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FUTURE COSTS OF FUEL CELL ELECTRIC VEHICLES

Silvio Carlos Anibal de Almeida
Guilbert Gomes Nassif
Federal University of Rio de Janeiro, COPPE/UFRJ, Department of Mechanical Engineering, Ilha do Fundão, CT, sala G -204, Cx. Postal: 68503, Rio de Janeiro, RJ, - Brazil CEP 21941-972
silvioa@gmail.com, guilbert.nassif@poli.ufrj.br

Abstract. *Fuel cell electric vehicles (FCEVs) have zero tailpipe emissions, but are still considerably more expensive than internal combustion engines vehicles, which is the most significant obstacle to the mass adoption of these vehicles. FCEVs can become cheaper as manufacturing technology matures, economies of scale improve and hydrogen fuel costs decrease. This work presents a simplified analysis comparing the costs of an FCEV currently commercialized (the Nexo), a BEV (Kona) with the costs of a conventional vehicle of the same category (the Tucson). Fuel cell cost forecasts for production volumes of 100,000 and 500,000 units per year are presented, as well as the impact on purchase price and operating costs of an FCEV for the 2030 scenario. The results presented show that, with the establishment of fuel cell technology and the reduction of hydrogen prices, fuel cell vehicles can become economically competitive with internal combustion vehicles.*

Keywords: *Hydrogen, Fuel Cell Electric Vehicle, ADVISOR, Cost Analysis*
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1. INTRODUCTION

Many governments are introducing incentive programs to encourage the adoption of zero-emission vehicles, such as battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) (Li et al., 2012). There are several barriers to FCEV adoption: high vehicle and fuel costs, distribution infrastructure and hydrogen production (Strahs et al., 2012). Even with a 60% decrease in fuel cell system (FCS) cost compared to 2006 (EPA, 2018), FCEVs´ purchase price is still much higher than ICEVs and almost twice of BEVs´ price. Despite this, according to the International Energy Agency FCEV's market share could reach 17% by 2050 (Little, 2020). By 2030, the price of an FCEV is expected to be competitive with ICEVs (Offer et al., 2010).

This work presents a simplified analysis comparing the costs of an FCEV currently commercialized (the Nexo), a BEV (Kona) with the costs of a conventional vehicle of the same category (the Tucson). The study takes into account the cost of acquisition and the cost of fuel over the lifespan of these vehicles. Several scenarios were studied in the work of Nassif (2019). This article presents only the projection of these costs for the 2030 scenario, made with the data available in the literature. Advisor vehicle simulation software was used to estimate the fuel consumption of each vehicle.

2. ELECTRIC VEHICLES AND FUEL CELL ELECTRIC VEHICLES

BEVs are more efficient than FCEVs. Analyzing only the operation of the vehicle, the BEV has an efficiency of up to 83%, while the FCEV reaches about 48%. (Eaves, 2004).

Regarding autonomy, FCEV is able to travel greater distances than BEV, even though it is less efficient. This is because FCEV uses hydrogen as a fuel, whose mass energy density is considerably higher than the battery (Vidyanandan, 2018). Regarding the recharge / supply time, the FCEV can be refilled in a few minutes, while the BEV needs at least 30 minutes.

Considering the vehicle´s purchase price, BEV is cheaper than FCEV. In 2019, the purchase price of Nissan Leaf (40 kWh) and Hyundai Ioniq Electric ranges from US$ 30,000 to US$ 37,000 (CarAdvice, 2019). Toyota Mirai, the most selling FCEV, costs US$ 58,500 (Woodyard, 2019). DOE expects the cost of the fuel cell system (FCS) to reach US$ 30 /kW by 2030 (DOE, 2019a). FCEV operating cost is also high due to the high price of hydrogen (US$ 15.8/kg) compared to gasoline and electricity costs (DOE, 2019b)

Considering fuel costs over the life of the vehicle, the BEV has a lower cost than the FCEV, mainly due to the high price of hydrogen in relation to electricity, as will be presented in this job.

The US Department of Energy estimates that increasing the volume production of fuel cell vehicles, coupled with the development of the hydrogen large scale production, will significantly reduce the cost of the vehicles and of hydrogen. Meanwhile, the US and California government are encouraging the purchase of BEV and FCEV through consumer subsidies. The Hyundai Nexo is available for sale for US$ 58,300 in California. The US government and the California government offer a grant of US$ 7,500 and US$ 5,000 for the purchase of Nexo, respectively. In addition, Hyundai offers consumers free fuel for 3 years or US$ 13,000 to purchase fuel, whichever comes first (Lieber, 2019)

3. COST SCENARIOS

The purchase price of FCEVs is higher than the prices of ICEVs and BEVs due to the current high cost of the FCS. The high-volume production can reduce the FCEVs´ components costs and the hydrogen cost (DOE, 2019c). This is due to the economies of scale and change of manufacturing methods. Regarding the FCS total cost, the fuel cell stack would represent 66% of the total FCS system for a volume production of 1,000 units/year and 43% for 500,000 units/year. Figure 1 shows the FCS cost for different volume productions.

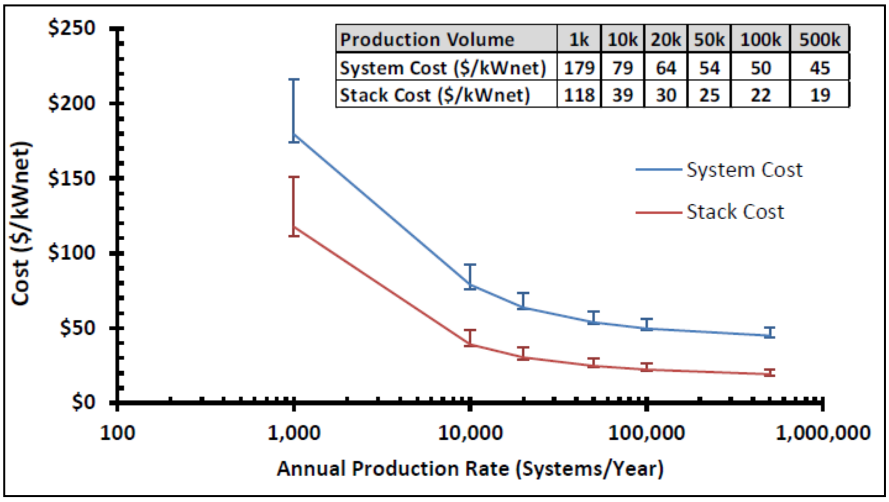

Figure 1 – Fuel cell cost versus volume production (Wilson et al., 2017).

The most expensive component of the fuel cell stack is the platinum catalyst, which represents about 40% of its cost. According to the DOE forecast, it is possible to reduce the total platinum loading used as a catalyst and increase the power density of fuel cell stack by 29%. Thus, it is possible to reduce the FCS cost to 45 US$/kW, for volume production of 500,000 units/year (Wilson et al., 2017).

According to DOE, the hydrogen cost can reach US$ 4/kg by 2030 (DOE, 2015). The goals to achieve this price varies with the possible pathways to produce hydrogen and with the type of production (centralized or distributed) (Rustagi et al., 2018).

An analysis of the FCEVs for the 2030 scenario is done in this work. The lifespan of the FCEV was estimated to be 10 years. The manufacturing and fuel costs are calculated for the vehicle´s lifespan and the values obtained are compared to a BEV and to a same-segment gasoline-engine vehicle.

The selected ICEV is the 2019 model of the Hyundai Tucson 2.0 L, which has the same maximum engine power (120kW) as the Nexo (Hyunday, 2019), an equivalent fuel consumption of 26 MPGe (combined cycle), and its purchase price is US$ 25,599. The chosen BEV was Hyundai Kona Electric. The Kona has an equivalent fuel consumption of 120 MPGe (combined cycle) and costs US$ 37,945 (Pod Point, 2018).

The purchase price of ICEV and BEV was considered constant. Electricity and gasoline costs were also considered constant over the vehicle´s lifespan, to simplify the analysis. The gasoline sells at US$ 3.95 a gallon in the US (EIA, 2019a). The cost of electricity is US$ 0.193/kWh, which corresponds to the price of electricity in California (EIA, 2019b).

In the last ten years, fuel cell cost has decreased by 60% (EPA, 2018). It is possible to evaluate the effect of the technological evolution of the FCEVs and government policy on the vehicle total cost. DOE foresees a significant cost reduction for the FCS, the hydrogen tank, and hydrogen fuel until 2030. The costs of these components and fuel are showed in Tab. 1 for four scenarios (Nassif, 2019):

a) 2020 cost scenario;
b) 2020 high-volume scenario (100,000 units/year)
c) 2020 high-volume scenario (500,000 units/year)
d) 2030 scenario.

Table 1. Components cost for different scenarios

Scenario	2020	100k units/year [c]	500k units/year [c]	2030[d]
FCS cost [US$/kW]	180 [a]	50	45	30
Hydrogen Tank cost [US$/kWh]	20 [a]	17	15	8
Hydrogen cost [US$/kg]	15.8 [b]	10	10	3.98 [e]

[a] Source: FASTSim database for the IX35 (Brooker, 2015).
[b] Source: (DOE, 2019b).
[c] Source: (Wilson et al., 2017).
[d] Source: (DOE, 2019c).
[e] Source: (DOE, 2015).

At volumes of 100,000 and 500,000 units/year, the FCS costs are US$ 50/kW and US$ 45/kW, respectively (DOE, 2019c). The same study also estimates the cost of the hydrogen tank and hydrogen at fuel stations for different volume productions. The hydrogen tank costs US$ 17/kWh for 100,000 units/year and US$ 15/kWh for 500,000 units/year. The hydrogen cost is also calculated for both volume productions, its price forecast is US$ 10/kg the two volume productions, and US$ 3.98/kg for the 2030 scenario.

3.1 Vehicle total cost: 2020 scenario

Table 2 presents the costs of the vehicles studied for the2020 scenario. The vehicle total cost is obtained by adding the vehicle purchase price and the fuel cost.

Table 2. Vehicle total cost - 2020 Scenario

Vehicle	Nexo	Tucson	Kona
Fuel economy - Combined cycle [MPGe]	61	26	120
Driving range [km]	612	606	405
Purchase price [US$]	58,296	25,599	37,945
Fuel cost [US$]	39,388	22,679	8,112
Total cost [US$]	97,684	48,278	46,057
Ratio of vehicle total cost to Tucson	2.02	-	0.95
Total cost with subsides and fuel credits [US$]	73,753	48,278	35,565
Total cost reduction due to subsides and fuel credits	24.5%	-	22.8%
Ratio of vehicle total cost to Tucson with subsides and fuel credits	1.53	-	0.74

As can be seen in Tab. 2, the FCEVs´ total cost is considerably higher than Tucson´s total cost. Without subsidies and fuel credits, Nexo´s total cost is US$ 49,406 more expensive than Tucson (or 2.02 times more expensive). Due to the impact of the subsidies and fuel credits, the vehicle total cost is reduced up to 24.5%. This shows the relevance of the government and vehicle manufactures as encouraging agents in the dissemination of the FCEVs.

3.2 Vehicle total cost: 2030 scenario

From the values in Tab. 2, it was possible to estimate the Nexo´s purchase price in the 2030 scenario (see Tab. 3). Comparing Tab. 2 with Tab. 3, it can be seen that, in the 2030 scenario, there is a 63.1% reduction in the Nexo´s purchase price compared to the current scenario.

Tabela 3. Vehicle cost for the 2030 scenario

Vehicle	**Nexo**	**Tucson**	**Kona**
Purchase price	US$ 35,742	US$ 25,599	US$37,945
Difference between vehicle´s purchase price to Tucson	US$10,143		US$12,346
Ratio of vehicle´s purchase price to Tucson	1.40		1.48

With the results from Tab. 2 and 3, and with the aid of the Advisor software, it is possible to calculate the vehicle total cost for the 2030 scenario. Fuel cost is calculated by extrapolating the daily cost to 10 years (estimated FCEV´s lifespan). Table 4 details the total cost of the vehicles analyzed in the 2030 scenario.

Table 4. Vehicle total cost: 2030 scenario

Vehicle	**Nexo**	**Tucson**	**Kona**
Purchase price [US$]	35,742	25,599	37,945
Fuel cost [US$]	10,135	22,679	8,112
Total cost [US$]	45,878	48,278	46,057
Difference between vehicle´s total cost to Tucson	(2,589)		(2,221)
Ratio of vehicle total cost to Tucson	0.95		0.96

As can be seen in Tab. 4, the total cost of the FCEVs in the 2030 scenario drops about 50% compared to the 2020 scenario without subsidies and fuel credits. The total cost of the FCEVs in this scenario is slightly lower than Tucson´s total cost. Nexo´s total cost is 5% lower (US$ 2,589) than Tucson´s.

Despite the simplicity of the cost analysis, it can be considered that the total cost of FCEVs can be equivalent to to that of ICEVs in the 2030 scenario.

4. CONCLUSIONS

The results presented show that, with the establishment of fuel cell technology and the reduction of hydrogen prices, fuel cell vehicles can become economically competitive with internal combustion vehicles.

5. REFERENCES

Brooker, A., 2015. FASTSim: A Model to Estimate Vehicle Efficiency, Cost and Performance. SAE Technical Paper.

CarAdvice, 2019. 2019 electric vehicle comparison: Jaguar I-Pace v Hyundai Ioniq v Nissan Leaf v Tesla Model S v Renault Zoe. https://www.caradvice.com.au/737312/2019-electric-vehicle-comparison-i-pace-v-ioniq-v-leaf-v-model-s-v-zoe/

DOE, 2015. *Multi-Year Research, Development and Demonstration Plan – 3.1 Hydrogen Production*, US Deparment of Energy.

DOE, 2019a. “Energy, Fuel Cell R&D Overview. 2019” Annual Merit Review. U.S. Department of Energy.

DOE, 2019b. "Clean Cities Alternative Fuel Price Report". July 2019. U.S. Department of Energy.

DOE, 2019c. “Hydrogen and Fuel Cell Program Overview “. Annual Merit Review, 2019. U.S. Department of Energy.

Eaves S., 2004. A Cost Comparisson of Fuel-cell and Battery Electric Vehicles”. Journal of Power Sources, p. 208-212.Pod Point, 2018. Hyundai Kona: https://pod-point.com/guides/vehicles/hyundai/2018/kona-64-kwh.

EIA, 2019a. Weekly Retail Gasoline Prices 2019. https://www.eia.gov/dnav/pet/ PET_PRI_GND_DCUS_SCA_W.htm.

EIA, 2019b. Eletric Power Monthly. https://www.eia.gov/electricity/monthly/epm_table_grapher .php?t=epmt_5_6_a.

EPA, 2018."Fact of the Month April 2018: Fuel Cell Cost Decreased by 60 % since 2006," 25 October 2019. [Online]. Available: https://www.energy.gov/eere/fuelcells/fact-month-april-2018-fuel-cell-cost-decreased-60-2006.

Hyunday, 2019. Hyundai Tucson Specifications: https://www.hyundaiusa.com/tucson/specifications.aspx.

Li, Q., Weirong C., Shukui L., Zhiyu Y., Shiyong T., and Yankun L., 2012. "Power Management Strategy Based on Adaptive Neuro-Fuzzy Inference System for Fuel Cell-Battery Hybrid Vehicle." Journal of Renewable and Sustainable Energy 4 (1): 1–13. doi:10.1063/1.3682057.

Lieber, G., 2019. "First 2019 Hyundai Nexo Hydrogen Fuel Cell SUV Delivered In NorCal". https://insideevs.com/news/342718/first-2019-hyundai-nexo-hydrogen-fuel-cell-suv-delivered-in-norcal/

Little, A. D., 2020. "What's in the Future for Fuel Cell Vehicles?" Accessed May 13. https://www.adlittle.com/en/insights/viewpoints/what's-future-fuel-cell-vehicles.

Nassif, G. ,2019. "Análise da performance e custos de diferentes configurações de um veículo à célula a combustível: o Hyundai Nexo". UFRJ/ Escola Politécnica. Rio de Janeiro.

Offer, G. J., D. Howey, M. Contestabile, R. Clague, and N. P. Brandon. 2010. "Comparative Analysis of Battery Electric, Hydrogen Fuel Cell and Hybrid Vehicles in a Future Sustainable Road Transport System." Energy Policy 38 (1): 24–29. doi:10.1016/j.enpol.2009.08.040.

Pod Point, 2018. Hyundai Kona: https://pod-point.com/guides/vehicles/hyundai/2018/kona-64-kwh.

Rustagi, N., Elgowainy, A. & Vickers, J., 2018. Current Status of Hydrogen Delivery and Dispensing Costs and Pathways to Future Cost Reductions. DOE Hydrogen and Fuel Cells Program Record, 17 12.

Strahs, Peter, Jordan Weaver, Luis Breziner, Christophe Garant, Keith Shaffer, Georgiy Diloyan, and Parsaoran Hutapea. 2012. "Development of a Proof-of-Concept Hybrid Electric Fuel Cell Vehicle." Journal of Renewable and Sustainable Energy 4 (3): 1–15. doi:10.1063/1.4718369.

Vidyanandan, K.V. 2018. Overview of Electric and Hybrid Vehicles. Energy Scan (A House Journal of Corporate Planning, NTPC Ltd., India). III. 7-14.

Wilson, A., Kleen , G. and Papageorgopoulos, D., 2017. "Fuel Cell System Cost - 2017," DOE Hydrogen and Fuel Cells Program Record, 30 September.

Woodyard, C., 2019. "Review: Toyota Mirai dresses up, but hard to fill up". USA TODAY. https://www.usatoday.com/story/money/cars/2015/12/11/toyota-mirai-review/77106202/.

6. RESPONSIBILITY NOTICE

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