrumentation. The electrolysis happens with the water contact and stainless steel when electricity current is applied on their terminals [18, 19, 30]. The hydrogen generation only occurs when is needed and do not be stored meanwhile the hydrogen engine is turn off.

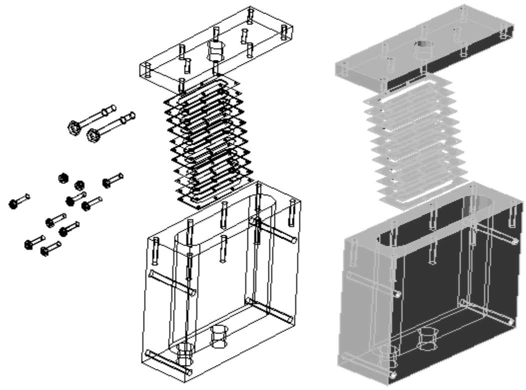

Fig. 13. Hydrogen fuel cell designed and built in the Instituto Politécnico Nacional.

IV. Conclusion

This article provides a new solution to apply hydrogen fuel cells as power supply for a public transport bus or vehicles. Hydrogen is obtained by electrolysis from the water just if the bus engine is running; the water comes from the storage system and passes through the fuel cell where the hydrogen is obtained to be used as the bus engine fuel; the hydrogen is not stored when the bus engine is turn off, only water is stored (water storage system) as a safety measure for passengers.

Hydrogen fuel cell was designed and manufactured in the laboratories of the Instituto Politécnico Nacional, the fuel cell being tested with finite element analysis to prove the materials and parts used for his manufacturing, as well measurements of parameters like temperature, pressure, current, voltage.

The fuel cell is experiment with different fluids mixed with water and others reaction elements to give greater efficiency to electrochemical process, resulting with this more production of hydrogen.

The advantages and disadvantages of fuel cells are important to take decisions for every application; specifically here are the most important.

The main advantages include:

· Efficiency
· Simplicity
· Low emissions
· Silence
· Flexibility and wide application range

The main disadvantages include:

· Cost
· Hydrogen infrastructure

With this in mind, if can avoid the high cost construction of an hydrogen infrastructure to refueling the hydrogen storage system of a public transport bus for a low cost construction of a water infrastructure to refueling the water storage system proposed in the Mexican public transport bus, reducing the cost of maintenance and transportation. Figure 14 and figure 15 represent this idea.

In the water fueling facility need only the water tank and a control panel water transfer system.

Respecting to the economy and environment, both will benefit directly to the people thanks to the utilization of this kind of clean energy.

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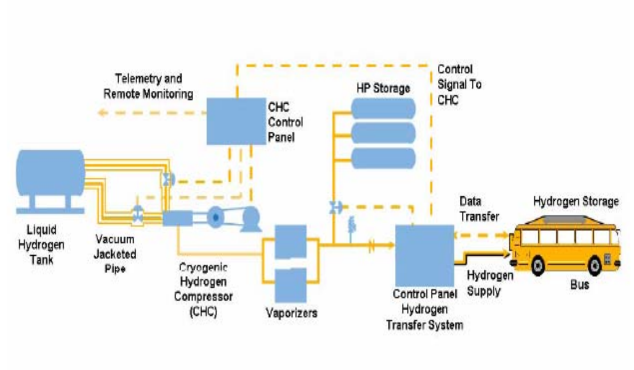

Fig. 14. Hydrogen fueling facility.

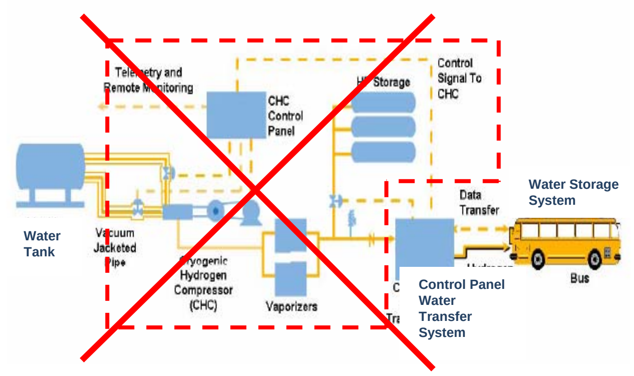

Fig. 15. Water fueling facility.

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