# Roadmap for Hydrogen Technology in Urban Public Transport in the Metropolitan Area Of Merida, Yucatan

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## Abstract

This work is a first step towards a road map for hydrogen technology in the transport sector in the city of Merida, Yucatan, Mexico. In the case of the Metropolitan Area of Merida (MAM) approximately 34.3 % of the mobility is by public transport, with approximately 750,000 trips and moving 352,262 habitants every day. For this reason, it is important to improve the efficiency of the local transport system, in order to supply the demand with a high quality service. In addition, the public transport system consists of an obsolete fleet of approximately 1,700 units. As a consequence it is generating high operation costs due to maintenance and serious environmental pollution. The local public transport system indeed is one of the major causes of carbon emissions.

In this study it is proposed to replace part of the existing transport system by hydrogen-based technology, in order to achieve a more sustainable public transport infrastructure. This road map includes the selection of a specific route and estimation of the required hydrogen production, from clean renewable energy sources connected to the grid according to the potential of natural resources. Also, the challenges that need to be overcome along the implementation of the hydrogen technology are analyzed. Based on an interpretation of environmental, economical and social benefits, the most adequate chain for production, distribution, storage and conversion of hydrogen, according to the requirements of the MAM and available hydrogen technologies, is being determined. Finally, the economical feasibility for this proposal is determined.

Keywords: Hydrogen technology, Metropolitan Area of Merida, Urban Public Transport.

## 1. Introduction

Nowadays, sustainable development is one of the global biggest challenges, being at the same time an opportunity to develop new projects. According to the last population census of INEGI (National Institute of Statistic and Geography) the Yucatan state had around of 1,955,577 inhabitants in 2010 and it is expected to reach 2,180,690 inhabitants in 2020 [1, 2].Therefore, it is important to mention that approximately 52.5 % of the population of the Yucatan state is concentrated in the Metropolitan Area of Merida (MAM). The MAM is composed by six municipalities: Progreso, Ucú, Umán, Kanasín, Conkal and Merida [3].In the case of MAM, the transport system is one of the major local pollutants that is currently expanding throughout the city. According to a mobility study approximately 34.3 % of the mobility within the MAM is by public transport [4].

Likewise, according to the department of transport of the Yucatan state, approximately 750,000 trips are made daily by 362,752 habitants every day [5]. In addition, the public transport system consist of 247 routes and approximately 1,700 units that use approximately 51 million gallons of fuel per year and produce 135 kton/day of $CO_2$ emissions, being a sign of high operating costs and serious environmental pollution [5].

In order to implement a more sustainable public transportation infrastructure that includes hydrogen fuel cell buses, we must produce the energy carrier, hydrogen, from clean renewable energy sources. In this project we analyze the options that the MAM has to put us onto the clean hydrogen pathway, and the challenges that need to be overcome along the implementation of hydrogen technology. Therefore, it is expecting to get the best chains of production, distribution, storage and conversion of hydrogen, according to the potential of the MAM and the available hydrogen technologies options. Likewise, it is expected to determinate the possible environmental and social benefits, as well as the dimension of energy charge for produce hydrogen from renewable sources, in this case specifically from wind and photovoltaic because of the detection of potential areas in the zone of Yucatan, with moderate wind resources of an average 4-6 m/s range [6, 7] and with daily high solar radiation of > 5 $kWh/m^2$ [8, 9]. Also the region has 4 central powered electricity plants with the capacity of annual electricity production of 7,721,000 MWh [10].

In order to produce clean hydrogen by the separated from water via electrolysis, electricity can be taken from the grid (from a variety of sources) and generated by wind turbines or photovoltaics that feed the hydrogen production facility directly [11].

## 2. Experimental

The development of this work is based on the information available in data base of several Mexican institutions like SENER, INEGI, SCT, SEDUMA, PEMEX, CFE. The next paragraph describes the methodology followed for this work.

First it has been necessary to describe the characteristics of mobility within the MAM and the structures of the Urban Public Transport (UPT). One specific route was selected for gradual hydrogen bus implementation. Next, available $H_2$ technologies ($H_2$ buses and electrolyzers) were analyzed according their technical specifications and local requirements and an estimation of required hydrogen production and electrical energy could be calculated. In order to determine the implementation strategy an analysis of regional electrical energy resources was performed; and based on the previous information, the emission reduction potential could be determined according to emissions factors of IUPT (International Urban Public Transport): 70 gr/passenger/km for $CO_2$, 1 gr/passenger/km for CO, 0.5 gr/passenger/km for HC and 0.9 gr/passenger/km for $NO_x$ [12] and the average emission factor of electricity that is 0.4698 ton$CO_2$eq/MWh [13]. Finally, a cost analysis was realized, based on theoretical costs for different energy sources for the chains of production, distribution and supply of $H_2$ and others costs taken for direct price quotes. The internal rate of return (IRR) and the net present value (NPV) were determined in order to evaluate the economical feasibility of this work; besides, a sensibility and risk analysis has been made with a variation in 10 % of the cost of economic variables of income and expenditures obtained in this work. Based on the information obtained in the different parts of this project, conclusions are drawn on the technical- economic viability for the implementation of $H_2$ technology in the UPT in the MAM. The next diagram demonstrates the methodology.

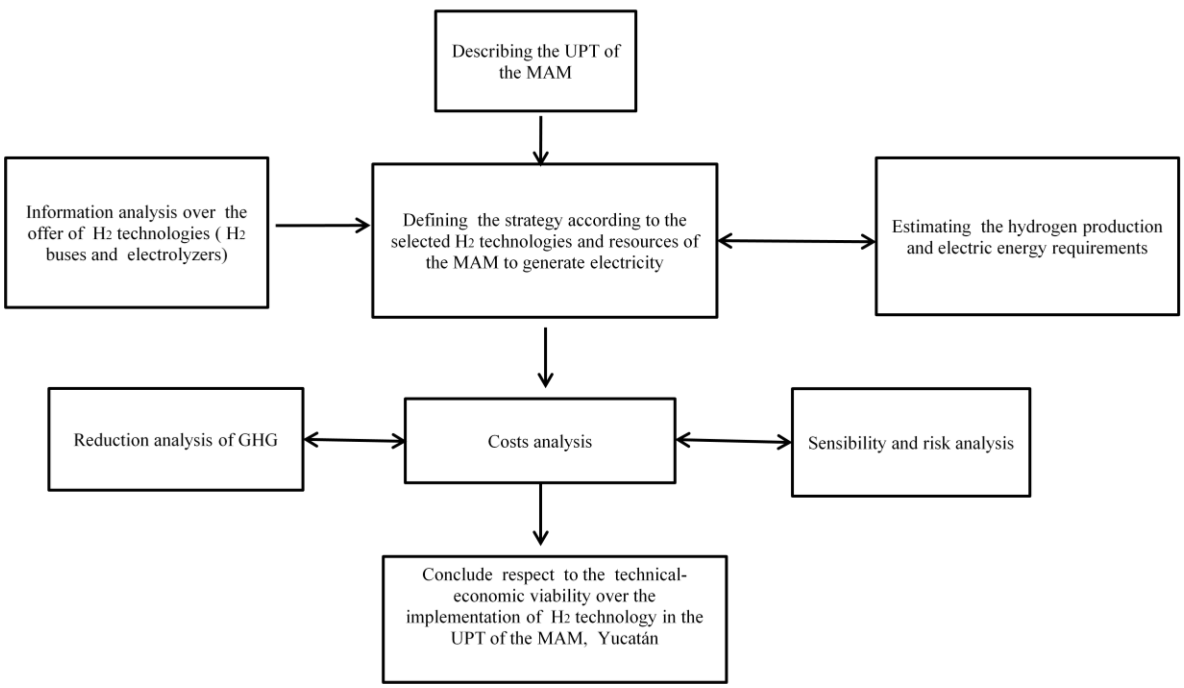


Figure 1. Methodology diagram for the technical-economic evaluation $H_2$ technology in the UPT in the MAM.

## 3. Results and discussion

First, it was necessary to define the principal stakeholders that potentially play a role in the implementation of this pilot project, main stakeholders include federal government secretaries like SENER (secretary of energy) and SCT (secretary of communications and transport), state government secretaries such as SEDUMA (secretary of urban development and environment) and DTEY (transport department of the Yucatan state), local transport business organizations of the MAM, research and educational institutes such as CINVESTAV (Center for Research and Advanced Studies of the National Polytechnic Institute), CICY (Yucatan Center for Scientific Research),UADY (Autonomous University of Yucatan) and ITM (Merida Institute of Technology) and finally national energy companies such as CFE (The Federal Electricity Commission), PEMEX (Mexican Petroleum) , and a number of private companies. Besides it is necessary to obtain financial support of international organizations such as World Bank, NadBank, ONU and governmental organizations; for example, the European Union.

A gradual implementation of $H_2$ buses is proposed for one specific route for in the UPT based on analysis of the characteristics of the MAM and the available renewable hydrogen technology. The strategy consist in a short time period (2014-2020), for metropolitan circuit route, which circumscribes the city of Merida, is 63 Km long, has a fleet of 40 buses, buses operating 18 hours each day [14]. For $H_2$ production, electrolysis using renewable energy sources is considered. The estimation of hydrogen production and electrical demand has been estimated according to the characteristics and needs of the electrolyzers system Hystat 60 (Hydrogenics) with a flow rate of 5.5 kg/hr and conversion efficiency of 53.4 kWh/kg [15] and transport model based on the Citaro autobus (Mercedes-Benz), which has an autonomy of 200 km for 35 kg of $H_2$ [16]. Based on this information, it has been estimated that each $H_2$ bus will perform 6 full trips per day and needs running 378 km per day requiring 66.15 kg of $H_2$.

It is considered to introduce 4 $H_2$ buses in 2014, and increase up to a total of 20 $H_2$ buses in 2016, 28 $H_2$ buses in 2018 and 40 $H_2$ buses in 2020. In order to supply the total $H_2$ demand for these buses a yearly hydrogen production of 110 $H_2$ ton/year for 2014 is required 516 $H_2$ ton/year for 2016, 700 $H_2$ ton/year for 2018 and 994 $H_2$ ton/year for 2020. The required yearly renewable energy production is of 7 GWh/year for 2014, 34 GWh/year for 2016, 46 GWh/year for 2018, 65 GWh/year for 2020.The amount of water needed is of 1,752 $m^3$ for 2014, 8,176 $m^3$ for 2016, 11,096 $m^3$ for 2018 and 15,768 $m^3$ for 2020. Also, it has been determinate the emission reduction from clean fuel is in order of 16 kton/year of $CO_2$eq , 0.2 kton/year of CO, 0.1 kton/year of HC, 0.2 kton/year of $NO_x$. The emission reduction from using renewable energy instead of fosil energy for $H_2$ production is around 31 kton of $CO_2$eq/year. Therefore, a total yearly GHG ( Green House Gases) reduction of 47 kton of $CO_2$eq can be achieved, as is shown in the figure 2.

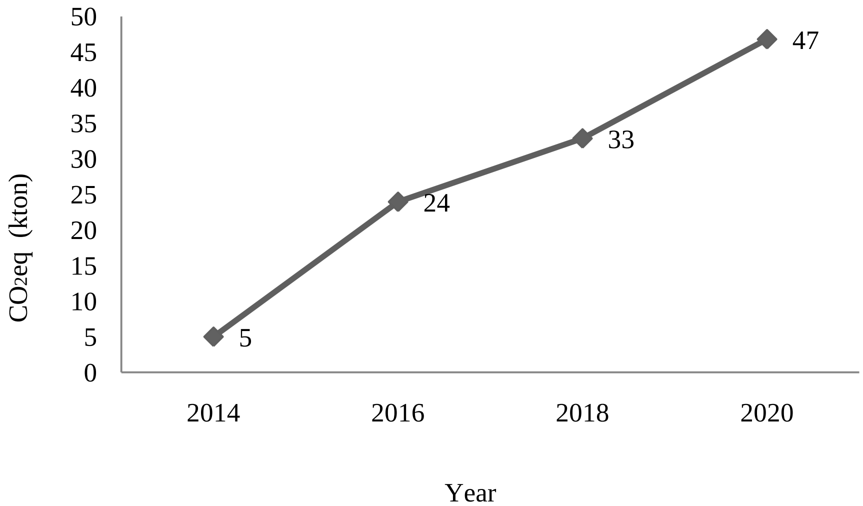


Figure 2. Total $CO_2$eq avoided emissions for $H_2$ technology implementation for UPT in the MAM.

Once that the requirements of $H_2$ production, electrical demand, GHG and pollutants reductions have been estimated; an economical analysis was performed in order to determine which are the most sensitive variables and the economical needs for this technology application. The basic cost calculations are based on theoretical cost of hydrogen production in midsize electrolysis plants, including the initial investment, as well as the variable and fixed costs for the chain of production, distribution and supply of $H_2$. Different schemes of energy production are compared [11, 17] and the calculated hydrogen cost is of 5.33 USD/kg $H_2$ for an onsite electrolysis grid power system, 4.26 USD/kg $H_2$ for an onsite electrolysis wind turbine power system, 4.78 USD/kg $H_2$ for an onsite electrolysis hybrid wind turbine/grid power system, 7.66 USD/kg $H_2$ for an onsite electrolysis photovoltaic power system and 5.69 USD/kg $H_2$ for an onsite electrolysis hybrid solar photovoltaic/grid power system. Besides, apart from direct income from transport users, an additional income from carbon bonds is estimated to be 5 USD for each ton of $CO_2$ [18]. The cost of water is considered to be 1.01 USD/$m^3$ in 2014 [19]. The project has been evaluated with a real rate of 7.69 %, considering a minimum acceptable rate of return of 12 % (the rate at which public projects in the Yucatan state are evaluated) and also considering an inflation of 4 %. The amount that the government sector has to provide trough financial mechanisms in order to support the project is indicated in the figure 2. An average amount of 20 million USD a year is needed (actual subsidies for local transport amount to 7,757,952 USD/year).The table 1 indicates in ascendant order the variables that are financially more sensitive and represent a high risk in case of variation and show that the amount of government support is the most sensitive variable, followed by the cost of the fuel cell bus, the cost of $H_2$ production chain, the price of transport service, carbon bonds and the water cost is the less risk variable. It was noted that in Mexico there is a lack of financial and legal support as well as of norms and standards that stimulate the implementation of clean energy technologies.

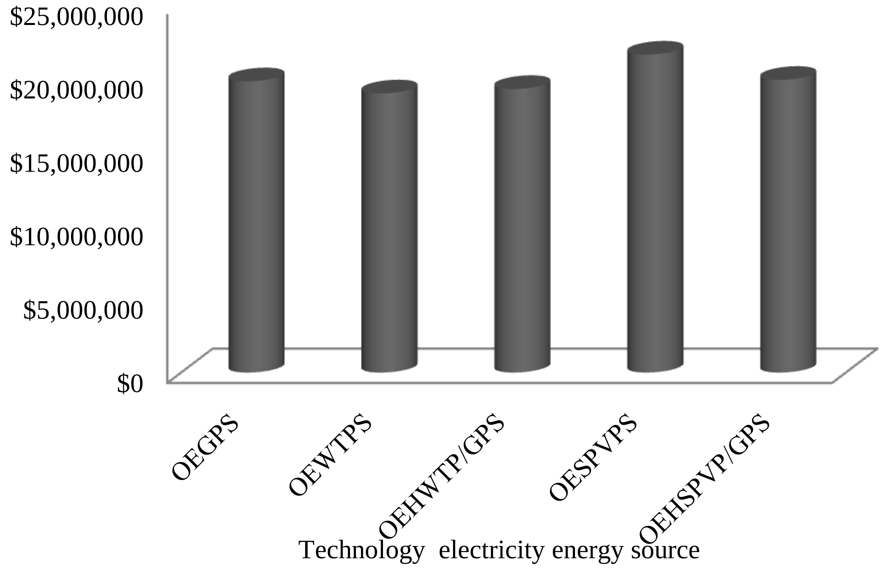


Figure 3. The amount of necessary money by government in order to support the $H_2$ technology implementation for UPT in the MAM.

Table 1. Results of sensitive analysis for different energy sources technologies.

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| Variable | OEGPS IRR (%) | OEGPS NPV(USD) | OEWTPS IRR (%) | OEWTPS NPV(USD) | OEHWTP/GPS IRR (%) | OEHWTP/GPS NPV(USD) | OESPVPS IRR (%) | OESPVPS NPV(USD) | OEHSPVP/GPS IRR (%) | OEHSPVP/GPS NPV(USD) |
|---|---|---|---|---|---|---|---|---|---|---|
| Governmental economic support | 33.51 | 10,413,009 | 30.12 | 9,981,094 | 31.77 | 10,138,546 | 37.21 | 11,368,312 | 33.79 | 10,464,491 |
| Cost of Citaro Fuel Cell Bus | 26.25 | 7,178,907 | 24.05 | 7,178,907 | 25.17 | 7,178,907 | 28.21 | 7,178,907 | 26.41 | 7,178,907 |
| Cost of $H_2$ Chain | 15.02 | 1,994,943 | 12.60 | 1,559,040 | 13.76 | 1,778,955 | 18.77 | 2,835,332 | 8.42 | 127,569 |
| Price of Transport service | 12.37 | 1,106,568 | 11.37 | 1,106,568 | 11.84 | 1,106,568 | 13.71 | 1,106,568 | 12.46 | 1,106,568 |
| Carbon Bonds | 7.87 | 31,445 | 8.05 | 92,074 | 8.11 | 92,074 | 8.50 | 92,074 | 8.21 | 92,074 |
| Water costs | 7.66 | -5,820 | 7.67 | -5,820 | 7.66 | -5,820 | 7.63 | -5,820 | 7.66 | -5,820 |

## 4. Conclusions

A gradual implementation of hydrogen technology in public transport was proposed for one specific route in Merida, and energetic, environmental and economic requirements were determined.

It can be concluded that $H_2$ bus implementation in Merida is technically and sustainably viable. However, according to the sensitivity and risk analysis, it is necessary to obtain financial support, from governmental funds and international collaborations.

## 5. Akcnowledgements

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