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Dynamics in Behavioral Response to Fuel-Cell Vehicle Fleet and Hydrogen Fueling Infrastructure

An Exploratory Study

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Transportation is a major contributor of carbon dioxide 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, along with petroleum dependence and energy security, has led to innovations in automotive and fuel technology. However, the behavioral response to the newest transportation technologies, such as hydrogen fuel-cell vehicles (FCVs) and fueling infrastructure, is not well understood. The results of an exploratory hydrogen FCV fleet study, which focused on fleet drivers' attitudes and perceptions over a 7-month period in 2006, are examined. The study employed a longitudinal survey design, with three phases and one focus group. There were limitations to the exploratory data set generated from this study (e.g., small sample size, self-selection bias, and generalizability). However, the results provided insights into participants' responses to the FCV and hydrogen fueling infrastructure over time and could help to inform further inquiry. Higher levels of hydrogen exposure were correlated with increased comfort with hydrogen, especially among those who were less experienced. Early adopters of the technology generally felt safer driving the FCV than later adopters. Respondents mostly felt safe refueling the FCV. As experience with the FCV increased, participants felt increasingly safe with the vehicles. The driving range was considered a limitation. Furthermore, over the course of the study, participant perception of vehicle range increased because of learning.

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 few currently known vehicle alternatives that can simultaneously address air pollution, petroleum dependence, and rising levels of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere.

A key motivation for alternative-fuel vehicles, such as FCVs, is 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 CO_2 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, researchers at the University of California (UC), Berkeley, partnered with Mercedes-Benz to conduct an exploratory driver study of 24 Mercedes-Benz FCVs deployed in fleet settings in 2006.

The Mercedes-Benz FCV 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 hybrid differs from gasoline–electric hybrids, in which the propulsion system is hybridized. The FCV employs a 72-kW (97 hp) proton-exchange membrane fuel-cell system, a 1.4-kW-h and 15-kW (20-hp) nickel–metal hydride battery, an electric motor with torque rated at 210 N-m (156 ft-lb), and approximately 2 kg of gaseous hydrogen stored at 5,000 psi. The vehicle has a rated 160-km range and a top speed of approximately 137 km/h.

Mercedes-Benz has deployed approximately 100 FCVs worldwide. About 25 FCVs were placed in California with participating for-profit companies, nonprofits, governmental agencies, and universities, including one that was delivered to UC Berkeley. The demonstration of the vehicles is supported in part by a 5-year U.S. Department of Energy program titled Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project.

Presented here are the results of a longitudinal survey of the attitudes and perceptions toward 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 7-month period. The participant sample was drawn from for-profit companies, governmental agencies, nonprofits, 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

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related to hydrogen acceptance: (*a*) higher levels of hydrogen exposure are correlated with higher levels of hydrogen acceptance, and (*b*) positive attitudes toward the environment are correlated with greater F-cell acceptance.

BACKGROUND

Since hydrogen passenger vehicles have only recently been introduced to the public to be driven and refueled, 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 destruction of the *Hindenburg* zeppelin, 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.

However, in a similar more recent study conducted with 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, by O'Garra et al., explored determinants of awareness and acceptability of hydrogen vehicles through a 400-person socioeconomic survey in London. This study found that awareness was a function of gender, age, and environmental knowledge, whereas acceptability was primarily determined by previous knowledge of hydrogen technologies (*5*).

Through focus groups and a survey, a study of London taxi drivers' sentiments discerned that willingness to pay for FCVs was influenced by level of air pollution concern, education, and knowledge about 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 the vehicles to be all-around cars were more likely to buy a hydrogen vehicle, whereas those who considered hydrogen vehicles to be city cars were less enthusiastic of hydrogen.

Research examining electric vehicle (EV) acceptance has been more extensive. Gould and Golob 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 EVs were explored, especially in the California market (*9–14*). 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 2-week household trials in California, where it was found that the households could conduct the majority of their travel by using range-constrained vehicles (*13*). Although travel diaries employed in this study suggested that daily trip making rarely exceeded about 80 km a day, exposure to the EV did not change participant expectation that the vehicle should have a range of 160 km 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 make up an early-adopter market segment that rated fuel consumption as a more important vehicle purchase criterion 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 those of the average market and control group (*15*).

Behavioral research on electric-drive technology acceptance has taken a variety approaches in 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 consideration, but it alone is not sufficient for acceptance. 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, with respect to safety.

METHODOLOGY

The longitudinal survey population for the 24-FCV 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, in which 10 vehicles were placed (one of the 10 vehicles was deployed in Michigan), and governmental agencies, nonprofits, and universities in California and Michigan, in which 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 (it should be noted that not all participants fueled the vehicles). Study criteria required that qualifying participants drive the F-cell once or more a month, drive it at least 65 km per month, and 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 2 in Michigan). Not surprisingly, there was some attrition over the 7-month study. Fifty-four participants completed two of the three survey phases, and 49 completed all three phases. Initial and final response rates of 45.5% and 34.3%, respectively, were tabulated, based on the total participant pool.

Subjects were recruited with an e-mail 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 the company (e.g., management, staff, administrative),
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 and 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 FCV and fueling; they were completed in September 2006 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 software package was used to publish the survey online at www.imr.berkeley.edu. Data were securely stored on a structured query language (SQL) server associated with the website. Before implementation, researchers pretested the questionnaires to make sure that they were clear and easy to understand.

Focus Group

The purpose of the focus group was to gain a richer insight into the underlying trends and impressions that emerged from the survey results. 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, 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, impacts on travel behavior, safety perceptions, potential effects of the F-cell experience on future alternative-fuel vehicle ownership and use decisions, and potential negative and positive impacts of hydrogen. Through the 2-h 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 in driving the vehicle.

Study Limitations

The data set generated for this study reflects an exploratory analysis. There are several inherent limitations to the data set due to the data collection process that were beyond the control of the research team at UC Berkeley and Mercedes-Benz. These limitations do not prevent the use of the data set to obtain insights into the drivers' responses 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 analysis that follows explores distinctions in response across subgroups within survey phases as well as longitudinal trends across the surveys. When appropriate, nonparametric tests were employed to assess the relative robustness of group distinctions and trends. The relatively small number of respondents limited the degree to which insights yielded from the analysis of subgroups and trends could be deemed statistically significant. Still, the authors believe that certain findings could help guide future inquiry by revealing dynamics that began to emerge within this exploratory study.

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 it should be used more as a guide to further inquiry than as a basis for broad conclusions.

DEMOGRAPHICS OF STUDY PARTICIPANTS

Key demographic variables from the survey are as follows. The majority of the initial survey subjects were men (52 participants), with 12 women and one individual who declined to state gender. The average age of all respondents was about 44. Approximately half of the respondents who completed the survey had 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 with 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, 9 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 U.S. 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 partition was conducted on the basis of 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., course work, 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, including the performance attributes of acceleration and handling, but they felt safer around it. They also exhibited less concern regarding the limited availability of fueling infrastructure in driving the F-cell. Between the first and final survey phases, certain perceptions changed between the two groups for two key questions: "What is your overall impression of the F-cell?" and "Limited hydrogen refueling infrastructure is a concern in my decision to drive the F-cell." Table 1 shows the changes in the responses of the two groups during the first and third phases.

Overall F-cell perception diverged in the final phase, with experienced respondents having a slightly less positive perception over time. Interestingly, no major change in opinion was reflected among inexperienced respondents to this question. Both experienced and inexperienced respondents felt safer in the F-cell over time. Another finding is that the opinions 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 question: "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: esthetics of the F-cell exterior and F-cell safety driving perception. Early adopters were more inclined to find the exterior of the F-cell more esthetically appealing. In addition, 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. In addition, the degree to which the early adopters felt safer than later adopters was statistically significant at the 10% level during the first phase. The gap in safety perception, although still present, closed over time, since the final survey did not find distinctions in safety perceptions to be statistically significant.

VEHICLE AND HYDROGEN ACCEPTANCE FINDINGS

Researchers also explored safety perceptions, range, vehicle performance, and hydrogen and F-cell acceptance in the longitudinal survey.

F-Cell Impressions

Initial F-cell impressions appeared to be influenced by participants with a greater sensitivity to the environment. However, the link between environmental sentiment and favorable impression of the F-cell dissipated by the end of the study. In each questionnaire,

TABLE 1 Perceptions of FCV and Hydrogen by Respondents Experienced and Inexperienced with Alternative Fuels (Average Response)

	Phase 1		Phase 3	
Question	Experienced	Inexperienced	Experienced	Inexperienced
What is your overall impression of the F-cell?[a]	3.60	3.71	3.48	3.75
I feel equally safe in a hydrogen vehicle compared with gasoline vehicles.[b]	3.88	3.58	4.32	4.04
Limited hydrogen refueling infrastructure is a concern in my decision to drive the F-cell.[b]	3.68	4.17	3.88	4.00

[a]1 = not adequate, 2 = adequate, 3 = good, 4 = very good, 5 = excellent.
[b]1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

respondents were asked to give their general impression of the F-cell, with possible answers of "not adequate," "adequate," "good," "very good," and "excellent." As part of the first survey, of the 49 respondents who completed all three questionnaires, 31 participants had an exceptionally positive impression of the F-cell, with a rating of "very good" or higher, which distinguished them from the 18 remaining respondents. As might be expected, those respondents also had a more positive response to vehicle attributes such as braking, acceleration, and handling.

Environmental sentiment was assessed with seven attitudinal questions that were asked in the first questionnaire. These questions addressed the degree to which respondents perceived the significance of environmental issues as well as their willingness to adjust personal behavior to mitigate environmental impacts. On the basis of average scores, this 31-member subgroup from the first questionnaire exhibited higher scores across all seven attitudinal questions. Although none of these differences were statistically significant, the higher average score across all seven attitudinal questions was unusual and indicated that this subgroup, which had higher overall F-cell opinions, was on balance more sensitive to environmental issues.

In the final survey phase, the respondents holding similarly favorable opinions of the F-cell were not characterized by such strong environmental sensitivities. In Phase 3, the same question was asked assessing the overall respondent impression to the F-cell. The distribution of responses was the same, with 31 respondents viewing the F-cell very favorably and 18 viewing the F-cell less favorably. However, some respondents changed their opinion of the vehicle throughout the survey, and hence, the groups were not composed of the same people. Seven respondents in each group had changed their answers and moved to the other group. The two groups were demographically balanced in both survey phases, but in the third questionnaire neither group exhibited dominant environmental sentiments as measured by the same questions. These longitudinal trends in impression suggest that environmental sentiment may affect early impressions of technologies that have a favorable environmental image; however, final impressions are more a function of vehicle performance.

Safety Perceptions

Researchers hypothesized that safety perceptions regarding fueling might negatively influence individuals' perceptions of the F-cell. However, respondents generally felt safe when refueling the F-cell, as shown in Figure 1. Perceptions of refueling safety were relatively stable and benign over time. The average responses to two questions are plotted in Figure 1. The top plot illustrates the stable trend of feeling safe while refueling, whereas the bottom one 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 these results are interpreted. Not all respondents fueled the vehicles, and some relied on 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.

As experience with the F-cell increased, respondents felt increasingly safe with the vehicle. As shown in Figure 2, drivers' feelings of safety with the F-cell in comparison with gasoline vehicles increased with exposure. 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

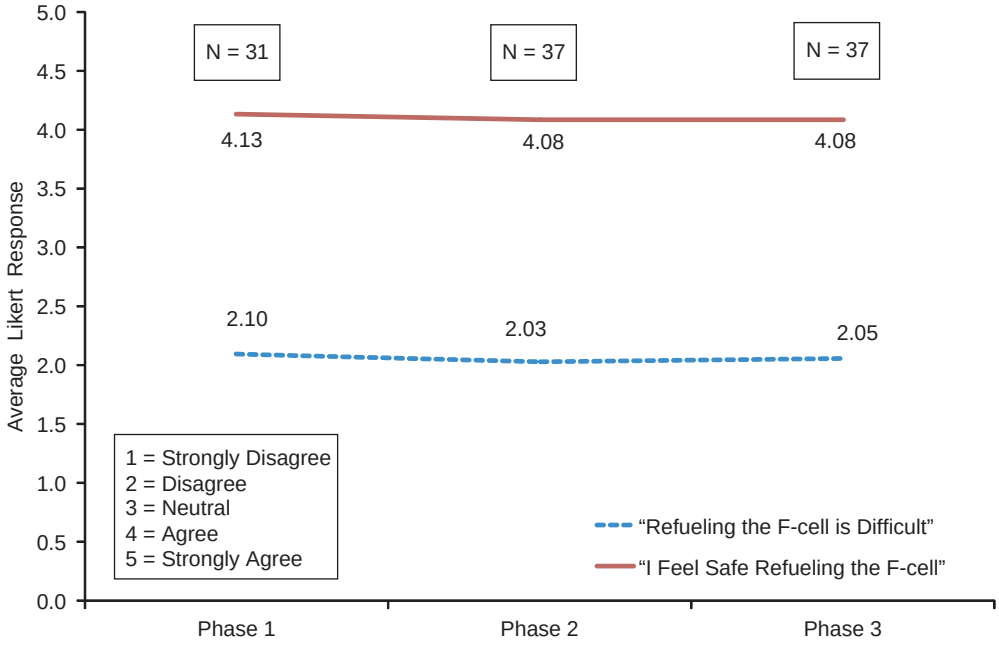

FIGURE 1 Trend in response with regard to refueling safety.

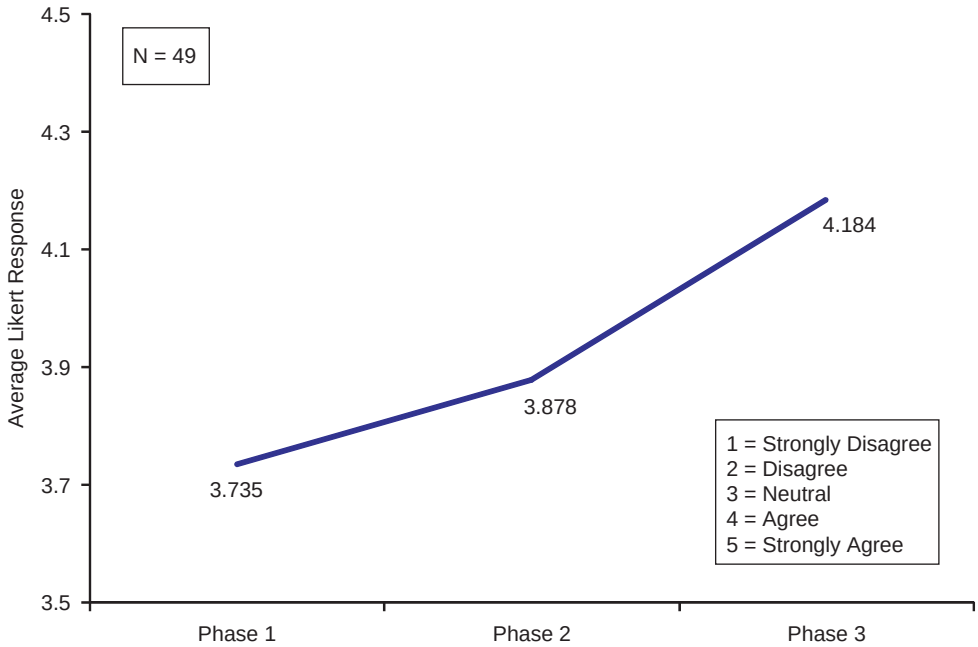

FIGURE 2 Trend in response to "I feel equally safe in a hydrogen vehicle compared with a gasoline vehicle."

the F-cell as in 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 regarding increased collision danger due to the hydrogen tanks on board. One participant felt safer because hydrogen gas was believed to disperse more quickly than gasoline in a crash.

Limited Range

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

The consistent separation of perceived and actual range by participants throughout the study of approximately 32 km suggests that although the vehicle has an actual range of 160 km, 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. Because of variations in station hydrogen storage pressure levels, some stations would provide less than a 100% fill at times. Drivers would immediately notice this effect by means of the fuel level needle and because they were regularly completing fueling logs detailing the exact percentage fill, which they retrieved from the dashboard digital display.

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

During the UC Berkeley focus group, participants thought the actual range of the F-cell was between 130 and 150 km. 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 km was generally acceptable; this range 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 3 shows 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.

Focus group participants provided a great deal of feedback on FCV performance. Features that they liked the most included suspension and braking; zero tailpipe emissions; handling of the vehicle in the wind; the fuel gauge, which provided a percentage number for remaining fuel, considered more useful than a dial display; the style; roomy interior; size; and navigation system. The top three features were zero tailpipe emissions, size, and roomy interior. They disliked several performance features: 10- to 15-s wait time before turning off the vehicle, short range, short range of the keyless remote, difficulty opening the fuel cover, lag in start-up time of the vehicle, constant hum of the vehicle due to the air compressor, difficulty of operating some of the driving controls (e.g., window and door controls in odd locations), and

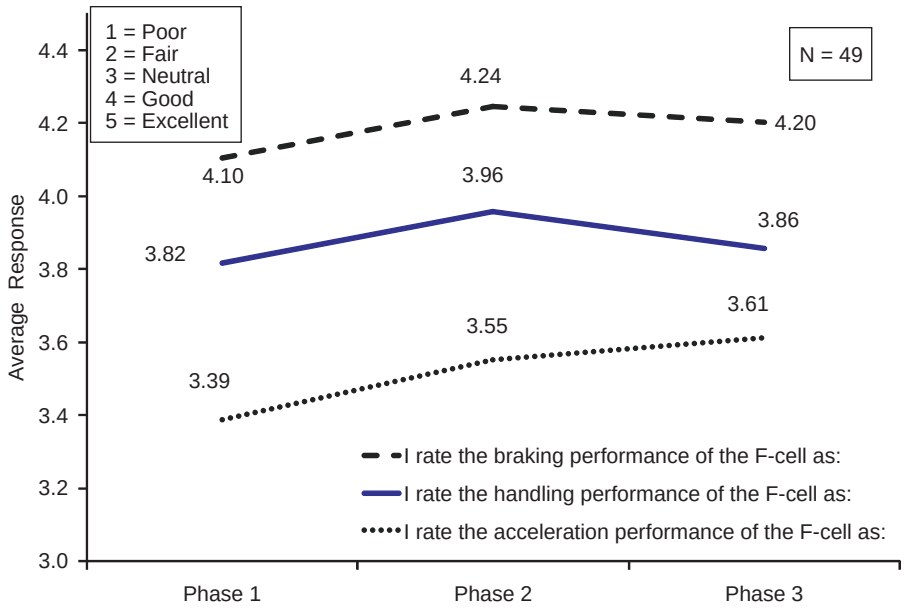

FIGURE 3 Trend in response with regard to vehicle performance metrics.

vehicle style. The three most disliked features were limited range, weak start-up acceleration, and long start-up ignition time.

Hydrogen and FCV Acceptance

In this study, there were two key hypotheses related to hydrogen and F-cell acceptance: "Higher levels of exposure to hydrogen are correlated with greater hydrogen acceptance." "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 toward acceptance of the F-cell to a greater degree by the final phase. Acceptance was defined as feeling as safe with a hydrogen vehicle as with a gasoline vehicle. As presented in the longitudinal analysis, the trend in 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 nonparametric 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 and illustrated 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, test statistics below 0.05 are statistically significant. The difference between Phases 1 and 2 (0.332) was not statistically significant. However, the distribution of responses between Phases 1 and 3 (0.011) was different to a degree that was statistically significant. Thus, over the course of the study, people felt safer with hydrogen. The distribution changed to be skewed more toward agreement with the statement "I feel equally safe in a hydrogen vehicle compared with gasoline vehicles."

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

Researchers also sought to understand whether 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 general finding was that positive environmental sentiments appeared to raise impressions of the vehicle by some participants initially. But this impact was temporary. At the end of study, environmental sentiments were less of a determinant of positive F-cell impressions. Statistical evidence linking environmental sentiments to acceptance was not found, but the emerging evidence appeared to be broadly consistent with past research, such as the study by Kurani et al., who concluded that environmental sentiment alone was not sufficient for acceptance (*12*).

This finding does not imply that the more environmentally conscious respondents received the F-cell poorly, since the vehicle was well received overall by this group (between "good" and "very good"). Nevertheless, environmental sentiment was not a factor governing exceptional levels of acceptance or positive impressions.

CONCLUSIONS

The results are presented of an exploratory study of a prototype FCV fleet and its supporting hydrogen infrastructure. In 2006, UC Berkeley researchers, in partnership with Mercedes-Benz, examined the behavioral response of 65 participants to use of the FCV and hydrogen fueling over a 7-month period. Although there are several

limitations to the study (sample size, self-selection, and generalizability), this fact does not prevent the use of the data set to obtain insights into the drivers' responses to the vehicle and fueling. Although researchers 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 finding 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 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' perceptions 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 km 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. Although 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 response could reflect some self-selection bias, and it is possible that nonparticipants in fueling included those who were fearful of this process.

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 vehicle.

In short, some targeted improvements toward the practical utility of the vehicle are needed before market viability is possible, particularly with regard 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 noteworthy; 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 understanding.

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