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**DYNAMICS IN BEHAVIORAL RESPONSE TO A FUEL CELL VEHICLE FLEET
AND HYDROGEN FUELING INFRASTRUCTURE:
AN EXPLORATORY STUDY**

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DYNAMICS IN BEHAVIORAL RESPONSE TO A FUEL CELL VEHICLE FLEET AND HYDROGEN FUELING INFRASTRUCTURE: AN EXPLORATORY STUDY

ABSTRACT

Transportation is a major contributor of carbon dioxide (CO₂) and other greenhouse gas emissions from human activity. It accounts for approximately 14% of total anthropogenic emissions globally and about 27% in the United States. Growing concern regarding the impacts of climate change and greenhouse gas emissions has led to innovations in automotive and fuel technology. However, behavioral response to the newest transportation technologies, such as hydrogen fuel cell vehicles (FCVs) and fueling infrastructure, is not well understood. This paper examines the results of an exploratory F-Cell hydrogen fuel vehicle fleet study, which focused upon fleet drivers' attitudes and perceptions over a seven-month period in 2006. The study employed a longitudinal survey design, with three phases and one focus group.

There are limitations to the exploratory dataset generated from this study (e.g., small sample size, self-selection bias, and generalizability). However, the results of this study provide insights into participants' response to the FCV and hydrogen infrastructure over time and can help to inform further inquiry. Higher levels of hydrogen exposure are correlated with increased comfort with hydrogen, especially among those who were less experienced. Early adopters generally felt safer driving the F-Cell than later adopters. Respondents mostly felt safe refueling the F-Cell. As experience with the F-Cell increased, participants felt increasingly safe with the F-Cell. Driving range was considered a limitation. Furthermore, over the course of the study, participant perception of vehicle range increased due to learning.

Key Words: Hydrogen, fuel cell, infrastructure, behavioral response

INTRODUCTION

Hydrogen fuel cell vehicles (FCVs) experienced a major research and development effort in the 1990s, primarily motivated by air quality concerns in urban areas of the United States, Europe, and Japan. They have been a continued focus of attention in recent years for a combination of reasons. Hydrogen powered vehicles are among the only currently known vehicle alternatives that can simultaneously address air pollution, petroleum dependence, and rising levels of carbon dioxide (CO₂) and other greenhouse gases (GHG) in the atmosphere.

The primary motivation for alternative fuel vehicles, such as FCVs, today is arguably climate change and recognition is growing across the globe. Approximately 14% of GHG emissions come from the transportation sector worldwide (1). GHG emissions from transportation are expected to increase rapidly over the next few decades. Between 2000 and 2030, the International Energy Agency (IEA) projects that energy use and CO₂ emissions will increase by approximately 50% in developed countries (2). Transportation supply and demand management strategies are being explored to reduce GHG emissions, particularly with innovative engine and vehicle technologies. However, user response to the latest of these approaches is not well understood given limited vehicle production and availability. To further behavioral

understanding of hydrogen FCVs and infrastructure, University of California, (UC) Berkeley researchers partnered with DaimlerChrysler to conduct an exploratory driver study of 24 DaimlerChrysler “F-Cell” vehicles deployed in fleet settings in 2006.

The DaimlerChrysler F-Cell vehicle is a hybrid fuel cell electric vehicle with a hybridized fuel cell/battery power system that is linked to an electronic motor/power controller propulsion system. This differs from gasoline-electric hybrids where the propulsion system is hybridized. The F-Cell employs a 72-kilowatt (97 horsepower) proton-exchange membrane fuel cell system, a 1.4-kilowatt hour and 15-kilowatt (20 horsepower) nickel-metal hydride battery, an electric motor with torque rated at 210 Newton-meters (156 foot-pounds), and approximately two kilograms of gaseous hydrogen stored at 5,000 pounds of pressure per square inch (psi). The vehicle has a rated 160-kilometer range and a top speed of approximately 137 kilometers per hour.

DaimlerChrysler has deployed approximately 100 FCVs worldwide. About 25 F-Cell vehicles were placed in California with participating for-profit companies, non-profits, governmental agencies, and universities, including one that was delivered to UC Berkeley. The demonstration of the vehicles is supported in part by a five-year U.S. Department of Energy program titled: “Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project.”

This paper presents the results of a longitudinal survey of the attitudes and perceptions towards hydrogen and alternative fuel vehicles of F-Cell fleet drivers. The study included three survey phases to examine potential trends in F-Cell driver perceptions over a seven-month period. The participant sample was drawn from for-profit companies, governmental agencies, non-profits, and universities in California and Michigan where the vehicles were placed for study.

Researchers examined safety perceptions, limited range, and vehicle performance. The study also investigated two hypotheses related to hydrogen acceptance: 1) higher levels of hydrogen exposure are correlated with higher levels of hydrogen acceptance, and 2) positive attitudes toward the environment are correlated with greater F-Cell acceptance. The paper is organized into six sections: an overview of behavioral research on alternative fuels, a brief discussion of the methodology and study limitations, demographics of the study population, an analysis of alternative fuel experience and technology adoption behavior, vehicle and hydrogen acceptance findings, and study conclusions.

BACKGROUND

As hydrogen passenger vehicles have only recently been introduced to the public to drive and refuel, there is a relatively short research history focused on the observed consumer response to hydrogen as a transportation fuel. Few studies to date have explored the direct interaction of consumers with a fleet of hydrogen personal vehicles over an extended time period.

One of the earliest hydrogen acceptance studies occurred nearly a decade ago in Germany (3). This study evaluated the perception of hydrogen by bus passengers, as well as the general response of students to the idea of using hydrogen for transportation (3). It assessed Likert-scale responses of secondary school students to eight statements gauging their acceptance of hydrogen use in transportation. It then evaluated the sentiments of adults and students traveling on the first hydrogen bus to be deployed worldwide in Munich. Overall, the study did not find significant barriers to hydrogen acceptance. Researchers found that positive assessments were higher among

respondents on the bus, who had direct contact with the technology. Negative events in hydrogen history, such as the H-bomb or the Hindenburg, were not a factor. Interestingly, researchers also noted that a high personal priority on environmental issues or an elevated general knowledge of hydrogen did not have a clear influence on overall acceptance. This does not correspond with findings from the exploratory F-Cell study described in this paper.

However, in a similar more recent study conducted on hydrogen bus passengers, O'Garra found that direct contact with the technology did not have a significant impact on acceptance or willingness-to-pay for the technology (4). The definition of acceptance in this study was "unconditional support for large-scale introduction of hydrogen buses in each city," which was found to have increased in all cities receiving a bus during the trial period. In this context, the study determined that simply riding in a hydrogen bus did not result in acceptance (4).

Another study led by O'Garra explored determinants of awareness and acceptability of hydrogen vehicles through a 400 person socio-economic survey in London. This study found that awareness was a function of gender, age, and environmental knowledge, while acceptability was primarily determined by previous knowledge of hydrogen technologies (5).

Through focus groups and a survey, a study of London taxi driver sentiments discerned that willingness-to-pay for FCVs was influenced by level of air pollution concern, education, and knowledge of hydrogen. In addition, taxi drivers stated that they did not have safety concerns about driving hydrogen powered cars (6).

Schulte *et al.* provide a good review of acceptance literature with an emphasis on hydrogen, as well as a conceptual framework for acceptance studies (7). This work also interpreted the results of an earlier German study that evaluated the sentiments of BMW employees in which roughly 600 respondents provided feedback on their opinions of hydrogen technology (8). Researchers in this study found that high technical knowledge corresponded with more positive opinions of the technology, whereas those less knowledgeable perceived risks to be higher. In addition, participants who considered vehicles to be "all-round cars" were more likely to buy a hydrogen vehicle, whereas those who considered the cars to be "city cars" were less enthusiastic of hydrogen.

Research examining electric vehicle (EV) acceptance has been more extensive. Gould and Golub provide a concise review of many of the most important econometric and behavioral studies of EVs during the 1990s (9). During this period, techniques evaluating behavioral response to electric vehicles (EVs) were explored, especially in the California market (9, 10, 11, 12, 13, 14). One thrust of behavioral research sought to understand the dynamics of the "hybrid household," defined as a household that uses both electric and gasoline vehicles in a complementary fashion (12). Through a four-stage household survey, Kurani *et al.* conclude that households would choose EVs to obtain the benefits of home recharging and zero emissions, but that environmental concern alone does not translate into the adoption of an EV (12). EVs were also placed in two-week household trials in California, where it was found that the households could conduct the majority of their travel using range-constrained vehicles (13). While travel diaries employed in this study suggested that daily tripmaking rarely exceeded about 80 kilometers a day, exposure to the EV did not change participant expectation that the vehicle should have a range of 160 kilometers or more (13). Another study by the same authors found that exposure to EVs raised opinions of their environmental benefits during a period in which public opinions were declining (9).

More recent research has focused on hybrid electric vehicle (HEV) adoption. A 2007 survey of HEV buyers in Switzerland concluded that purchasers still comprise an early adopter

market segment that rated fuel consumption as a more important vehicle purchase criteria than the control group. It also found that HEV buyers had higher levels of education and income but were buying vehicles that were smaller than the average market and control group (15).

Behavioral research on electric-drive technology acceptance has taken a variety of approaches assessing market response to vehicles, such as household interviews, surveys, focus groups, and vehicle trials. Many, but not all, behavioral studies find that exposure to EV and hydrogen technology does increase awareness and acceptance. Environmental awareness seems to be an important criterion that dictates acceptance, but it is not sufficient alone. Consumers do require some other personal benefit to be serious candidates for adoption, and range constraints are a considerable limitation. Finally, increased knowledge of the technology as obtained through education or direct experience has been connected to greater acceptance. This study builds on much of this work, supporting some of these conclusions as well as offering some novel insights into the interaction with hydrogen vehicles and fueling, namely safety.

METHODOLOGY

The longitudinal survey population for the 24 F-Cell vehicle study deployed in California and Michigan in 2006 included an initial sample pool of approximately 143 participants. The subjects were drawn from for-profit companies in California and Michigan, where 10 vehicles were placed (one of the 10 vehicles was deployed in Michigan), and at governmental agencies, non-profits, and universities in California and Michigan, where another 14 vehicles were deployed (one of the 14 vehicles was located in Michigan). Participant criteria for the F-Cell driver fleet study were established to ensure that drivers had driven the vehicles enough during the course of the study to form an opinion about the F-Cell and hydrogen fueling (note that not all participants fueled the vehicles). Study criteria required that qualifying participants: 1) drive the F-Cell once or more a month, 2) drive at least 65 kilometers per month, and 3) be willing to complete the three survey phases.

Many of the initial sample pool (143 individuals) did not meet the study criteria. During the first survey phase, a total of 65 drivers from 15 public and private sector organizations were recruited on a voluntary basis (13 of the participant organizations were located in California and two in Michigan). Not surprisingly, there was some attrition over the seven-month study. Fifty-four participants completed two of the three survey phases, and 49 completed all three phases. An initial and final response rate of 45.5% and 34.3%, respectively, was tabulated, based on the total participant pool.

Subjects were recruited with an email solicitation to participate in the study. Volunteer participants were asked to complete and return a study consent form and then were issued a participant identification number that allowed them to complete the first questionnaire. Respondents received a small incentive (e.g., F-Cell coffee mug) after completing each study questionnaire.

Longitudinal Survey Design

The longitudinal survey was designed to assess general demographic characteristics of the F-Cell drivers, psychographic characteristics such as their stated level of environmental concern and willingness to experiment with new technologies, as well as their specific response to various F-Cell aspects (e.g., vehicle performance).

The first survey phase consisted of four main categories of questions: 1) function of driver in company (e.g., management, staff, administrative, etc.); 2) experience with alternative fuel vehicles; 3) psychographics (environmental perception and technology adoption among participants); and 4) acceptance of the F-Cell and hydrogen fueling. Psychographic and F-Cell/hydrogen acceptance questions were asked on a five-point “Likert” scale. Researchers administered the initial survey in May 2006. The second and third survey phases were shorter and only addressed the response to the F-Cell vehicle and fueling; they were completed in September and November 2006, respectively. The purpose of the second and third phase surveys was to determine to what extent drivers’ views of the FCV and fueling changed over time as they gained more experience.

All study participants completed the questionnaires online (an Internet-based survey). A licensed version of the Nsurvey® software package was used to publish the survey online at www.innovativemobility.org. Data were securely stored on a structured query language (SQL) server associated with the website. Prior to implementation, researchers pre-tested the questionnaires to make sure that they were clear and easy to understand.

Focus Group

The F-Cell focus group with UC Berkeley drivers was convened on May 17, 2007, with four men and two women (the total fleet driver population in the F-Cell longitudinal study at UC Berkeley). The sample was of diverse ages, and with four of the six participants holding a bachelor’s degree or higher. The group provided a social setting in which individuals who had driven and refueled the F-Cell came together to explore their perceptions toward the vehicle and fueling (four of the six participants refueled the F-Cell) over time. Participants discussed experiences with the F-Cell, what they liked most and least about the vehicle, potential vehicle features, limited vehicle range and impacts on travel behavior, safety perceptions, potential effects of the F-Cell experience on future alternative fuel vehicle ownership/use decisions, and potential negative and positive impacts of hydrogen. Through the two-hour discussion, participants revealed how they valued the FCV and hydrogen infrastructure (including range, safety considerations, and environmental impacts) and how that value was constructed from their experiences driving the vehicle.

Study Limitations

The dataset generated for this study reflects an exploratory analysis. There are several inherent limitations to the dataset due to the data collection process that were beyond the control of the research team at UC Berkeley and DaimlerChrysler. These limitations do not prevent the use of the dataset to obtain insights into the drivers’ response to the vehicle, which can lead to the generation of important research questions. However, the limitations do suggest caution regarding generalization to a larger population.

The relatively small number of respondents is a major reason why several of the insights yielded from the analysis of subgroups and trends were not statistically significant. Although the insights presented below are consistent across survey phases, the magnitude of differences was often found to not be statistically significant. A small sample size often requires any uncovered distinctions between subgroups or across survey phases to be dramatic for statistical significance.

Another limitation of the study was that the population was ultimately self-selected. As an indication of self-selection, the participants were overwhelmingly male, constituting 39 of the 49 final respondents. Participants were volunteers, and researchers were unable to discern why some participated and others did not. Researchers were able to evaluate the partial responses of those who dropped out midway through the study and determined that hydrogen safety concerns were not a consideration in their departure. Nevertheless, the sample represented in these results is not random, and thus should be used more as a guide into further inquiry than as a basis for broad conclusions.

DEMOGRAPHICS OF STUDY PARTICIPANTS

In this section, the authors review key demographic variables from the survey. The majority of the initial survey subjects were male (52 participants), with 12 females and one individual that declined to state gender. The average age of all respondents was about 44. Approximately half of the respondents who completed the survey reached the bachelor's degree level of education. Eleven of the survey respondents had higher degrees (master's or doctoral). In total, nearly 73% held a bachelor's degree or higher. In comparison to California averages, respondents were generally more educated. According to the 2005 American Community Survey (16), only 30% of all Californians held a bachelor's degree or higher.

Across the final survey population (n=49), 19 respondents reported household income levels of \$100,000 per year or more, while nine had incomes of \$75,000 to \$100,000 per year, and 13 reported household incomes of less than \$75,000 per year. Eight declined to respond. Those who responded to the income question exhibited a distribution that is skewed above the median household income for California, which was about \$54,000 US in 2005.

ALTERNATIVE FUEL EXPERIENCE AND TECHNOLOGY ADOPTION BEHAVIOR

Researchers partitioned participants into mutually exclusive groups according to two areas: experience with alternative fuels and technology adoption behavior. This was conducted based on their response to several questions, which helped researchers in distinguishing attitudes on particular issues. Respondents were divided into two groups for each category and responses to F-Cell and hydrogen questions between the two groups were compared.

Experience With Alternative Fuels

The following analysis presents differences in average response to FCV and hydrogen infrastructure questions among those experienced and inexperienced with alternative fuels. Those who answered "Agree" or "Strongly Agree" to: "I have scientific training in alternative fuel vehicles (e.g., coursework, on-the-job training)" were considered experienced with alternative fuels, whereas those who did not provide these responses were classified as inexperienced.

During the initial survey, experienced respondents had a slightly lower impression of the F-Cell but felt safer around it. They also exhibited less concern regarding the limited availability of fueling infrastructure in driving the F-Cell. Perceptions changed between the two groups among two questions throughout the survey: 1) "What is your overall impression of the F-Cell," and 2) "Limited hydrogen refueling infrastructure is a concern in my decision to drive the F-

Cell.” See Figure 1 below, which shows the changes from the responses of the two groups to the first and third phases.

FIGURE 1 Experienced/inexperienced with alternative fuels respondents’ perceptions of F-Cell vehicle/hydrogen (Phase 3).

Overall F-Cell perception diverged by 0.16 points (between the initial and final phases), with experienced respondents having a less positive perception over time. Interestingly, no major change in opinion was reflected among inexperienced respondents to this question. Another key finding is that the opinion of experienced and inexperienced respondents converged during the final phase on the issue of limited infrastructure concerns. Those with scientific training considered limited infrastructure to be a greater concern (perhaps as the novelty effect wore off), and those with less scientific training learned to better handle the limited fueling infrastructure.

Early Adopters of New Technology

Early adopters of new technology are often considered an important market segment since they are most likely to be the first consumers of new products. Researchers identified early adopters with the following questions: “When a new technology that I am interested in becomes available for purchase... 1) I am among the first people to purchase it, and 2) I wait to read a review of it, and then buy it if the review is favorable.”

Distinctions were found for the early adopter partition in a few areas: 1) esthetics of the F-Cell exterior and 2) F-Cell safety driving perception. Early adopters were more inclined to find

the exterior of the F-Cell more esthetically appealing. Additionally, early adopters felt safer driving the F-Cell than later adopters in both the first and final study phases. In the final phase, the Likert-scale response of early adopters was an average of 4.25, whereas for those considered later adopters the average was 3.81. Overall, the average was 4.06, indicating that in general, the respondents felt safe with the F-Cell. But the degree to which the early adopters felt safer than later adopters was statistically significant at the 10% level in the first phase with a score 0.012 and just above 20% in the third phase with a score 0.105.

VEHICLE AND HYDROGEN ACCEPTANCE FINDINGS

Researchers also explored safety perceptions, range, vehicle performance, and hydrogen and F-Cell acceptance in the longitudinal survey. Key findings are described in the following sections: 1) F-Cell impressions, 2) safety impressions, 3) limited range, and 4) vehicle performance.

F-Cell Impressions

Respondents were asked to give their general impression of the F-Cell, with possible answers of “Not Adequate,” “Adequate,” “Good,” “Very Good,” and “Excellent.” Considering the 49 respondents who completed all three questionnaires, the 31 participants who answered “Very Good” or “Excellent” were distinguished from the 18 remaining respondents. The average responses of this subgroup to vehicle attributes were consistently higher than those who answered “Good” or worse.

Another interesting characteristic of this partition was that those having initially more favorable impressions of the vehicle indicated stronger sentiments towards the environment across all attitudinal questions. However, none of the differences were statistically significant at the 10% level using the Mann-Whitney test. Demographically, the groups were similar. This result indicates that favorable environmental sentiments were correlated with an initial positive reception to the technology.

In the final phase, the distribution of responses to vehicle impression were the same, with 31 respondents viewing the F-Cell very favorably and 18 viewing the F-Cell less favorably as defined above. However, the groups are not comprised of the same people, as seven respondents in each group changed their answers and swapped places. The two groups remained demographically balanced, but the gap of positive environmental response between the two groups narrowed significantly. This indicates that environmental sentiments impacted participants’ initial vehicle impression. As the novelty effect of the vehicle wore off, positive environmental views were less a factor in determining a high overall impression of the F-Cell.

This change occurred because seven respondents, who viewed the car less favorably at the end of the study, were individuals with strong environmental attitudes and a high self-assessed experience with alternative fuels. The second group, who grew to appreciate the car more over time, was not as experienced with alternative fuels and did not express as strong positive views toward the environment.

Safety Perceptions

Researchers hypothesized that safety perceptions regarding fueling might negatively influence individuals' perception of the F-Cell. However, respondents generally felt safe when refueling the F-Cell, as shown in Figure 2 below. Perceptions of refueling safety were relatively stable and benign over time. The average responses to two questions are plotted below. The top line illustrates the stable trend of feeling safe while refueling, whereas the bottom line illustrates that there is a general disagreement with the statement "Refueling the F-Cell is difficult," and that this sentiment is stable over the course of the study.

However, caution should be exercised when interpreting these results. Not all respondents fueled the vehicles, and some relied upon others within their institution to ensure that the vehicle had fuel for their use. The results below reflect a growing population, as individuals received training throughout the study. Motivations for not participating in refueling are broad and could include safety concerns. Furthermore, fuel providers required training for fueling, and only a limited number of training sessions were provided.

FIGURE 2 Trend in response with regard to refueling safety.

As experience with the F-Cell increased, respondents felt increasingly safe with the F-Cell. As shown in Figure 3, drivers' feeling of safety with the F-Cell in comparison to gasoline vehicles increased with exposure to the vehicle. At the end of the study, the average response was just over 4.0, meaning that respondents on balance had come to agree with the statement that they felt equally safe in the hydrogen vehicle compared with a gasoline vehicle.

During the May 2007 focus group with F-Cell drivers at UC Berkeley all four refueling participants stated that they felt safe fueling the F-Cell. When the group was asked about whether they felt as safe in the F-Cell as with a gasoline vehicle, participants indicated that there was a danger of getting stranded from running out of fuel with the sparse available fueling network. Additional concerns were expressed for increased collision danger due to the hydrogen tanks on board. One participant felt safer as hydrogen gas was believed to disperse more quickly than gasoline in a crash.

FIGURE 3 Trend in response to “I feel equally safe in a hydrogen vehicle compared to a gasoline vehicle.”

Limited Range

Driving range was almost universally a concern with the F-Cell. But over the course of the study, participants’ perception of vehicle range did increase. Of course, the range of the F-Cell did not change throughout the study, remaining at approximately 160 kilometers for a full tank of hydrogen. The perception of increased range is perhaps an illustration of the respondents learning how far the vehicle can be driven before needing to refuel.

The consistent separation of perceived and actual range by participants throughout the study of approximately 32 kilometers suggests that although the vehicle has an actual range of 160 kilometers, in reality it has a lower “effective range” (i.e., the distance the travelers believe they can drive without being stranded). This discrepancy could also be related to the level of

hydrogen fill that drivers were able to obtain, with some stations typically providing less than a 100% fill.

The average desired range remained close to 322 kilometers throughout the study. During the final phase, the minimum desired range was the actual range of 160 kilometers; the maximum desired range was stated as 644 kilometers. The majority stated a desired range between 200 and 400 kilometers.

During the UC Berkeley focus group, participants thought the actual range of the F-Cell was between 130 and 150 kilometers. The lower end of the range (130 km) is consistent with the survey results. In addition, focus group subjects thought that a future F-Cell driving range of 400 kilometers was generally acceptable; this corresponds to the higher end of the range stated by survey respondents.

Vehicle Performance

Participants were asked to rate their approval of several key performance characteristics of the vehicle including: acceleration, handling, and braking. Respondents generally appreciated the performance capabilities of the F-Cell. Figure 4 below illustrates how the average responses to the performance features of braking, handling, and acceleration, compared with each other over time. The regenerative braking system employed by the F-Cell was well received by respondents. The vehicle braking performance was rated highest overall among the F-Cell performance features, followed by handling and then acceleration. With the exception of handling, the average assessment of the performance features generally improved over time.

FIGURE 4 Trend in response with regard to vehicle performance metrics.

Focus group participants provided a great deal of feedback on F-Cell vehicle performance. Features that they liked the most included: 1) suspension and braking; 2) zero tailpipe emissions; 3) the vehicle handled well in the wind; 4) the fuel gauge provided a percentage number on remaining fuel, which was considered more useful than a dial display; 5) the style; 4) roomy interior; 5) size; and 6) navigation system. The top three features were zero tailpipe emissions, size, and roomy interior. They disliked several performance features: 1) the 10 to 15 second wait time before turning off the vehicle; 2) short range; 3) the short range of the keyless remote; 4) the fuel cover was difficult to open; 5) lag in start-up time of the vehicle; 6) the constant hum of the vehicle due to the electric motor; 7) some driving controls were difficult to operate (e.g., window and door controls in odd locations); and 8) vehicle style. The top three disliked features were: 1) limited range, 2) weak start-up acceleration, and 3) long start-up ignition time.

Hydrogen And F-Cell Vehicle Acceptance

In this study, there were two key hypotheses related to hydrogen and F-Cell acceptance. The first was: higher levels of exposure to hydrogen are correlated with greater hydrogen acceptance. And, the second was: positive attitudes toward the environment are correlated with greater F-Cell acceptance.

Higher Levels of Exposure to Hydrogen Are Correlated With Greater Hydrogen Acceptance

The degree to which respondents were exposed to hydrogen was measured as a function of time coinciding with the longitudinal survey. The test of this hypothesis sought to ascertain whether all the respondents as a group moved towards accepting the F-Cell to a greater degree by the final phase. Acceptance was defined as feeling as safe with a hydrogen vehicle as a gasoline vehicle. As presented in the longitudinal analysis, the trend of average responses to the question “I feel equally safe in a hydrogen vehicle compared with gasoline vehicles” was positive. The test applied to this hypothesis is the non-parametric Sign test because ordinal observations are paired with the same respondent answering the same question at two different times. The test observed the change in distribution among responses across the study phases to illustrate when major changes in sentiment occurred.

The null hypothesis is that the distribution of responses is the same from one phase to the other. A 10% significance level was used. Since the test is two tailed, the 10% rejection region is divided in half, and thus, test statistics below 0.05 are statistically significant. The difference between phase one and two (0.332) did not meet the 0.05 statistical significance test. Neither did the transition from phase two to three (0.093), although close. However, the distribution of responses between phase one and three (0.011) were different to a degree that was statistically significant. Thus, researchers rejected the null hypothesis and can say that the distribution changed to be skewed more towards agreement with the statement “I feel equally safe in a hydrogen vehicle compared with gasoline vehicles” during the study.

Positive Attitudes Toward the Environment Are Correlated With Greater F-Cell Acceptance

Researchers also sought to understand whether or not respondents who expressed strong environmental views and a willingness to reduce their own consumption for environmental reasons would react to the F-Cell in a manner that was different from others. Several questions within the initial questionnaire probed participants' environmental sentiments. The question that elicited the greatest diversity in response and distinguished those who stated a willingness to change personal behavior for environmental reasons was: "I am willing to reduce my personal auto use to improve transportation and air quality."

Those who projected a greater willingness to reduce personal consumption did not differ statistically in their overall impression of the F-Cell. Researchers used the Mann-Whitney test to determine statistical significance at 0.05 (two-tailed test) across the study phases on F-Cell acceptance and environmental consciousness. However, statistical significance was not demonstrated: phase one (0.241), phase two (0.931), and phase three (0.565). This, however, does not imply that the environmentally conscious respondents received the F-Cell poorly, as the vehicle was well received overall (between "Good" and "Very Good"), but the distinction between these groups was not different enough that it was statistically significant within the dataset.

CONCLUSION

This paper presents the results of an exploratory study of a prototype FCV fleet and its supporting hydrogen infrastructure. In 2006, UC Berkeley researchers, in partnership with DaimlerChrysler, examined the behavioral response of 65 participants to the F-Cell vehicle and hydrogen fueling over a seven-month period. While there are several limitations to the study (sample size, self-selection, and generalizability), this does not prevent the use of the dataset to obtain insights into the drivers' response to the vehicle and fueling. While researchers have focused on key findings, there were a couple of variables that did not demonstrate notable relationships as expected. Specifically, environmental consciousness and a tendency toward experimentation among the participants did not appear to be strong explanatory indicators. However, this is likely due to the self-selection bias and small sample size. It is recommended that these variables be considered in future study.

Overall, the F-Cell was well received by study participants. Key findings include that individuals experienced with alternative fuels express a greater concern for the environment, have higher education levels, and higher incomes. In addition, higher levels of hydrogen exposure are correlated with greater hydrogen acceptance in terms of safety. Environmental consciousness was found to have a positive impact on the impression of respondents initially, but by the end of the study, those with the most favorable impression of the vehicle did not show distinctions in environmental attitude.

Not surprisingly, the limited range and fueling infrastructure posed restrictions on participant behavior. Driving range was considered a limitation. Over the course of the study, respondents' perception of vehicle range increased due to learning. The sparse network of hydrogen fuel that existed during the study placed constraints on participants and required significant trip planning. The range limitation lowered the utility of the car for practical purposes. The average desired range was 322 kilometers throughout the study. Alternative

designs that improve the range by even 50% could help to bring the F-Cell within reach of the mean desired range indicated by survey respondents. Another important insight of the study centers on refueling. While fueling infrastructure remains a challenge, the refueling process was not challenging to those who tried it. Among the participants who actually experienced fueling, an ability to adapt to a new fuel and infrastructure was demonstrated. However, this could reflect some self-selection bias, and it is possible that non-participants of fueling included those who were fearful of this process.

Participants felt safer with the vehicle throughout the study. Early adopters were found to feel safer driving the F-Cell than later adopters. Respondents generally felt safe refueling the F-Cell. Furthermore, as experience with the F-Cell increased, participants felt increasingly safer with the F-Cell.

The F-Cell was considered easy to operate. Vehicle braking was rated highest overall among the F-Cell performance features, followed by handling and then acceleration. Lower vehicle acceleration, however, was a safety concern in a few situations. With the exception of handling, the average assessment of vehicle performance features improved over time. Starting and stopping the F-Cell was not problematic.

In the future, some targeted improvements towards the practical utility of the vehicle are needed before market viability is possible, particularly with regards to infrastructure and driving range. In addition, a significant reduction in the cost of the fuel cell technology must occur for the next generation of vehicles to be affordable. These challenges are notable; however, much progress has been made in recent years, as demonstrated by this limited study. Overcoming the challenges to FCV commercialization will not be easy, but the introduction and testing of the F-Cell prototype represents a notable milestone along this journey. Not surprisingly, further study with the general public and a larger sample population is recommended to continue to inform our understanding.

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