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# Hydrogen fuel cell electric vehicle performance and user-response assessment: Results of an extended driver study

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ABSTRACT

This study examined driver acceptance and performance of hydrogen fuel cell electric vehicles as tested in real-world conditions over a two-year period. The study sample was a volunteer group of "n = 54" drivers who drove the vehicle for a month-long trial period. Each driver took 'before' and 'after' surveys regarding their driving experience. Drivers drove an average of 1400 miles per month, and either witnessed and/or performed vehicle refueling 3–10 times during their test period.

Key findings from the study include that: 1) 80% of study participant drivers found that the fuel cell vehicle (FCV) performance "exceeded" or "greatly exceeded" their expectations; 2) 98% of study participant drivers view hydrogen as a fuel for vehicles as being "as safe" or "safer" than gasoline as a fuel for vehicles; and 3) 94% of participants view the process of fueling a vehicle with hydrogen to be "as safe" or "safer" than gasoline fueling. Other findings include that 85% of study participants who performed their own fueling described hydrogen fueling to be "somewhat" or "very" simple. Of the participants, 62% percent had to forgo at least one trip due to lack of hydrogen fuel, although vehicle range was rated by 75% of participants as entirely or mostly adequate. If fueling infrastructure availability was not an issue, and fuel cost per-mile was at parity with gasoline, 75% of participants would be willing to pay $40,000 or less for an FCV.



## Introduction

Motor vehicles using cleaner fuels and drivetrain technologies are being commercialized around the world, based on a variety of hybrid electric, plug-in electric, biofuel, and other types. Hydrogen fuel cell electric vehicles (FCVs) are an emerging option to complement plug-in electric vehicles and other advanced technology vehicles to help reduce petroleum usage and air emissions from vehicle fuel cycles. FCVs produce no noxious tailpipe emissions (water vapor only) confining emissions to the fuel production part of the fuel cycle. Typical hydrogen production based on steam reforming of natural gas is now being complemented by production from biogas and electrolysis from renewable electricity sources, showing the potential for a future low carbon fuel cycle.

Hydrogen fuel cell vehicles have been under development since the unveiling of the General Motors "Electrovan" in 1966

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and in a more serious way starting with the Daimler-Benz "NECAR" series of vehicles starting in the mid-1990s. After about 20 years of prototype vehicle design and development, commercial light-duty FCVs have become available only since 2016 and in selected regions where refueling infrastructure is available. However, this is now expanding to additional regions and with more vehicle models expected in the near term. The latest FCVs can refuel in 4–5 min and have driving ranges of around 450–580 kilometers (km), closely matching previous consumer expectations based on use of gasoline and diesel vehicles [1].

This original study examines vehicle acceptance and performance of a group of FCV test drivers in the San Francisco Bay Area. For this study, 54 drivers completed a month-long test drive including two online surveys ("before" and "after" the test drives). The study was completed from early 2014 through the end of 2015 using a group of six prototype 2010/2011 Toyota Highlander "FCHV-adv" vehicles (Fig. 1) that have a driving range of approximately 275 miles. Toyota produced a limited number of these vehicles based of the 2007 model year Highlander sport-utility vehicle to help further the development of their hydrogen fuel cell vehicle powertrain and to gain experience with hydrogen storage/fueling systems operating at pressure levels of 700 bar (10,000 pounds per square inch). Based on steady progress with FCV and hydrogen storage and dispensing system technology, Toyota has released the next generation "Mirai" vehicle in Japan and the United States, also shown in Fig. 1

## Study background

A few previous fuel cell vehicle acceptance studies have been conducted and these are discussed below. Few studies have been conducted of drivers of light-duty FCVs due to the small number of these vehicles that have been historically produced (and only as prototypes prior to 2015) and placed into research settings. Fuel cell buses have been in commercial production since about 2000, and a few more studies have been conducted on the passenger and driver response to those vehicles. These fuel cell car and bus studies are briefly reviewed below.

UC Berkeley has conducted FCV operation studies starting in late 2005 when early generation FCV prototypes were studied and tested first with Daimler-Benz and then with Toyota and Hyundai. These vehicles featured hydrogen stored at 350-bar (5000 psi) and had driving ranges of 100–160 miles (160–255 km). The following figure shows the progression of FCVs tested by UC Berkeley, with a key feature being the extended driving range (now 400–500 km) offered with the introduction of hydrogen fuel storage at 700-bar. Research on this latest generation of FCVs, capable of driving 250–300 miles (400–480 km) on a tank, has continued in the latest phase of the program. Research studies at UC Berkeley are also conducted on plug-in electric vehicles, and including comparisons between them, conventional hybrid vehicles, and FCVs [2] (see Fig. 2).

In one previous study, Martin et al. [3] report on the outcomes of a brief exposure "ride and drive" study of FCVs in Northern California using a prototype Mercedes-Benz A-Class "F-cell" FCV. The study consisted of 182 drivers conducting a test drive along with before and after surveys. The study found that over 80% of participants had a generally favorable opinion of the vehicle and refueling, the majority would be willing to travel 5–10 min to a hydrogen station, and more than 90% of respondents said that an FCV driving range of 300 miles (480 km) would be acceptable. This compared to the approximate 100-mile (160 km) range of the A-Class F-Cell vehicle at the time, based on older 350-bar (5000 psi) hydrogen storage pressures.

Also, in a similar study but with a newer class of FCV, Hardman et al. [4] had 81 participants who drove a Hyundai Tucson FCV in the United Kingdom of which 30 of them consented to participate in the study. The study found that participants generally described the FCVs to be similar to combustion engine vehicles, and particularly liked the "quiet drivetrain," "new technology," and "low environmental impacts" of the FCV. Key hurdles to their potential adoption of the vehicles were identified as lack of hydrogen fueling infrastructure and relatively high purchase prices of the vehicles.

A more general and recent study examined the current barriers present to the adoption of FCVs. The study considered the attitudes of high-level professionals (company executives, university professors, doctors) who already owned high-end battery electric vehicles (EVs). The study participants expressed as many as twelve perceived barriers to FCV adoption with "lack of refueling infrastructure" and the "source of hydrogen" being predominantly form fossil fuels, as the two largest perceived barriers. The other three dominant barriers were inability for FCVs to be charged at home, the cost of the vehicles, and perceptions about safety [5].

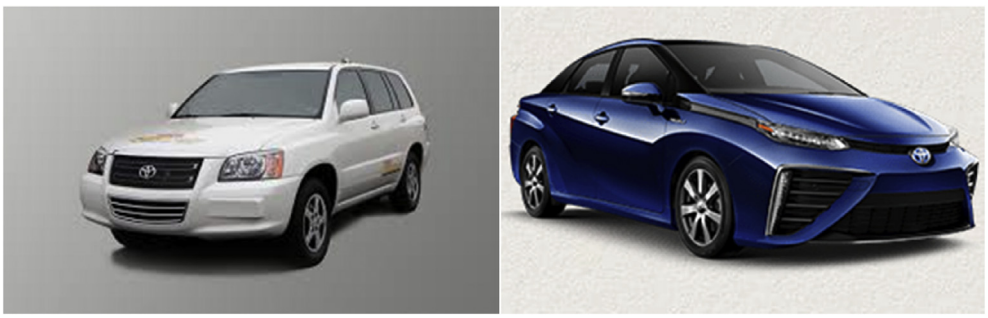

**Fig. 1 – Toyota Highlander FCHV-adv (MY 2011) study vehicle and Toyota Mirai (MY 2016) (source: motortrend.com).**

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