CONTENT ANALYSIS OF INTERVIEWS WITH HYDROGEN FUEL CELL VEHICLE DRIVERS IN LOS ANGELES

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ABSTRACT

Hydrogen fuel cell vehicles (HFCVs) are zero-emission vehicles (ZEVs) and their widespread adoption may help to mitigate some of the issues arising from fossil-fuel usage in the transportation sector. Only in recent years have these vehicles become available for purchase or lease in the United States, and only within the state of California. To date, nearly 5,500 HFCVs have been sold or leased there, supported by a developing refueling infrastructure there. This population represents a unique opportunity, as previous studies on HFCV adoption have largely employed hypothetical stated preference surveys distributed to likely adopters. Seeking to investigate the real experiences of actual adopters from their own perspective, we conducted semi-structured interviews with twelve early adopters of HFCVs in the Los Angeles metropolitan area. We conducted thematic content analysis using these interviews to identify the prevalence of factors deductively derived from published literature. All respondents consider lifetime cost of vehicle ownership, engage in comparison shopping, and assess the adequacy of the refueling infrastructure by various geographic criteria. Environmental concerns motivated many respondents to pursue HFCV adoption, though only if it made financial sense. Respondents chose HFCVs over battery electric vehicles (BEVs)s after consideration of range, refueling time, and cost. Early HFCV adopters consistently cast their adoption of the technology as a contribution to a diverse ZEV marketplace. Strategies for the promotion of HFCV technology must account for this range of variation in early-adopter motivations, concerns, and behaviors that might complicate targeted HFCV promotion strategies.

Keywords: Hydrogen, Fuel Cell Vehicle, Content Analysis, Interview, Early Adopters

INTRODUCTION

Widespread adoption of alternative fuel vehicles (AFVs) may address multiple issues inherent to current transportation systems, including rising rates of greenhouse gas emissions and criteria air pollutants. Recently, the rate of global AFV sales has garnered much attention, especially in the electric vehicle market. The increasing number and variety of plug-in battery electric vehicle (BEV) models either available for purchase or promised by a number of prominent automobile manufacturers, has been accompanied by notable advances in the hydrogen fuel cell vehicle (HFCV) market that warrant attention. From 2014 to 2017, 6,364 HFCVs were sold or leased worldwide, largely in the United States, Japan, and South Korea (*1*). In the US, California is the only state where HFCVs—the Honda Clarity, Toyota Mirai and Hyundai Tucson—are available for purchase or lease. From late 2015 to November 2018, Californians bought or leased >5,400 HFCVs, > 75% of those since the beginning of 2017 (*2*). This uptick—and the resultant hydrogen shortages at stations—signals that the nascent HFCV market in California is becoming more robust, which is noteworthy given relatively low gasoline prices during this period and the number of available BEVs that compete with HFCVs in the AFV market.

Fuel-cell vehicles have been anticipated for decades; several expected launch dates passed before automakers could move from prototype to commercial product. Like other AFVs, HFCVs require a comprehensive "business ecosystem" (*3*) involving numerous stakeholders to achieve a successful roll-out. Planning agencies have laid out "roadmaps" for coordinating the essential parts of the HFCV ecosystem: hydrogen fuel and fuel cell production; refueling stations; adequate on-board storage and driving range; safety and zoning concerns; insurance; maintenance; education of dealers, consumers, and first responders; regulatory approval; and government incentives for several stakeholders (*4; 5*). Yet, after decades of preparation for commercializing HFCVs, consumers who choose to drive the vehicles remain central to the fate of HFCV proliferation. Thus, it is essential to understand the factors most important to those who decide to purchase or lease an HFCV, particularly as HFCVs become available in other geographic markets.

All light-duty conventional and alternatively fueled vehicles involve tradeoffs for consumers. The potential appeal of HFCVs includes: zero tailpipe pollutant emissions; longer driving range than most BEVs; fast refueling; quiet electric motors; government and industry incentives including rebates, subsidies, high-occupancy vehicle (HOV) lane access; and access to cutting-edge technology. Disadvantages involve: scarce or unreliable refueling stations; high fuel and vehicle costs; lower energy efficiency than BEVs; shorter driving range than most gasoline/diesel cars; unfamiliarity with the technology; and uncertainty about HFCVs' future (*62*). How early adopters view these and other issues is important to understand.

Research on AFV market analysis has used several methods, including agent-based modeling, consumer discrete-choice models, and diffusion analysis (*6*). Actual and potential early adopters have been profiled as wealthy, educated, and environmentally concerned individuals with multi-car households and longer commutes (*7; 8; 9*). Recent surveys have observed increased sociodemographic heterogeneity (*10; 11*). The most popular approach—stated preference choice analysis—typically involves surveys of potential buyers based on hypothetical choice scenarios (e.g., *12; 13; 14*). The stated willingness to purchase certain types of vehicles is a function of vehicle cost and attributes, demographic and attitudinal characteristics, and refueling availability (*12; 13; 15; 16; 17; 18; 19; 20; 21; 22*).

The growing population of early HFCV adopters represents an opportunity to gain insights on revealed purchasing behavior and associated important factors directly from first adopters that a stated preference approach may miss. This helps to address known

inconsistencies between stated intentions and revealed behavior when using stated preference approaches.

For this purpose, ethnography offers a number of techniques to systematically study people and their lived experiences from their own perspectives (*23*). To date, research on HFCV adoption has commonly used a proxy or hypothetical approach out of necessity. This is no longer the case in California, and understanding how known adopters worked through their decision to ultimately adopt an HFCV is a priority research topic. Given the uncertainty in consistency between past work on hypothetical HFCV adoption and revealed HFCV purchasing behavior, the nascent nature of the HFCV market, and the need to understand factors important to early adopters as the HFCV market continue to grow, we ask the following research question: how did a group of actual HFCV adopters work through their decision to ultimately purchase or lease the vehicle? Specifically, what factors did respondents indicate were of greatest importance in their decision to adopt an HFCV? To address this, we interviewed 12 early adopters of HFCVs in the Los Angeles metropolitan area in the summer of 2018 and analyzed their statements to identify factors important to their purchasing decisions using thematic content analysis. We followed a rigorous qualitative protocol to conduct in-depth, open-ended interviews. We coded each statement using theoretically derived codes from a review of HFCV adoption literature. We then coded the interview transcripts to identify the most important common factors and report exemplary comments.

LITERATURE REVIEW

Literature on AFV adoption is dominated by stated-preference consumer choice studies. This approach involves asking a sample of presumed or potential AFV adopters whether or not they would consider adopting hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), BEVs, or HFCVs, or if they prefer certain AFV types over others. These stated-preference or stated intent-type survey responses, along with demographic, travel behavior, and attitudinal information, form the foundation of choice or agent-based models, which identify a set of key factors influential to stated willingness to consider a future AFV purchase. Such studies generally find that vehicle characteristics such as price, performance, and range are significant to respondents (*11; 19; 24; 25; 26; 27; 28; 29; 30*). Personal characteristics and individual attitudes are also commonly observed to influence the stated willingness to consider or intent to purchase an AFV. These include: environmental concern, seeking status as technologically savvy, seeking status as responsible and intelligent, and a desire for national energy independence (*18; 31; 32; 33; 34; 35; 36; 37; 38; 39*). Wealthier households with other vehicles available for use are more likely to purchase an AFV (*39; 40; 41; 42*).

Others have analyzed how drivers respond to an experiment in which they drive an AFV. Workshops, focus groups, and interviews determine how the individual considers AFV adoption after gaining some experience with the vehicle. These approaches find that individual benefits outweigh broader societal concerns identified in stated preference approaches (*43; 44; 45*).

Studies focused on how potential early adopters consider other AFVs may not be entirely transferable to HFCVs. HFCVs differ from other types of AFVs in ways that merit import. One is a general concern about the nature of hydrogen safety, though some have found that knowledge of—and experience with—hydrogen technology has alleviated this concern to some degree (*46; 47*). This is a key consideration; other studies worldwide have shown that the public harbors low hydrogen knowledge and familiarity (*38; 46; 48*). Test drivers of HFCVs and HFCV bus riders express higher opinions of the vehicle's performance and safety relative to initial perceptions (*49; 50*). Interaction with hydrogen vehicles, refueling infrastructure, or other early

HFCV adopters may be important pathways for prospective HFCVs adopters to gain the knowledge, experience, and confidence with approaching the decision to adopt an HFCV. Little is known about the mechanisms by which these factors influence HFCV adoption at present.

Other HFCV adoption studies identified refueling time and refueling infrastructure scarcity as primary concerns of potential early adopters (*22; 32; 49; 51; 52; 53; 54*). Indeed, prior to commercial availability of HFCVs, a majority of stakeholders and experts considered station scarcity the primary barrier to widespread HFCV adoption (*55*). Refueling station availability is important for HFCV drivers because, unlike PHEV and BEV drivers, they depend on publicly available refueling station networks and cannot refuel at home.

Due to the HFCV market's nascency, there is limited understanding of these identified factors' degrees of importance to those who ultimately decided to adopt an HFCV, or if the decision includes other previously unidentified factors. This was noted in (*54*), where 39 respondents who purchased a Tesla BEV were specifically asked why they did not purchase an available HFCV option. Respondents noted hydrogen fuel sources and the inability to refuel at home as key reasons to adopt a BEV over an HFCV. Previous studies have not considered these to be primary barriers to HFCV adoption. Hardman et al. (*54*) interviewed respondents who decided *not* to purchase an HFCV, and therefore offered no insights into the important considerations of those who *did* adopt an HFCV over available alternatives.

While surveys distributed to potential or known AFV adopters can help to better understand the vehicle adoption process, there are limitations involved with using this methodological approach on a population about which little empirical data exists, such as the HFCV market. For these reasons, we use a qualitative method of employing open-ended interviews with respondents known to have purchased or leased an HFCV in California, then applying structured text analysis of the transcripts. The initial population of HFCV adopters thus provides more in-depth information about their decision-making processes that a survey could miss. Using this approach, we can compare the list of factors identified by previous research to the more comprehensive set of prominent factors identified by the early adopters of HFCVs at this crucial early stage of the HFCV market.

METHODS AND DATA

We interviewed 12 HFCV drivers in the greater Los Angeles area. We selected the Los Angeles area for participant recruitment for its large concentration of HFCV drivers. We recruited participants via Facebook groups designed for HFCV drivers and enthusiasts with ~1,000 and ~400 members, respectively. We selected a non-probabilistic, purposive sample who: responded to our call for participants; lived in the region; had taken possession of their HFCV; and were available during June 5-12, 2018. Our sampling strategy suffices for the collection of cultural data to be analyzed qualitatively (*57*), and methodological literature suggests that 12 respondents—purposively sampled in a relatively homogenous population and interviewed on a focused topic—suffices to generate primary themes (*56, 63, 64*).

The California Vehicle Rebate Program (CVRP) reports education and income demographics of HFCV drivers who applied for a rebate (*58*). Approximately 45% of HFCV drivers attained a post-graduate degree, ~38% attained a bachelor's degree, and ~16% did not attain a bachelor's degree; our participant population reports 50%, 33.3%, and 16.6% for those respective categories. The CVRP reports ~31% of HFCV drivers with household income >$200K, ~41% between $100K and $199K, 14% <$100K, and 10% declining to answer; our participant population reports 33.3%, 33.3%, 25%, and 8.3% for those respective categories. See Table 1 for a demographic breakdown of our sampled respondents.

Our interview protocol explored how participants made the decision to purchase or lease a HFCV. We conducted cognitive pre-testing (*59*) in Phoenix, Arizona with BEV and CNG vehicle drivers to ensure that the questions were appropriately framed. We directed participants to focus on their thoughts at the time of purchase. The interview was semi-structured with open-ended questions asking the respondent to discuss their considerations preceding HFCV ownership. Each interview started with a grand tour question (*60*) that asks the respondent to walk the interviewer through their decision-marking process. We included geocoding of hydrogen refueling stations that they considered using regularly, key travel locations, and anticipated driving patterns when making the decision to acquire the HFCV, though analysis of this data is not presented in this article. Our primary focus here is understanding the set of factors of greatest importance to the decision-making process of a known population of initial HFCV adopters. Whenever respondents began to discuss post-decision experiences, the interviewer redirected respondents to focus on experiences prior to purchase or lease.

A PhD student trained in ethnographic interviewing conducted all interviews at places of the respondents' choosing. Participants received $35 gift cards for their hour-long time commitment. All study materials and incentives were approved by the Arizona State University Institutional Review Board.

Interviews were audio recorded, professionally transcribed, then analyzed using thematic content analysis. 14 codes were derived deductively from existing literature on HFCV adoption; two codes—Immediacy and Future Viability—were inductively derived from the interviews. The final codebook included 16 themes (Table 2) and cites sources by which codes were deduced, but is too large to include in total. We iteratively revised the codebook using a 10% sample of the interviews until a sufficient interrater reliability was reached (Cohen's Kappa > 0.7). Cohen's Kappa is a statistical measure of agreement that accounts for potential interrater bias by measuring observed agreement against the possibility of agreeing by chance (*61*). We coded the full interviews at the sentence level. The patterns that emerged during this coding process form the basis of our analysis and are discussed below.

RESULTS

Table 2 reports the percentage of respondents who mentioned each code in discussing their decision-making process prior to purchasing or leasing an HFCV. Three factors: refueling infrastructure, costs, and comparisons to other vehicles, were mentioned by 100% of respondents. HOV lane access was mentioned by 25%, significantly less than the next lowest codes. Environmental concerns were discussed explicitly by only 75% of respondents—lower than expected. Below, we discuss nuances of how respondents considered the coded concepts. Our discussion of these results is divided into three thematic categories. First, we explore how respondents characterized the suitability of an HFCV for themselves and vice-versa. Second, we discuss how respondents assessed refueling infrastructure network configuration and accessibility. Finally, we consider how respondents compared HFCVs to BEVs and PHEVs.

The "Fit" Between Vehicle and Driver

As expected, drivers frequently discussed whether vehicle characteristics met their needs. Almost as frequently, drivers framed the discussion as whether they and their household were a right match for the car. Drivers often discussed these factors in tandem.

Cost-Benefit of Environmental Impact

Concern for the environment was a primary motivator to acquire an HFCV for most respondents.

The decision to purchase a HFCV was sometimes framed as HFCVs being the environmentally friendly option that made financial sense for them. Several respondents commented that the real value of the car exceeds the car's sticker price and monthly lease payments. Many respondents calculated the lifetime costs of having a vehicle given state and federal rebates, free fuel, and free maintenance and concluded that the car would effectively cost the same or less than a luxury vehicle or a different AFV. A few respondents indicated that the cost would be slightly more than other options they were considering; these respondents were willing to pay more to support the HFCV market. One respondent noted, "Even with the free fuel, I could've gone and gotten the most economical to drive a car, a Toyota Prius or something like that. I wasn't as interested in that. I was willing to pay a little bit extra to help drive this technology."

Three respondents did not explicitly describe environmental concern as a factor in their decision making, though environmental concern could be inferred. One respondent, while describing the cost of the vehicle, said "I'm happy that there's a benevolent side effect of the choice of vehicle that I made, but let's say that it didn't have that benefit, I don't think it would change my willingness to buy the car." The other two reported a desire for a "non-gasoline" or "efficient" car, but did not frame this desire explicitly within an ecological worldview.

Interest in Hydrogen Technology

Several respondents reported long-standing interest in hydrogen fuel cell technology as their primary motivation. Respondents noted learning about fuel cells in *Popular Science* during the 1970s oil crises, knowing about NASA's fuel cell usage, and constructing a model HFCV with their son. These respondents periodically checked the state of fuel cell technology and were excited to own a HFCV. Other respondents described themselves as avid early adopters of new technology and cited innovation as an impetus to drive an HFCV. These drivers frequently envisioned themselves as champions of the new technology. One respondent was disappointed when their Hyundai Tucson was delivered without "Powered by Hydrogen" decals seen on the prototype and requested that the decals be added on, saying "we wanted to be noticed. We wanted to be asked questions. That was part of the whole reason we did it."

Vehicle Trust and Performance

Previous experience with the brand of the vehicle was important to some respondents. One driver noted, "Since we've been Toyota buyers for a long time, we also felt there's confidence in knowing that Toyota's gonna be behind you." Another respondent discussed learning of HFCVs because they were only looking at Toyota vehicles.

Alongside brand, vehicle performance was a feature discussed by some drivers who cited the "smooth," "peppy," or "quiet" drive as an attractive feature of the vehicle; others described drive quality as "just this side of tolerable." About half of respondents had already made a tentative decision to purchase the vehicle before test driving it, and most described performance as a secondary consideration. One driver, however, described it as a primary motivator, saying "I wasn't really that interested, but … when I test drove it, that's when I said, 'Oh my God. This thing is really good.'"

Interaction with Other HFCV Drivers

For several drivers, word-of-mouth communication with earlier HFCV adopters or seeing HFCVs in their neighborhood helped establish trust in the technology. One respondent stated, "My sisters next door neighbor had one and he goes, 'you wanna drive it?' … That kinda put me over the edge. Then asking him all the questions, you know? As opposed to the Toyota sales

guy." These conversations supplemented independent research that drivers were doing, and are coded under evidence of an "Existing Market" for HFCV vehicles. While all of our respondents were recruited from Facebook groups, none of them discussed using social media to communicate with other drivers *prior* to their purchase.

Family Structure

One characteristics of themselves that drivers frequently discussed was their family structure, such as being single or having adult children. This driver characteristic was framed as reducing the impact of the smaller carrying capacity due to the HFCV's hydrogen tanks. One respondent noted, "A few years ago, if I had to haul baseball equipment around, all that stuff, it would've been pretty tight, kinda undoable. Now that it's more just me, it was an easier decision." The Toyota Mirai's split back seat was problematic for other drivers with children. Discussions of family structure were never framed as primary motivators.

Employment

Similarly to family structure, employment conditions factored into whether an HFCV would work for them. Two respondents—both earning over $200K in household income—noted that their work required a significant amount of driving, and thus HOV access motivated their purchase: "I needed to get in the carpool lane to shorten my commute because I hate to commute. That got me looking into fuel-cell cars in general because [the California Department of Transportation and CARB] had really restricted carpool lane access...The other classes of vehicles wouldn't work for me at my level of income."

Two retired respondents said that not having a job meant fewer trips and greater flexibility to refuel when convenient. One noted that "at the time that I purchased the car, we had a meeting of people who were on the list to take delivery of Mirais, and the majority of them were retired." Retirement was characterized as an attribute that made HFCVs feasible, but not as a motivator to purchase or lease.

Individual Driving Patterns

As the previous respondent noted, drivers' driving patterns played a key role in whether an HFCV could meet their needs. For one respondent, regenerative braking was a motivation to adopt an HFCV because their commute involved numerous hills that induced extreme wear on ICE vehicle brakes. Most often, commutes and driving patterns were discussed in relation to driving range and whether the vehicle had a sufficient range for their needs. What constituted a sufficient range varied according to characteristics of the driver.

One such characteristic was the driver's geographic activity space. Drivers with a large activity space sought out the longer driving range of an HFCV as compared to available BEV ranges. Some respondents indicated that they personally lacked range anxiety, making them a good fit for an HFCV. Other drivers with smaller activity spaces still preferred the longer HFCV driving range to avoid frequent refueling compared to the frequent recharging of a BEV. Two drivers cited driving range as a primary motivation for pursuing HFCV ownership.

Secondary Vehicle Availability

Ten of the twelve respondents had at least one back-up vehicle when they made their purchase, including three of the four respondents living alone. Several respondents framed the back-up vehicle as a prerequisite for HFCV ownership. As one driver noted, "there's a few people that it's their only vehicle. If a station is down they're [without recourse]. I don't think I ever would have

put myself in that position." Respondents anticipated using their other vehicles or renting a vehicle for long-range travel or carrying large loads, and reserving use of the HFCV for commuting to and from work.

Experience with Planning Refueling

Several drivers discussed refueling practices resulting from previous experiences as personal characteristics that made them a good fit for HFCVs. Some described a refueling routine, with one respondent saying, "even when I didn't have a fuel-cell, I planned my trip to the gas station. I know what day I was going to do it to schedule around it, so it was convenient for me regardless of where my gauge was." Other drivers described refueling at every opportunity. A few drivers described how experiences managing fuel amid limited refueling infrastructures while piloting small planes, driving in the rural Midwest, and driving other AFVs made them a good fit as an early HFCV driver. Ability to deal with the limited hydrogen refueling infrastructure was always discussed as a reason that the driver was a fit for the vehicle, but never as a motivator for seeking a HFCV.

Refueling Infrastructure

Refueling infrastructure limitations were a frequent discussion point in each interview. Respondents had different criteria for what made the hydrogen refueling infrastructure sufficient for consideration of an HFCV purchase. Respondents discussed station locations in terms of temporal and spatial convenience to home, work, or driving routes.

> "I have three or four... Not too far away from me."
>
> "At that time two years ago there was probably less than 20. There was nothing close to my home. Everything was in my work area."
>
> "This station, you just come right down. I join the 405. I go up one exit, get off, and I get right back on and then they have the carpool lane."

Drivers characterized convenience across a broad range of times and distances, from a "three to five minute" detour from their normal commute to "thirty, forty minutes" as "not a big deal." Several respondents decided to purchase an HFCV with no refueling station within their definition of close proximity, anticipating that a station would soon open. One respondent stated, "there's one gonna be opening in Burbank, supposedly, this year… okay, I can go to these other places for a year or six months, or however long it takes."

Seven respondents indicated that they needed to have at least two stations near their home or work. Drivers often indicated this as a requirement: "if one goes down—and they go down—then you need to have a backup." Some respondents described the anticipation of access to a second station as sufficient, while others chose to lease their vehicles due to the uncertain status of future infrastructure. Others were unaware when they bought their HFCV that stations are not always operational.

Choosing an HFCV over BEVs or Hybrids

Interviewees commonly compared HFCVs to BEVs in terms of their personal fit or the wider market. Personal comparisons focused on issues such as the limited range of BEVs, the differences in refueling versus recharging times, purchase price (specifically in comparison to

Tesla), and whether their living situation was conducive to setting up home recharging for a BEV.

Several respondents noted similar issues, but focused on their concerns with the BEV market writ large. One respondent said:

> "If I wanna drive from here to San Francisco, stay within speed limits, I'll race all of the Teslas there are, 'cause they're gonna have to stop for at least an hour-plus on the way, where I would have to stop for five minutes. I think the future will be fuel cell cars to a vast majority. People that live in crowded apartments where they don't have access to overnight charging themselves—a fuel cell car would be far superior for their needs. They need to have some place to recharge it that doesn't consume their time."

Other issues cited by respondents included battery disposal, complications in installing home BEV chargers, cost of hydrogen fuel, and battery size and range. Respondents who discussed the limitations of the BEV market also opined that there is a future for BEVs but that they are not the only viable zero emission vehicle. Some respondents saw their early adoption of HFCVs as supporting a diverse ecosystem of zero emission vehicles.

Eight respondents discussed consideration of PHEV options. Reasons against PHEV ownership included: environmental concerns associated with gasoline usage; costs of the vehicle or gasoline; availability of PHEVs that suited driver criteria; and poor drive quality due to ICE noise and vibration.

LIMITATIONS

This study's methodology entails inherent limitations that may have influenced our results. The one-hour time window for interviews limited us from exploring all branches of conversation in depth; we mitigated this by asking respondents to highlight their most important factors. Second, the semi-structured format of our interviews did not allow for asking respondents an exact sequence of questions, and limits quantitative comparison of respondents. Third, recruitment of respondents was limited to drivers who are members of the Facebook groups where we posted about our study, and who were willing to discuss their decision making processes. Our small sample, however, was fairly consistent with the education and income levels reported for the entire population of CVRP applicants (*60*). Fourth, since all of our respondents are over 45 years old, age-dependent factors such as employment or family structure may have greater import to the adoption decision by younger adults than reflected in our sample. Fifth, our findings may be most reflective of early adopters of technology, rather than of potential future adopters of HFCV.

CONCLUSIONS

The future HFCV market has long been a subject of interest in the AFV adoption literature. Stated preference approaches that ask people to consider adopting HFCVs have consistently found that vehicle characteristics and cost, personal attitudes about the environment and technology, and the hydrogen refueling infrastructure are crucial considerations. These topics received substantial attention in semi-structured interviews with 12 early HFCV adopters in the greater Los Angeles area, though other novel insights emerged that carry implications for future policies aimed at enabling more widespread HFCV adoption. All of our respondents discussed costs and refueling infrastructure, and compared HFCVs to other vehicles, especially BEVs. While HOV access has been an oft-cited incentive to adopt an HFCV, especially in this region, only three mentioned HOV lane access.

While environmental consciousness is an important component of decision-making process, respondents viewed HFCVs as a cost-effective method to adopt a green transportation technology. Policies for the promotion of HFCVs may function most effectively by keeping the vehicles as cost-competitive as possible while enabling early adopters to be prominently visible in their communities as champions of a novel and environmentally friendly technology. The stated motivations for HFCV adoption varied widely. Therefore, strategies that assume a common predominant reason why people adopt HFCVs may be limited in efficacy. Additionally, the simultaneous consideration of the vehicle as a good fit for the driver and of the driver as a good fit for the vehicle warrants further attention, as this conceptualization was consistently noted by respondents but is not often framed in this way in the HFCV adoption literature.

There are notable implications for future refueling infrastructure planning. Different drivers defined convenient locations in terms of proximity to home, work, and driving routes. Therefore, station location planning methods should more prominently consider the stated desire to have a "back-up" station in a similarly convenient location to their home or work as a means to encourage more people to make the decision to purchase or lease an HFCV.

Our respondents viewed HFCV and BEV competition for ZEV market share through personal and societal lenses. Early HFCV adopters consistently viewed themselves as integral to the longer-term success of HFCVs and as prominent champions of the technology. While other literature has studied reasons for choosing BEVs over HFCVs, our respondents cited driving range, refueling time, and cost—at least compared to Teslas—as reasons they adopted an HFCV. Nevertheless, they envision a future in which both ZEV technologies compete, innovate, and thrive.

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TABLE 1 Characteristics of Sampled Drivers

Category	% of Respondents (n = 12)
First HFCV Leased / Purchased	
Toyota Mirai	58.3%
Honda Clarity	33.3%
Hyundai Tucson	8.3%
Year of First HFCV Lease / Purchase	
2014	8.3%
2015	8.3%
2016	25.0%
2017	41.7%
2018	16.7%
Lease or Purchase	
Lease	
Purchase	
Previous AFV Ownership	
Yes	41.7%
No	58.3%
Second Vehicle Available	
Yes	83.3%
No	16.7%
Age	
45-49	33.3%
50-54	25.0%
55-59	8.3%
60-64	16.7%
65-69	16.7%
Household Income Brackets	
< $49.9K	8.3%
$50K – $74.9K	0.0%
$75K - $99.9K	16.7%
$100K - $149.9K	25.0%
$150K – $199.9K	8.3%
> $200K	33.3%
Prefer not to answer	8.3%
Education	

High School Diploma	8.3%
Associate Degree	8.3%
Bachelor's Degree	33.3%
Graduate Degree	50.0%
Gender	
Man	10
Woman	16.7%
Race / Ethnicity	
Asian	16.7%
Hispanic	8.3%
White	75%
Political Leanings	
Very Conservative	0.0%
Conservative	16.7%
Moderate	25.0%
Liberal	33.3%
Very Liberal	16.7%
No Opinion	8.3%
Children < 18 y.o. in house	
Yes	41.7%
No	58.3%

TABLE 2 Code Definitions

Code	Definition	Exemplar(s)	Kappa	% Occurrence (n = 12)
Comparison to Other Vehicles	This code includes discussion of the relative advantages and disadvantages of HFCVs compared to non-HFCVs and always co-occurs with codes describing the aspect being compared.	"It's a very nice car and has all the latest safety features on it. It's a lot more advanced than the Toyota Rav4 BEV was, so I thought I would balance all that. I balanced the inconvenience knowing that I was saving money due to the rebate, due to the fuel reimbursement, and having a nicer, safer vehicle that holds five people, just like the RAV4 did."	0.868	100%
Cost	This code includes all	"It really came down to what my perceived monthly total cost of	1.000	100%

	discussion of cost as both a barrier and a motivator, including purchase price, maintenance costs, and fuel price.	ownership was for the vehicle. I back in, or I had the lease payment. I had the tax and the lease payment. Free fuel comes in super heavily at this point in the equation. I was more or less able to justify financially, that was the big swing." "I love being green, but I love saving green."		
Refueling Infrastructure	This code covers consideration of hydrogen refueling stations, in terms of their geographic distribution, availability, convenience, and amenities.	"When I knew that the station was there, and they were trying to convert it into a retail location, that was like, okay, I can go to these other places for a year or six months, or however long it takes. There's gonna be one in Burbank, and that's super convenient for me."	0.897	100%
Other Vehicle Available	This code covers discussion of other vehicles available to the household, including rental cars but excluding public transit and taxis/ride sharing.	"I think that [being retired] may have also played a role in the decision. 'Cause I kept my [PHEV] so I do have a back-up and also I have a long-distance, out-of-state vehicle."	0.775	91.7%
Range / Travel Needs	This code include references to the driving range of HFCVs and the range needs of the driver.	"That's why the Mirai seemed to fit the bill that I wanted. You could spend about five minutes to fill it up and give you a 300 mile range."	1.000	91.7%
Vehicle Characteristics	This code refers to all attributes and amenities of the vehicle that are independent of the fuel type (except handling,	"When I drove it, I was fascinated about how smooth the car was."	0.901	91.7%

	noise, and smell).			
Immediacy	This code covers time sensitive factors that lead the respondent to need to acquire a new vehicle.	"We were way overdue to get a car. We were dragging our feet."	0.905	75%
Environmental Concern	This code refers to people discussing environmental concern or pro-environmental attitudes as a motivator for HFCV purchase.	"To go fuel cell I would say, yeah, the biggest factors were driving something more climate friendly [than an ICE sedan] was about the first thing that started getting me thinking about it." “I love being green, but I love saving green.”	1.000	75%
Future Viability	This code refers to respondent’s concerns or comfort with the future of the HFCV market	"I knew I wanted to lease my car because who knows what the politics, and the fueling infrastructure, if three years down the road from the time I leased it, if I was still going to be able to fuel it. If it was going to be more difficult to fuel, because the, the infrastructure didn’t take off or anything else like that.”	1.000	66.7%
Other Incentives	This code covers all financial and non-financial incentives that are used by governments and non OEM/dealership corporations (with the exception of HOV lane access) to encourage HFCV purchases.	"[My son] told me about this car. I didn't want to lose out on the rebate and all of the incentives of this car."	1.000	66.7%
Sales Staff	This code focuses	“I contacted all three companies.	0.813	66.7%

	on interactions with dealership sales staff—both positive and negative—before and during the purchase process.	I didn't hear anything back from Hyundai—I think it was for four months after I asked them."		
Existing Market	This code refers to the influence of multiple aspects of the existing markets of HFCVs at time of purchase, including seeing HFCVs on the road or hydrogen refueling stations and interacting with HFCV drivers.	"[A friend] is driving one and he mentioned when we were hanging out one night, he's like yeah, I got this car. I had seen the Toyota online but ruled it out as not practical…then we started talking about it and it got me interested."	0.867	58.3%
Knowledge of Hydrogen	This code focuses on the respondent's knowledge of hydrogen and its properties (but not the environmental impacts of hydrogen).	"[My husband] got it [a fuel-cell mini car] for our son, and he put it together. You put the water in it, you have a little solar thing, you put the water in it, and it cracked [water into H_2 and O_2]."	0.789	58.3%
Refueling Time	This code includes comments on the length of time is takes to refuel a HFCV	"The time it takes to charge a car would've been a very big factor for me. I would not want to have had to depend on plugging in a car outside of my home to charge it. There are a lot of access to charging almost anywhere. Big department stores have them also. The people using them use that spot for literally hours, whereas the hydrogen fueling stations, the people use that pump literally for five minutes,	1.000	58.3%

		and they're done. Compare that to a charging -- let me just make a parallel just quickly in my head...You'd need 24 charging stations and parking space if you were doing 2-hour charges on cars to match what you could do with a single pump at a hydrogen station. You could fill up the same number of cars in two hours."		
Status Symbol	This code focuses on the driver's perceptions of owning a HFCV as a symbol of tech savviness, intelligence, or economic position (but not environmental friendliness)	"We were going to continue rolling with the full electric and that's -- but then also, I love the new technique. I love to get all the latest stuff, so I had one of the first TiVo's and we had one of the first electric cars in the United States."	1.000	58.3%
HOV Access	This code focuses on gaining HOV lane access via the Clean Air Vehicle (CAV) program as an incentive to purchase a HFCV.	"I'd seen an ad on TV and it sounded interesting 'cause primarily motivator was the HOV sticker since I drive so much."	1.000	25%

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