Title

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ABSTRACT
Over the last several decades, hydrogen fuel cell vehicles (FCVs) have emerged as a zero tailpipe-emission alternative to the battery electric vehicle (EV). There are key questions about consumer reaction and response to operations and refueling of FCVs. This paper presents the results of a "ride-and-drive" clinic series (n=182) held in 2007 with a Mercedes-Benz A-Class "F-Cell" hydrogen FCV. The clinic evaluated participant reactions to driving and riding in a FCV, as well as witnessing a vehicle-refueling event. Roughly 95% of respondents finished the clinic with either a positive or very positive impression of the F-Cell. More than 80% left with a positive overall impression of hydrogen. The majority expressed a willingness to travel five to ten minutes to find a hydrogen station. Approximately 50% would consider a 225 to 300 mile (360 to 480 kilometers) FCV range acceptable. Fifty percent would pay no more than a $3,000 premium over a similar gasoline vehicle. The clinic results are compared with the authors' previous study employing 24 F-Cells, which tracked respondents over a seven-month period. This comparative analysis helps to better discern which short-term effects may be influenced by the "novelty" effect and which are likely to persist due to new information.

Key Words: Hydrogen, fuel cell, infrastructure, drive clinic, behavioral response, before-and-after, longitudinal, survey

INTRODUCTION
Concerns over air pollution, energy dependence, and now climate change have motivated the exploration of cleaner alternative transportation fuels for several decades. Hydrogen fuel cell vehicles (FCVs) have recently emerged as a zero tailpipe-emission alternative to the battery electric vehicle (EV). Like battery vehicles, FCVs produce no tailpipe emissions (other than water vapor) and also have the potential to be near zero-emission on a full fuel-cycle basis when coupled with renewable energy sources. As the lightest element in existence, hydrogen has several intrinsic characteristics that make it an attractive transportation energy carrier. It has a high energy density by weight, and it can be produced in large quantities from a diverse array of primary energy sources. Furthermore, in contrast to battery recharging, hydrogen can be refueled at speeds comparable to gasoline. These advantages have generated considerable interest in FCVs among governments and the automotive industry. This has led to the controlled deployment and testing of several hundred fuel cell cars and buses around the world.

The techno-economic barriers to FCV deployment are still considerable, but recent progress has been made in several key areas. Remaining issues that require improvement include fuel cell system cost reduction and durability, hydrogen storage, and the costs and technical complexities associated with developing a hydrogen-refueling infrastructure. In addition, and arguably less well recognized, are potential challenges for consumer exposure and acceptance.

Hydrogen FCVs have some important differences from gasoline internal combustion engine (ICE) vehicles. Their recent introduction to US roads presents key questions about consumer reaction and response to their use and limited public knowledge of the dynamics and nature of response to operations and refueling. Overcoming potential consumer acceptance issues will require an understanding of values and perceptions, as well as the pace at which vehicle users develop their opinions.

This study presents the results of a "ride-and-drive" clinic (n=182) held in August and September 2007 with a Daimler AG/Mercedes-Benz A-Class "F-Cell" hydrogen FCV that is currently in operation in Northern California. The clinic evaluated the reactions of participants to driving and riding in a passenger FCV, as well as witnessing a vehicle-refueling event. In this study, FCV response is measured on a short-term basis through a before-and-after survey taken on the same day. The survey assessed consumer perceptions of safety, vehicle performance in contrast to gasoline vehicles, and willingness-to-pay (WTP) for clean fuel vehicles.

In addition, drive clinic results are compared with the authors' previous study employing 24 F-Cells by tracking respondents over a seven-month period (*1*). This comparative analysis can help discern whether reactions to a new technology occurring over short- and long-term exposures might differ in any way. It can also help corroborate previous study conclusions on exposure to new vehicle technology, given the two studies used the same vehicle model.

Although extensive research has been conducted on the behavioral response of commercial taxi and bus drivers to hydrogen technology, this study and its predecessor are among the few that contribute to behavioral research on hydrogen passenger cars. Notable work has recently emerged on consumer response to hydrogen buses in Europe (*2*, *3*). While customer experience with buses and passenger cars is clearly different, comparisons of this research indicate some similar trends in reaction.

This study's results are intended to advise policymakers and the auto industry on the relative challenges of introducing a new vehicle propulsion system to consumers who are accustomed to ICEs. At the same time, this work aims to contribute to future methodological designs of behavioral response studies by synthesizing the understanding generated by short- and long-term studies of the same vehicle type. This paper consists of four main sections. First, the authors present a background on alternative fuel acceptance research, with an emphasis on electric drive trains and hydrogen acceptance. Next, the study methodology is reviewed. Third, results from the pre- and post-clinic survey are presented. Finally, impacts of the authors' short- and long-term exposure studies are contrasted and implications for introducing new fuels are examined.

BACKGROUND

While research on hydrogen FCVs and fuel acceptance has largely coincided with recent vehicle deployment, related work on consumer response to electric drive trains has been active for nearly twenty years. The two are related in that they both face driving range and infrastructure issues, and both vehicle types rely on an electric motor powered by a unique fuel source. Much of the EV consumer response research occurred during the 1990s. Many of these studies focused on understanding how consumers could address fundamental EV limitations. This included the exploration of the "hybrid household" hypothesis, which considers households that incorporate EVs as part of their fleets alongside gasoline vehicles (*4*, *5*). Other research put EVs in households for a few weeks to study household travel behavior (*6*). In spite of range limitations, consumers used EVs for a majority of their basic household trips. However, respondents still desired driving ranges to be similar to that of a gasoline vehicle (*6*). In fact, some long-term studies found that interest in owning EVs actually decreases after a few months of use due to concerns over range and available infrastructure (*7*).

Thus, short-term exposure studies have significant differences and risks in contrast to longitudinal studies. But they can evaluate the direction and degree to which initial impressions change upon exposure. A study employing an EV drive clinic (a short-term ride and drive experiment) found over 70% of participants changed their general opinion of the technology after the test (*8*). However, a similar study revealed that short-term EV use did not improve user familiarity and comfort with the charging process (*9*). These discrepancies suggest that the type of exposure is important. For example, a carsharing (short-term auto use with reservations/access facilitated by electronic and wireless technology) trial clinic led to a much larger improvement in opinion and acceptance among participants compared to reading a brochure about the new service. Drawing upon social learning and marketing theories, this study suggested that a short-term trial is an effective way to increase familiarity and acceptance of transportation innovations (*10*).

Consumer interactions with hydrogen buses have been the source of most hydrogen response studies. One of the earliest occurred in 1998 when the first hydrogen bus was publicly deployed in Munich. Passengers aboard this bus were surveyed using standard Likert-scale responses. Overall, few barriers to hydrogen acceptance were uncovered. The survey found that direct contact with the technology was correlated with more positive assessments and that concern over negative associations with the Hindenburg dirigible accident in 1937 and the hydrogen bomb were not present (*11*).

About five years later, hydrogen bus deployments began in Luxembourg and quickly expanded to Berlin, Perth, and London and offered an opportunity to explore consumer response on a broader scale. The final report to the European Commission evaluating passenger response to the buses found that safety was not a concern, prior (positive) knowledge of hydrogen increased acceptance, and in contrast to the Munich study, suggested that direct exposure was not necessarily associated with acceptance or willingness-to-pay (WTP) (*12*).

At about the same time, a study of London taxi drivers operating prototype FCVs found WTP for the technology was correlated with higher education levels, hydrogen knowledge, and air pollution concerns. Taxi drivers also stated that they did not have safety concerns with respect to driving hydrogen-powered cars (*13*). More recently, several studies based on the deployment of fuel cell buses in Europe, Australia, and Canada, have greatly expanded knowledge of consumer response to hydrogen vehicles (*2*; *14*; *3*). Through a variety of methodologies, all of these studies evaluate the respondent reaction to riding or witnessing a hydrogen bus. O'Garra *et* *al.* (2007) also report on a contingent valuation survey of bus riders in the cities of Berlin, London, Luxembourg, and Perth. The Berlin and Luxembourg surveys asked riders if they would be willing to pay an increased fare to support a large-scale hydrogen bus deployment within their city. The mean WTP of surveyed riders was €0.32 per fare. The London and Perth surveys took a different approach, where both riders and non-riders were randomly surveyed to discern their WTP for hydrogen bus deployment in the form of additional taxes. The surveyors found that citizens of London and Perth had a positive WTP for hydrogen bus deployments of €24 and €15 in annual taxes per year, respectively. Across all cities, roughly 85% of respondents were willing to pay for hydrogen buses.

Hydrogen vehicle marketing experts have observed that exposure through media stories can impact public acceptance, especially general opinions of safety and quality of the hydrogen driving experience (*15*). To better understand potential consumer response to new vehicle types, marketing researchers support test-drives to raise consumer familiarity with new vehicle types, especially driving experience and safety attributes (*16*). However, some vehicle features, such as range restrictions and fuel-efficient driving potential, may take more time for consumers to understand and accommodate.

Research addressing consumer response to hydrogen has expanded significantly in the past few years. Almost all of these studies, however, have focused on agents within the public transportation system, including bus passengers, bus drivers, and taxi drivers. They reveal that a sizable portion of public transit riders would be willing to pay higher fares to run buses on hydrogen fuel. Across these studies, it appears that transit riders and drivers generally feel safe with the technology, and passengers overwhelmingly consider hydrogen buses to be as good, or better, than regular buses across a variety of performance metrics. This paper builds on this growing research by exploring similar response metrics among state and university employees in California to FCV passenger vehicles.

STUDY METHODOLOGY

In this section, the authors provide an overview of both the ride-and-drive clinic and longitudinal survey study methodologies. This includes a description of the surveys and study limitations.

Ride-and-Drive Clinic

The purpose of the ride-and-drive clinic was to gain feedback from a range of individuals who were provided an opportunity to drive the F-Cell vehicle under real-world driving conditions and view a fueling demonstration. After completing a pre-clinic questionnaire, participants drove the vehicle in groups of two on a three-mile route in West Sacramento or Richmond, California with a researcher to direct them. The maximum speed along the routes was 50 to 55 miles per hour (80 to 88 kilometers per hour). The route permitted respondents to personally test the acceleration, braking, and handling capabilities of the vehicle.

Participants had the opportunity to drive the vehicle and to ride as a front-seat passenger to maximize their exposure. In addition to driving the F-Cell, subjects were also directed to a hydrogen refueling station where they witnessed an F-Cell refueling demonstration. Some fuel was placed in the vehicle, but the vehicle was not always low on fuel, so in some cases the refueling was approximately half a tank. Once participants had driven the vehicle and witnessed the refueling, they completed a post-clinic questionnaire.

Employees from the California Department of Transportation (Caltrans), the California Air Resources Board (CARB), and the California Energy Commission (CEC) participated in the ride-and-drive clinic at the California Fuel Cell Partnership from August 8 to 17, 2007. University of California, Berkeley (UC Berkeley) employees attended the clinic at the Richmond Field Station and witnessed the fueling demonstration at the AC Transit hydrogen fueling station in Richmond between the dates of September 22 to 27, 2007. Research subjects were recruited from within UC Berkeley, Caltrans, CARB, and CEC via email soliciting participation. Total participant time ranged between 1.5 to 2 hours. An incentive raffle for a small digital music player was used to encourage participation. In addition, each respondent received a small gift, such as an F-Cell writing pad, upon session completion. A total of 107 individuals participated in the Sacramento drive clinic and 75 in Richmond. Each drive clinic had a goal of 100 participants, but recruitment proved to be somewhat more challenging for the UC Berkeley/Richmond location. Potential participants who had previously driven an FCV or had extensive knowledge of them were not allowed to participate in the ride-and-drive study.

"Before-and-After" Survey Design

Researchers administered questionnaires "before-and-after" exposure to the F-Cell and the refueling event. The initial questionnaire assessed experience with alternative fuels, impressions of hydrogen as a transportation fuel, expectations of vehicle performance and hydrogen safety, challenges of hydrogen vehicles, and attitudes toward the environment and experimentation.

The post-clinic questionnaire documented F-Cell impressions including acceleration, braking, handling, fuel economy, and ride comfort; hydrogen vehicle and fuel safety; range acceptability; fueling difficulty; WTP; and questions about participant demographics. When asked to provide their impressions of hydrogen safety, respondents were asked for their assessment relative to their gasoline safety impressions. For example, one question read: "What is your impression of the safety of driving a hydrogen vehicle?" Responses included: "Much less safe than gasoline," "Less safe than gasoline," "About as safe as gasoline," "Safer than gasoline," and "Much safer than gasoline." Fuel response benchmarking to gasoline is a recommended approach for two reasons. First, it grounds the answer relative to vast prior consumer gasoline experience. Second, it permits a more accurate assessment of impressions to the vehicles and fuel with which hydrogen (and perhaps other technologies) would likely compete. This approach also was employed for assessing consumer response to vehicle performance.

Ride-and-Drive Clinic Study Limitations

A primary limitation of this study consists of the participant self-selection bias from a restricted study population (i.e., state agency and university employees). The individuals participating in the clinic were volunteers, and hence, the sample is not random. However, only 55% of respondents entered the clinic with a positive hydrogen fuel impression, with much of the remaining sample classifying their opinion as "Neutral." The dataset generated for this study reflects an exploratory analysis, but these study limitations do not prevent the use of the dataset to obtain insights into consumer response to hydrogen vehicles and fueling, especially among likely early adopters. Nevertheless, the limitations do suggest caution when generalizing study findings to the broader population.

Comparative Analysis with Longitudinal F-Cell Study

In 2006, the authors conducted a longitudinal survey of 65 drivers of 24 F-Cell vehicles in California and Michigan (*1*). Drivers were drawn from for-profit companies in California and

Michigan—where 10 vehicles were placed. An additional 14 vehicles were deployed with governmental agencies, non-profits, and universities in those states (two of the 24 vehicles were located in Michigan). Participant criteria required that qualifying drivers: 1) drove the F-Cell once or more a month, 2) drove it at least 65 kilometers per month, and 3) were willing to complete the three-phase survey. The longitudinal survey was administered online at three discrete times over the seven months. There was some attrition over the study: 54 participants completed two of the three survey phases, and 49 completed all three phases.

As with the drive clinic sample, longitudinal participants were self-selected. Because the longitudinal survey required a longer sustained commitment to the research and vehicle, it is likely that this population represents a more enthusiastic group of participants overall than the general public. While the same can be said of the ride-and-drive clinic participants, their time commitment was far less. Because the vehicle deployed was the same in both the longitudinal and ride-and-drive studies and many survey questions were the same, an opportunity exists to contrast the short- and long-term reactions. A comparative discussion of results follows in the conclusion.

RESEARCH RESULTS

In this section, the authors present the research results. There are five key sections: 1) demographics, 2) F-Cell and refueling response, 3) response to vehicle performance metrics, 4) response to range and refueling distance, and 5) WTP responses.

Demographics: Sacramento and Richmond Study Populations

Table 1 presents the demographics of the drive clinic participants. They were mostly male (63%) and married (55.2%). The Sacramento clinic was more heavily weighted with males than the Richmond clinic. The difference between the two clinics was not large enough to be statistically significant, according to the Fisher Exact Test. Similarly, while there were perceptible differences between age and marital status distributions across the two samples, the relative differences were not statistically significant. However, survey respondents in Richmond had higher education levels (p=0.0038), but more respondents had relatively low incomes (p=0.025). This reflects the participation of graduate students employed by the university. Clinic demographics are summarized in Table 1. Since differences between the populations were not substantial, researchers have combined responses in the analysis that follows.

In comparison with the general population, the combined sample is not representative of the US or California populations (p<0.001 for all). A summary of the demographic comparisons of the sample with both the United States and California appears in Table 1. The study sample has a higher percentage of males, is younger, more often single, more educated, and has a higher household income than either the US or California populations.

TABLE 1 Demographic Attributes of Survey Respondents

Demographic Attribute	Richmond	Sacramento	Total	*p* -value	US 18+	CA 18+	*p* Tot-US	*p* Tot-CA
Gender	N=75	N=106	N=181					
Male	57.3%	67.0%	63.0%	0.21 *	48.6%	49.6%	<0.001 *	<0.001 *
Female	42.7%	33.0%	37.0%		51.4%	50.4%		
Age Category	N=75	N=106	N=181					
22-34	44.0%	25.5%	33.1%	0.0049 ***	24.8%	27.3%	<0.001 ***	<0.001 ***
35-49	22.7%	40.6%	33.1%		31.6%	32.7%		
50-59	21.3%	29.2%	26.0%		18.6%	17.7%		
60+	12.0%	4.7%	7.7%		25.0%	22.3%		
Marital Status	N=74	N=107	N=181					
Single	39.2%	29.9%	33.7%	0.094 ***	26.9%	30.6%	<0.001 ***	<0.001 ***
Married	55.4%	55.1%	55.2%		50.1%	46.6%		
No Longer Married	5.4%	15.0%	11.0%		23.0%	22.7%		
Education	N=75	N=107	N=182					
Associate Degree or Less	9.3%	10.3%	9.9%	0.0038 ***	75.0%	73.5%	<0.001 ***	<0.001 ***
Bachelor's Degree	41.3%	64.5%	54.9%		16.2%	17.4%		
Graduate Professional Deg.	49.4%	25.2%	35.2%		8.8%	9.1%		
Income (HH, $ US)	N=72	N=102	N=174					
Less than $50,000	29.2%	10.8%	18.4%	0.025 ***	49.2%	42.4%	<0.001 ***	<0.001 ***
$50,000 to below 75,000	13.9%	20.6%	17.8%		18.9%	18.0%		
$75,000 to below 100,000	18.1%	25.5%	22.4%		12.2%	12.7%		
$100,000 to below 150,000	23.6%	31.4%	28.2%		11.7%	14.6%		
More than $150,000	15.3%	11.8%	13.2%		8.0%	12.2%		

* Fisher's Exact Test
** ANOVA
*** Chi-squared Test

Source: American Community Survey, 2007

F-Cell and Hydrogen Refueling Response

The response of drive clinic participants to the F-Cell was evaluated from several perspectives. Pre-clinic survey questions were designed to assess preconceptions of the hydrogen fuel, hydrogen vehicles, and refueling. Post-clinic survey questions discerned how impressions shifted as a result of direct exposure to the vehicle and refueling process. The post-clinic survey also elicited respondent opinions of vehicle safety and operation. By the end of the clinic, most participants left with a good impression of the F-Cell. When asked of their opinion given the options of "Very Negative," "Negative," "Neutral," "Positive," and "Very Positive," roughly 95% of respondents finished the clinic with either a positive or very positive impression of the F-Cell. When asked of their overall feelings of vehicle safety, 89% reported that they "felt safe" with the F-Cell. Finally, 85% who witnessed the F-cell refueling considered it to be safe, and 82% did not consider it to be difficult.

To gain insights into short-term exposure impacts, the survey sought to measure whether technology exposure during the clinic had any effect on respondent safety and hydrogen fuel impressions. With respect to safety, respondents were asked to give their opinion of hydrogen safety relative to gasoline safety. Results indicate that short-term exposure to hydrogen technology can shift hydrogen and fuel safety opinions. Figure 1 illustrates the before-and-after response distributions to three paired questions. Sample size is indicated within each figure for the appropriate question. Some sample sizes vary slightly due to missing or invalid responses from a handful of respondents.

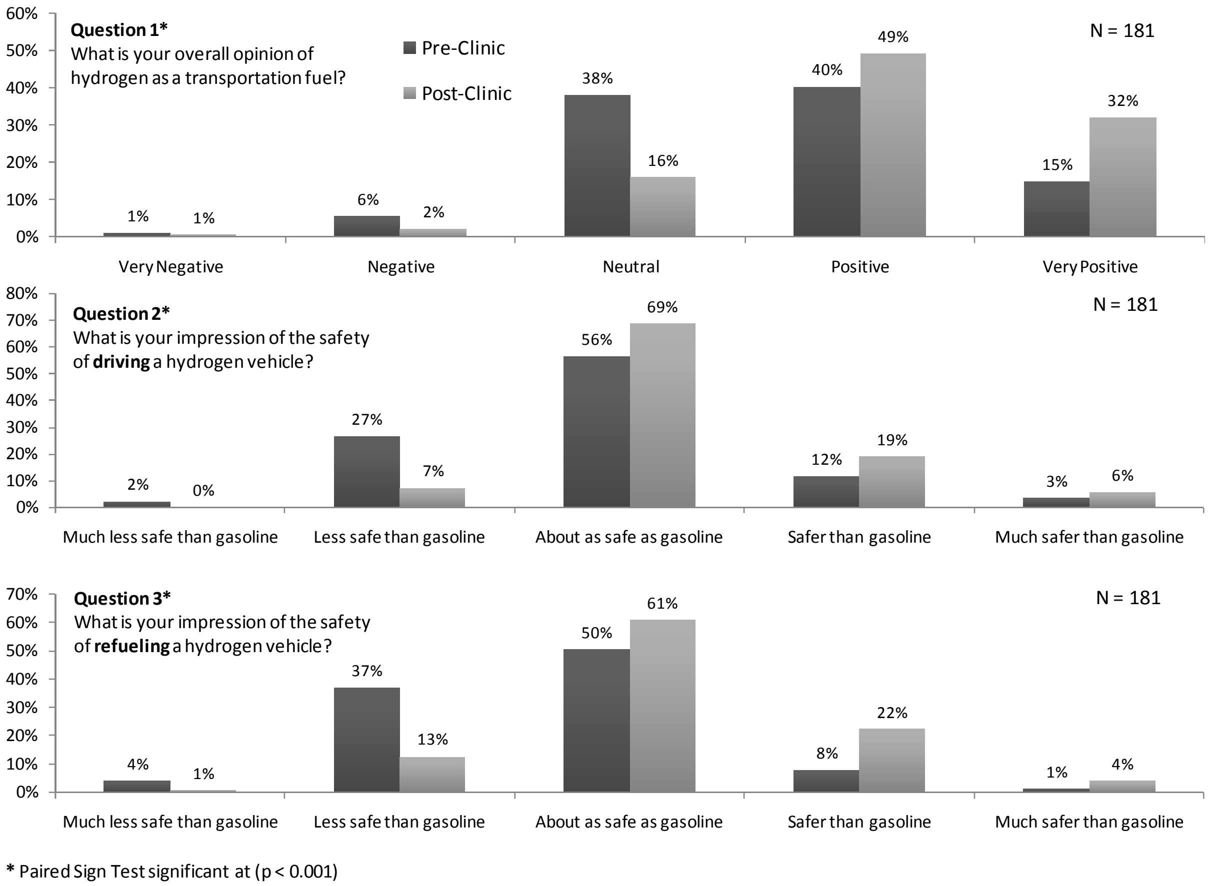

FIGURE 1 Before-and-after vehicle and refueling safety response.

These paired distributions illustrate several important points. Question 1 assesses respondents' before-and-after opinions of hydrogen as a transportation fuel. The pre-clinic survey distribution illustrates that a small majority (55%) entered the clinic with favorable hydrogen views, while the remaining respondents either had negative or neutral opinions. The shift after the clinic is evident from the post-clinic survey response distribution, which skews to the right. More than 80% of participants finished the clinic with a positive overall hydrogen impression. The Sign Test—a two-tailed non-parametric test applicable to paired responses—can assess whether paired response distributions are different statistically. When applied to the distributions of Question 1, the Sign Test generates a z-score of -5.8, indicating that the opinion shift is statistically significant.

Question 2 evaluates respondent safety impressions of driving a hydrogen-powered vehicle. The answers to this question were posed relative to gasoline as a familiar benchmark. The distribution of pre-clinic survey responses better approximates a normal distribution, with roughly 70% believing that hydrogen is equally safe or safer than gasoline. However, the remaining 30% believed that driving a hydrogen vehicle is less safe than gasoline. The post-clinic survey reveals a considerable impression shift, as the proportion of respondents feeling less safe with hydrogen than with gasoline dropped to 7%. Opinions mostly shifted towards the belief that gasoline is as safe as hydrogen, with some gains in the opinion that hydrogen is safer than gasoline. Question 2 had a z-score of -4.9 with the Sign Test, meaning that the difference between the distributions is statistically significant.

Finally, Question 3 illustrates a similar assessment of hydrogen refueling safety normalized to the impressions of gasoline refueling safety. Here, stronger safety reservations exist in the pre-clinic survey prior to exposure, as over 40% considered hydrogen refueling to be less safe than gasoline. As with the driving assessment, responses shifted in the post-clinic survey, with only 15% leaving the clinic with the impression that hydrogen refueling is less safe than gasoline refueling, while 60% felt that it was as safe and 25% believed it was safer. The z-score of the Sign Test on the paired responses for Question 3 was -6.7, also showing statistical significance. Thus, the response shift clearly demonstrated that short-term exposure to hydrogen vehicles and refueling can make at least some people feel more comfortable.

Response to Vehicle Performance Metrics

Participants were asked to assess their opinions of several hydrogen vehicle performance metrics. As with the questions in Figure 1, researchers designed the performance questions to assess response metrics calibrated to participants' gasoline vehicle perceptions. In the pre-clinic survey, respondents were asked to provide their hydrogen vehicle performance expectations in comparison to a typical gasoline vehicle with the following metrics: acceleration, braking, handling, and ride comfort. Respondents were asked whether they anticipated that the hydrogen vehicle would perform worse, better, or about the same as a typical gasoline vehicle. In the post-clinic survey, participants were asked to assess whether the vehicle had met, exceeded, or failed to meet their expectations. Table 1 illustrates the cross-tabulation of responses to two key metrics: acceleration and braking.

TABLE 2 Before-and-After Survey Responses to Vehicle Performance

Acceleration

Pre \ Post	Greatly Disappointed	Slightly Disappointed	Met Expectations	Slightly Exceeded	Greatly Exceeded	Total
Much Worse	0%	1%	2%	1%	1%	4%
Slightly Worse	0%	5%	9%	12%	7%	34%
About the Same	1%	11%	16%	5%	9%	42%
Slightly Better	0%	3%	5%	4%	1%	13%
Much Better	0%	2%	3%	1%	1%	7%
Total	1%	23%	35%	23%	19%	100%

Braking

Pre \ Post	Greatly Disappointed	Slightly Disappointed	Met Expectations	Slightly Exceeded	Greatly Exceeded	Total
Much Worse	0%	0%	0%	0%	0%	0%
Slightly Worse	0%	0%	1%	1%	0%	2%
About the Same	1%	3%	55%	21%	8%	88%
Slightly Better	0%	1%	6%	0%	1%	7%
Much Better	0%	1%	1%	0%	1%	3%
Total	1%	4%	64%	22%	9%	100%

[i] Pre-Survey Question: How do you expect the hydrogen vehicle to compare to a typical gasoline vehicle within the following performance categories?

[ii] Post-Survey Question: How did the following attributes meet, fail to meet, or exceed your expectations?

The cross-tabulation illustrates both the distribution of respondent expectations prior to exposure and how those relative expectations were met or unmet by the vehicle. As a performance metric, “acceleration” illustrated the widest distribution of prior expectations, with nearly 40% of respondents expecting the vehicle to perform worse than a gasoline vehicle, and 20% expecting it to perform better. The results of the post-clinic survey revealed that 25% of respondents considered acceleration to perform below their expectations, while the expectations of roughly 40% were exceeded.

Braking exhibited far less variance in expectations, as most respondents anticipated braking to perform about the same as gasoline vehicles. A little more than 30% found braking to exceed expectations, far more than the 5% that indicated disappointment in braking performance.

Response to Range and Refueling Distance

Participants also were asked about range and refueling preferences, which likely are critical to alternative fuel vehicle acceptance. Both aspects are important because restricted range and limited refueling infrastructure have long hindered alternative fuel vehicles. Results of two questions from the survey illustrate a distribution of preferences across these two parameters. In the post-clinic survey, respondents were asked to write-in a vehicle range (in miles) that they would consider acceptable for the F-Cell (which currently has a range of 100 miles/160 kilometers). Additionally, respondents were asked to characterize their tolerance in terms of extra travel time to drive to a fueling station. The response distributions to both questions are illustrated in Figure 2.

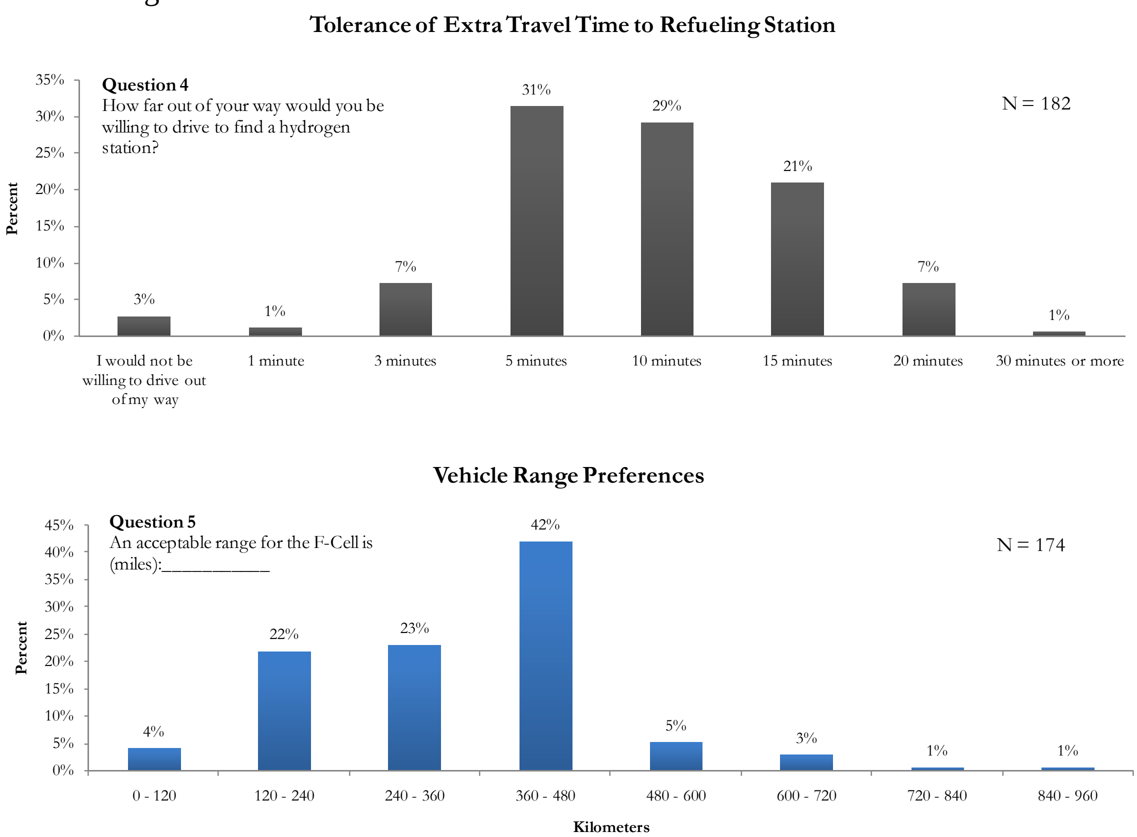

FIGURE 2 Distribution of range and refueling preferences.

Question 4 illustrates the refueling distribution and reveals that the majority of respondents would be willing to travel five to ten minutes out of the way to find a hydrogen station. A sizable minority also expressed a willingness to drive at least 15 minutes to find a station. The value of this information is applicable to informing time-distance tolerances for planning potential station networks and assessing whether consumers within a particular municipality are within an acceptable range of a refueling station.

Question 5 presents the distribution of range preferences and shows that roughly half of respondents would consider a vehicle with a range between 225 to 300 miles (360 to 480 kilometers) or greater to be acceptable for a vehicle like the F-Cell. An important caveat to this result relates to the selectivity bias of the sample, as these responses reflect those who were interested in driving a hydrogen-powered car in a study clinic. A random sample of the public would almost certainly be more skewed to the right. However, early market introduction of hydrogen cars would likely draw from an early adopter population, which is relatively more tolerant of range limitations.

Willingness-to-Pay Responses

The ride-and-drive clinic offered a forum to query respondents about their WTP for vehicles powered by clean fuel technology. Participants were made aware (if they did not already know) that hydrogen is only as clean as the primary energy sources from which it is made. Questions sought to gauge a more generalized personal valuation with respect to clean vehicle technology. The post-clinic survey queried respondents about the purchase price premium they would be willing-to-pay for a vehicle and fuel that were emission free, such as an FCV powered by hydrogen generated mostly from renewable resources. Not surprisingly, there is a theoretical limit to the degree to which consumers are willing to pay to offset externalities (e.g., air pollution). To explore this issue, respondents were asked the purchase price premium that they would pay for an emission-free car similar to their own, as well as the annual operating cost premium. The questions were asked sequentially, leading with that of the purchase price premium. Figure 3 illustrates the response distribution of both questions.

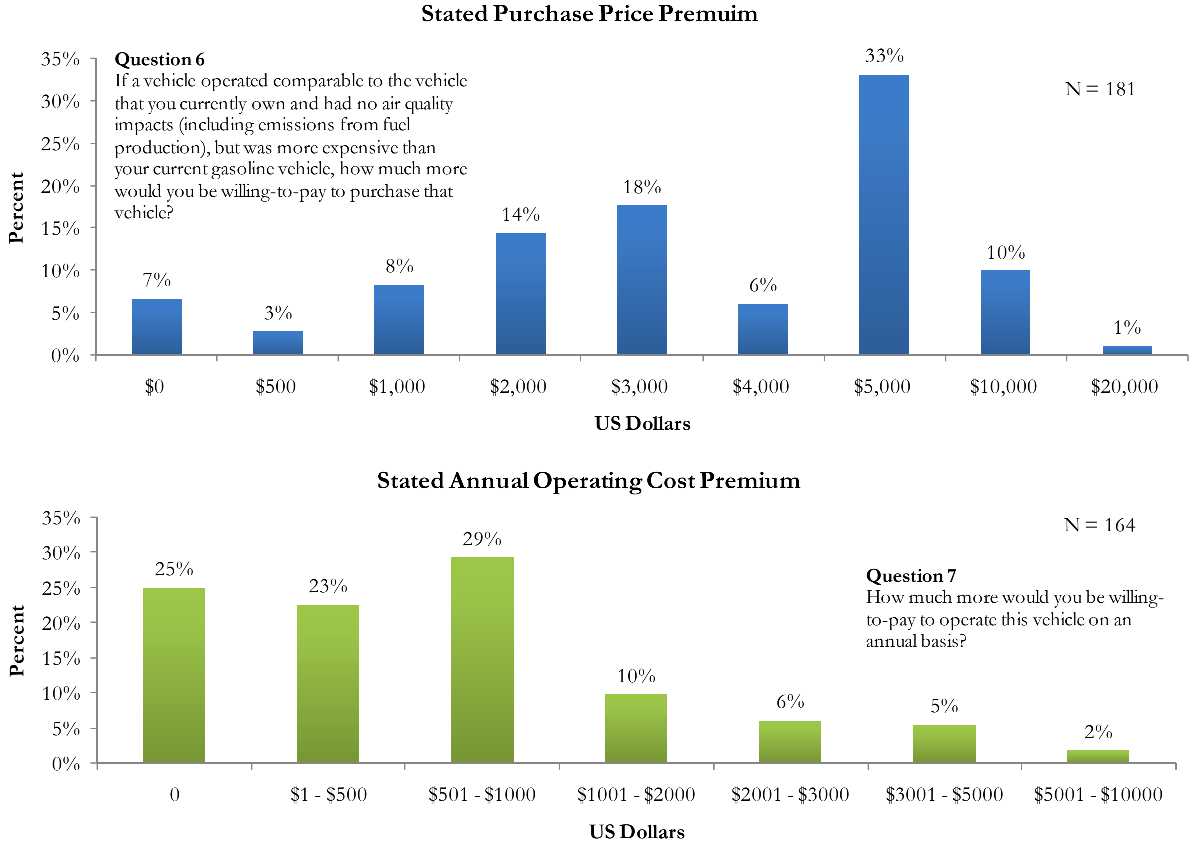

FIGURE 3 Response distribution to WTP questions.

The WTP distribution suggests several points about how consumers value the benefit of clean vehicles and fuels. In terms of purchase price premiums, 50 percent of respondents indicated that they would pay no more than a $3,000 US premium over a similar gasoline vehicle. The mode is $5,000 US, and WTP drops off significantly at greater values. The distribution for the annual operating cost premium suggests that consumers have a higher stated aversion to paying more for operating costs than purchase price premiums. A quarter of respondents stated a WTP of zero, and 75 percent indicated that they would pay no more than $1,000 US per year to operate a cleaner vehicle over what they would pay to operate a conventional vehicle. The drop in sample size observed in Question 7 is due to the fact that some respondents interpreted the question in percentage rather than absolute terms (e.g., "10% more") and therefore their responses were not included in the analysis for this question.

The main objective of assessing WTP is to appreciate the difference in price and anticipated operating costs that would have to exist between conventional and cleaner vehicle options for consumers to consider such alternatives. Stated WTP—reflecting the responses given here—is distinct from empirically revealed WTP, which is observed through actual behavior. Revealed WTP is preferred if its available, but stated WTP is useful when the product in question either does not yet exist or is not widely available. Respondents answering these questions are not held to their answers or accountable to actual financial circumstances.

Nevertheless, the response still offers a proxy as to what range of additional expenses would be tolerable to the consumer.

CONCLUSIONS

While the clinic and the longitudinal surveys were different in nature, the study results illustrate a fair amount of agreement. The clinic results indicate that short-term exposure to FCVs and refueling can improve participant hydrogen vehicle impressions. This conclusion is consistent with the results of the previous longitudinal study (*1*). For example, participants in both studies felt safer with the F-Cell, the more exposure that they had with it. The longitudinal survey illustrated an increase in feelings of safety (on average) over time, but it did not illustrate a statistically significant shift between the first and second study phases. In both studies, average safety assessments increased with exposure. The longitudinal study had less than one third the sample size of the clinic, and this is potentially one reason why near-term safety reactions were found to be statistically significant in the clinic but not in the longitudinal.

Questions of perceived hydrogen refueling difficulty were addressed in both studies, and the results indicate that refueling is not likely to be difficult for consumers. Both studies indicated that the majority of respondents felt safe refueling the F-Cell. The longitudinal survey found that participants who refueled the F-Cell consistently felt safe doing so. Similarly, clinic respondent impressions shifted towards feeling safer after exposure to a refueling event.

In both studies, vehicle performance impressions were generally positive, although the longitudinal survey observed a slight novelty effect over the course of the study. For instance, vehicle braking impressions first rose and then declined. However, general vehicle performance assessments in the longitudinal study remained relatively stable over time. Interestingly, the results for vehicle acceleration expectations prior to the clinic exhibited a wide distribution. Nearly 40% of respondents felt that vehicle acceleration would be worse than that of a gasoline vehicle. While after exposure slightly more than 40% of those participants found that the F-Cell equaled or exceeded their expectations.

The ride-and-drive clinic findings offer some potential policy insights for the introduction of new fuels. Among the leading petroleum alternatives, hydrogen is among the least familiar to consumers. Both study results appear to demonstrate that consumers could readily adapt to driving and refueling hydrogen vehicles. However, the clinic illustrates that between 30 to 40% of respondents had safety reservations prior to the study. These reservations decreased for most respondents in the post-clinic survey. These sentiments, nevertheless, were found in a population that was largely self-selected. Hence, one would expect the broader public to exhibit perhaps greater reservations. The clinic results suggest that short-term hydrogen exposure could be useful for introducing new vehicles and fuels to the general public.

Additional results provide potential parameters for station network planning of dedicated fuels outside of gasoline. In the clinic, most respondents were willing to travel five minutes out of their way to find fuel, and a sizeable proportion appeared willing to drive at least 15 minutes. In addition, range considerations indicate that vehicles designed to travel around 250 to 300 miles (400 to 480 kilometers) on one tank would meet the needs of most respondents. Similar range results were found among longitudinal study participants. Finally, WTP parameters illustrate that consumers might pay more to drive a vehicle that emits less air pollution. The WTP distribution for purchase price also suggests that consumers generally consider premiums of $5,000 US to be the upper limit of what they would personally pay just to improve public air quality. Premiums in operating costs exceeding $1,000 US would be unattractive to many.

Interestingly, nearly a quarter of all clinic respondents indicated no tolerance for operating cost premiums.

Overall, for dedicated fuels such as hydrogen to succeed, some pre-exposure could assist in educating the public and improving impressions. Hydrogen is among the most distinct fuels competing for future viability. Hence, adaptation strategies that account for exposing the public to vehicles in a neutral setting may help to expand the potential market. Of course, other techno-economic challenges that address driving range, limited infrastructure, and vehicle cost still must be addressed. The information provided in these studies offers an early proxy of vehicle and infrastructure specifications that would be required for the proliferation of FCVs and other dedicated alternative fuel vehicles in the future.

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