University of Nevada, Reno

The Road Beyond Early Adopters: An Analysis of the Experiences of Hydrogen Fuel Cell Drivers in California

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geography

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Abstract

This thesis focuses on hydrogen fuel cell vehicle (FCV) drivers experiences with the refueling infrastructure and vehicle, after initial adoption, to provide insight into their potential continued use of the vehicles. The recent growth in the California FCV market offers the opportunity to analyze how stations that drivers use after some experience compare to those they initially intended to use. The first part of this thesis uses data collected from an online survey completed by 124 FCV adopters in California in early 2019. Respondents listed stations they initially planned to use, stations that they later used, reasons for using them, and important travel destinations. Results show that 40% of respondents changed refueling stations, and in these cases their primary station was farther from home, work, and/or their commuting route than for those who did not change stations. Results indicate differing reasons for FCV divers to add stations over time, and that a mixture of geographic and station-level characteristics influence this outcome. Building from this study, the second part of this thesis assesses the varied nature of drivers' experiences and if this sample of FCV drivers would be willing to continue using their vehicles. Semi-structured interviews were conducted with 16 of the drivers who previously took the online survey. This research helps to understand how U.S. FCV drivers' opinions of the vehicles and their supporting infrastructure have changed since adoption. Drivers revealed that they are willing to re-adopt an FCV but many have concerns about the growing congestion at stations due to the growth in FCV sales. Additional reliable stations that are located in a safe area and are easily accessible would be beneficial for these FCV drivers and may also help incentivize others to adopt the vehicles and advance this pathway towards a more sustainable transportation future.

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Chapter 1 Introduction

Introduction

There is now a near-consensus in the scientific community that anthropogenic activity has contributed to an increase in greenhouse gas (GHG) emissions into Earth's atmosphere, which has resulted in a steady warming global climate. While contributions come from a variety of sources, fuel use in the transportation sector has been a key contributor to this activity. Within the United States (U.S.), transportation is responsible for 29% of the total U.S. greenhouse gas emissions, which is the highest among all economic sectors (EPA, 2019a). The transportation sector consumes the highest amount of petroleum, accounting for almost 14 million barrels per day in 2018 within the U.S. (EIA, 2019). Consequently, the transportation sector is a priority area to address when creating ways to mitigate GHG emissions (EPA, 2019b).

Encouraging greater use of public transit and building pedestrian and bicycle-friendly environments can help to reduce GHG emissions from the transportation sector, along with improvements in fuel economy. However, the persistence of the automobile and the cost that has been devoted to its supporting infrastructure means that personal vehicle travel will be an important component of any near-term transportation future and must therefore be taken into account by politicians and regional agencies when considering future policy. Decarbonizing the fuel or energy carrier required for personal travel is therefore an essential component of any comprehensive strategy that aims to reduce GHG emissions from the transportation sector. The more widespread use of alternative fuel vehicles (AFVs) is an important and feasible pathway to achieve this because they allow options for personal vehicle usage, but in a less carbon-intensive way.

AFVs include those that operate with compressed natural gas (CNG), hydrogen, liquid biofuels, and both plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), all of which have lower tailpipe emissions than conventional cars and trucks that operate with liquid petroleum fuels (Chapman, 2007). Table 1 provides a list of common AFV acronyms as well as other abbreviations used throughout this document.

Table 1 Document Acronyms

Acronym	**Meaning**
AFV	Alternative fuel vehicle
ZEV	Zero emission vehicle
FCV	Fuel cell vehicle
EV	Electric vehicle/Battery electric vehicle
BEV	Battery electric vehicle
PHEV	Plug-in hybrid electric vehicle
CNGV	Compressed natural gas vehicle
GHG	Greenhouse gas
TOP	Time of purchase
TOS	Time of survey

Most promising to reduce greenhouse gas emissions from passenger vehicle travel are zero-emission vehicles (ZEVs), which prominently include hydrogen fuel-cell vehicles (FCVs), BEVs and PHEVs. The market share of these vehicles has grown steadily in the United States in recent years (“Alternative Fuels Data Center”, 2019). In contrast to the growing literature on electric vehicles (EVs) adoption, this study focuses on FCVs, which are beginning to play a more prominent role in the state of California, which is the only place in the United States where these vehicles are available to the public. FCVs have zero tailpipe emissions beyond water, which mitigates the negative effects of conventional vehicle exhaust and offers potential health and climate benefits (Jacobson et al., 2005). There are currently three models of FCVs on the market: the

Toyota Mirai, the Honda Clarity, and the Hyundai Nexo. These vehicles offer drivers a refueling time of less than five minutes and a range of about 300 miles, which is comparable to conventional gasoline or diesel vehicles. The vehicles were first offered to the public in the fall of 2015, and though there are now over 8,200 FCVs on the road in California, this number is still extremely low compared to conventional vehicle sales (CAFCP, 2020).

Drivers are able to purchase an FCV or sign a 3 year lease, depending on the vehicle. The Honda Clarity is only available for lease, while the Toyota Mirai and Hyundai Nexo are available for both purchase and lease. (“NEXO Fuel Cell”, n.d., “Toyota Mirai – The Turning Point”, n.d., “2020 Honda Clarity Fuel Cell”., n.d.) FCV drivers are eligible for up to $15,000 of complimentary fuel, a $5,000 rebate and an HOV sticker. Increased adoption of these vehicles would help mitigate some of the negative impacts of greater relative shares of sales of conventional vehicles. Understanding early adopters’ considerations of FCVs after experience, may help develop effective marketing and roll-out strategies in other states to appeal to a broader audience, and this is especially true for understanding barriers to adopting them. Additionally, to continue increased adoption rates, understanding these considerations may also help the success of a transition to FCVs beyond initial adoption and offer new information beneficial to help inform the use of existing station planning methods, or modify them appropriately.

It has been hypothesized in previous research that one of drivers’ top considerations when adopting an FCV is inherently geographic in nature: studies have consistently noted that the lack of a convenient refueling infrastructure is the primary barrier to consumer adoption (Melendez, 2006). Stated preference approaches have also found that drivers express a desire for stations near home, work, and on their commuting route in order to feel comfortable adopting the vehicle (Kitamura and Sperling, 1987; Ramea, 2019). While these are helpful in understanding the kind of station locations that drivers would consider to be convenient and may influence their decision to adopt the vehicle, little is known about how this is translated to observed behavior after some experience with the vehicle and what the implications are for geographically-informed station location planning strategies that encourage widespread adoption.

There are a host of different models that have been developed to recommend potential station arrangement strategies that encourage people to adopt AFVs, including FCVs. Most prominent are facility location models, along with discrete choice models using sales forecasts of AFVs, both aimed at researching refueling network options (Green et al.,2008; Guerra et al., 2013; Hodgson, 1990). Green et al., (2008), used a sales forecast model that approached infrastructure choices by focusing on areas that are convenient to consumers and provide the support they need for maintenance. On the other hand, point based facility location models such as the *p*-median approach cluster stations near likely home locations of early adopters (Nicholas and Ogden, 2006; Ogden and Nicholas, 2011). Specifically, these focus on reducing the average distance from home locations of likely early adopters to respective refueling stations.

Flow-capturing approach models, in contrast, represent refueling demand as travel paths instead of proximity to home, and are structured to maximize capturing passing traffic flow at stations. Kelley and Kuby (2013), found empirical evidence for the application of the flow-capturing approach for locating AFV refueling infrastructure by concluding that reducing travel time from home is not as important to compressed natural gas (CNG) drivers as reducing trip deviation. CNG drivers in Southern California revealed they prefer to refuel on the way versus close to home with a 10:1 margin (Kelley & Kuby, 2013;2017). This signals that the logic behind the flow-capturing models may be best when recommending station locations, but a number of uncertainties remain. The observed drivers were reacting to a sparse infrastructure of stations in the Los Angeles area, but no information was collected about where those respondents lived and worked at the time they purchased the vehicle. While they currently did choose to predominantly refuel at stations that were conveniently on the way between observed origins and destinations, it is possible that having a station near home, work, or some other key activity site played a large role in the decision to purchase the AFV.

After some experience with the vehicle in limited refueling infrastructure, station considerations may change from the time a driver decides to adopt the vehicle, and this is a critically understudied research area that has implications for future station planning strategies. In addition to the geographic proximity of stations to important travel destinations, it is also unclear to what extent station-level considerations such as reliability, amenities, and congestion become more or less important after experience with the vehicle, and how these interact with the spatial considerations. More generally, opinions of the new vehicle technology after experience driving are relatively unknown, and an important aspect of the continued use of these vehicles. It is possible that drivers have changed their opinions of FCV ownership and refueling stations after some time with the vehicle, and these factors are likely to influence the persistence of these vehicles in the personal vehicle fleet. Understanding these key factors are important to future AFV adoption and roll-out strategies, marketing, policy development, and sustainability-related goals.

Weyant (2010) refers to the “valley of death” as a metaphor that describes ideas from research laboratories failing before they make it to the marketplace. Understanding drivers continued use of FCVs is an attempt at sustaining this new vehicle technology past initial adoption, in an effort to provide information and help move FCV adoption beyond initial adoption, through the “valley of death”, and to sustained adoption. Therefore, this thesis asks the general research question: **What can we learn from early adopters of FCVs after they gain experience with the vehicle?**

To provide insights into this broad question, this thesis consists of two distinct but related research studies. Chapter 2 (Krafft et al., 2020, in review) is the result of an effort to provide more insight on how FCV drivers’ station choices and considerations change over time. This study specifically analyzes to what extent drivers change stations from when they planned to purchase or lease the vehicle to after some initial experience driving and refueling. Drivers’ stated reasons for using stations and the revealed spatial relationships of these stations relative to their home, work, commuting routes, and other location types was taken into consideration.

To collect this data, an online survey was distributed to 124 FCV drivers in California. The survey asked respondents to list stations they initially planned to use, stations that they later used, reasons for using them, and important travel destinations. Results show that 40% of respondents changed refueling stations. These respondents’ primary station was farther from home, work, and/or their commuting route compared to those who did not change stations. Stations that respondents added to their lists after experience were farther from home than those they initially intended to use. Both the station reliability and station amenities were significant reasons drivers indicated for using their primary station after experience at the time of the survey.

Respondents also provided a number of open-ended comments in the survey instrument that suggest personally-important reasons why they no longer use certain stations, and signal some of the limitations of the survey-based approach in Chapter 2. Reasons drivers gave for no longer using a certain station included: New stations opened (7), The station was planned but never opened (6), Not convenient (5), Fuel price too high (5), Unreliable (5), Crowded (3), Station layout (3), and it was a backup station (3). Reasons such as “Not convenient”, “Station layout”, and “Crowded” suggest that other stated reasons aside from the options provided in the survey were important station considerations for respondents who changed stations.

In addition to illuminating other important considerations listed by drivers that the survey instrument may have missed, these questions were also helpful for creating follow-up questions for future interview purposes that prompted drivers to reflect on their experience with the vehicle and with the refueling infrastructure (Chapter 3). Chapter 3 focuses on a sample of drivers’ experiences with the refueling infrastructure and their fuel cell vehicles. This chapter aims to provide insight that informs this research question: After experience, what are FCV drivers’ top considerations for the continued use of this technology? This can provide valuable information on whether or not this sample of drivers is willing to continue using their vehicles now that they have moved past initial experience, and if the drivers have concerns regarding this new transportation infrastructure and technology. These findings can help provide recommendations to move FCVs beyond initial adoption and towards sustained use.

To understand driver's considerations after experience, semi-structured interviews were conducted with 16 of the drivers who previously took the online survey from Chapter 2. Participants were asked about their experiences with both their FCV and the refueling infrastructure. Discussions revealed that they are willing to continue to use an FCV but many have concerns about the growing congestion at stations due to the growth in FCV sales. Additional reliable stations that are located in a safe area and are easily accessible would be beneficial for these FCV drivers and may also help incentivize others to adopt the vehicles and help advance this pathway toward a more sustainable transportation future.

Chapter 2:
Hydrogen Refueling Station Consideration and Driver Experience in California

Introduction

By the end of January 2020, over 7,900 hydrogen fuel cell vehicles (FCVs) had been sold or leased to California residents, nearly doubling the state's total since the beginning of 2018 ("CAFCP", 2020). Over 40 retail hydrogen refueling stations and 21 additional planned stations support the growth in FCV adoption and the emergence of an FCV "business ecosystem" (Alternative Fueling Station Locator, n.d.; Lu et al., 2014). Regions such as the Northeast US are following California's lead in developing plans for station networks, and lessons learned from how early adopters assessed California's network of hydrogen stations will be helpful in this process. With the first wave of FCV leases nearing their end, understanding changes in drivers' station preferences and refueling behavior over time can be beneficial to developing strategies to encourage FCV market growth. Considering both drivers' preferences at the time of purchase and after some experience is important for the initial adoption and the continued use of FCVs.

Previous work on how to locate stations to encourage adoption hypothesized that potential FCV drivers would primarily need stations conveniently located near their home or work or along their commuting route in order to adopt an FCV which is corroborated by a recent California survey of FCV drivers (Kitamura & Sperling, 1987; Kuby & Lim, 2005; Ogden & Nicholas, 2014; "2018 Annual Evaluation", 2018) Others noted that convenience to other activities may also be important for refueling decisions once they have the vehicle (Kang & Recker, 2015). These perceptions and spatial relationships, however, may change after some initial experience with an FCV, and it is unclear to what extent station-level considerations such as reliability, amenities, and congestion change in importance. With new hydrogen stations opening, FCV drivers' travel activity may have expanded. This period of time in the California hydrogen station network development provides an opportunity to study these changes and preferences.

In this study, we ask the general research question: to what extent do early FCV adopters change the list of stations they intended to use when they first adopted their vehicle? Additionally, we ask: how do spatial relationships of listed stations' proximities to home, work, and frequently used routes compare between drivers who changed refueling stations since the time they purchased the vehicle and drivers who did not, and do stated reasons for listing stations change? We also determine if drivers add stations to their list that they did not initially consider, and analyze how these stations differ in their revealed spatial relationships between home, work, and frequently used routes, along with stated reasons drivers list them, relative to others they initially listed. To address this, we distributed a web-based survey to a sample of FCV adopters in California in early 2019, asking drivers when they decided to adopt an FCV, which stations they intended to use at that time and why, and the stations they now use and why. To address our research questions, we conducted proximity and deviation analysis using network GIS, and analyzed the survey data and GIS results with descriptive statistics, t-tests, and two binary logit models.

Before adopting an FCV, drivers in urban areas were accustomed to having a nearly ubiquitous network of gasoline stations from which to choose, which meant they had multiple stations that were near home and also on their way to work, shopping, or school regardless of the direction in which they were traveling (Kuby, 2019). We therefore hypothesized that the majority of respondents would list the station nearest to their home as one they intended to use when they adopted an FCV, but after some experience with the vehicle, stations on the way to or near work and other types of locations may become more important.

Literature Review

FCV adoption studies have identified that consumers prioritize the number and spatial distribution of hydrogen refueling stations (Ramea, 2019; Lopez et al., 2019; Zhang et al., 2016; Hardman et al., 2017); their absence inhibits FCV uptake (Melendez, 2006). Studies since have attempted to characterize the convenience of both individual stations and sets of stations on road networks. Many have developed optimization models that locate stations on networks in order to encourage FCV adoption, and implicitly assume certain definitions of convenience when locating facilities: nearness to homes of likely early adopters, minimal travel time deviation from road segments with high traffic flows, or some combination of factors (Brey & Brey, 2014; Mirhassani & Ebrazi, 2013; Nicholas, 2010; Hong & Kuby, 2016; Brey et al., 2016; Stephens-Romero et al., 2010). Most of these models were developed prior to the availability of empirical data on FCV refueling behavior. To overcome this limitation, prior to the construction and consumer usage of a hydrogen refueling network, studies of early adopter preferences for station locations relied on stated preference surveys, analysis of travel survey data, and observations of other AFV drivers' refueling behaviors. For example, surveys suggested that likely adopters would travel up to ten minutes or one mile to refuel (Martin et al., 2009; Lines et al., 2008). Prior to FCV roll-out in California, others found that transitioning to FCVs would not entail a substantial change in travel behavior for those with conventional internal combustion engine vehicles (Kang & Recker, 2014) and that the proposed hydrogen station locations in California would be sufficiently accessible for those who lived in target early adopter areas (Kang et al., 2014).

Compressed natural gas vehicle (CNGV) driver behaviors approximate FCV driver behaviors due to vehicle similarities in refueling time, driving range, station sparsity, and

California context. Studies of these drivers found that both individual and fleet CNGV drivers in Southern California prioritize minimizing deviation along travel paths over refueling near residences or depots (Kelley, 2018; Kelley & Kuby, 2017; Kelley & Kuby, 2013). These studies did not determine how CNGV drivers assessed the existing station network prior to adopting the technology, nor how their behaviors changed after experience with the vehicle. Studies of electric vehicle (EV) drivers demonstrated that drivers alter daily travel patterns to adapt to sparse recharging infrastructure and both use and desire more charging stations at work or near shopping destinations (*26* Woodjack et al, 2012; Philipsen et al, 2016).

While the quantity and arrangement of stations has been a primary focus of attention in the literature, unreliability is the primary reason why FCV adopters in California say they avoid certain stations, particularly with the early stations (Ramea, 2019; Kurtz & Bradley, 2019), which is why early adopters often mention back-up stations as essential when purchasing or leasing an FCV (Lopez et al., 2019). This signals that factors beyond proximity to home, work, or frequently traveled routes may be important when evaluating hydrogen station consideration or use by early adopters.

In sum, it is unknown how the list of refueling stations used by drivers post FCV adoption compares to those they planned to use at the time they decided to adopt the vehicle. For those that do indicate they changed stations, it is unknown what the common attributes of stations are that drivers now use relative to those they intended to use at the time they adopted the vehicle. These are essential considerations for future station network planning.

Methods and Data

An online IRB-approved survey was created using Qualtrics and disseminated to California FCV drivers in early 2019. Survey questions focused on asking respondents which refueling stations they considered and why, both when they decided to adopt the FCV and when they took the survey. In order to participate, respondents had to be a resident of California over the age of 18 and have taken possession of an FCV by purchase or lease.

We recruited respondents through social media and email distribution. Administrators of the Toyota Mirai Owners, Honda Clarity Fuel Cell Owners, Hydrogen Car Owners, and GM Project Driveway Facebook groups permitted us to post recruitment links on their pages. These groups included between 604 and 3,200 members. This recruitment technique effectively advertised the survey to known FCV adopters, though the sample makes results most applicable to those who are involved in these online communities.

Survey Instrument

The survey consisted of two primary sections. The first prompted drivers to think back to the time they initially decided to purchase or lease an FCV and indicate;

- the month and year they did so
- up to five refueling stations they planned to use at that time
- up to three reasons they planned to use each station listed
- their approximate home location and three most important trip destinations using an interactive Google Maps interface embedded in the Qualtrics survey platform which prompted them to place a pin on the map
- their confidence in the list of stations they initially intended to use from the following options: extremely confident, very confident, moderately confident, slightly confident, and not confident at all.

Stations listed could include those currently available or those planned to be built but not yet open. To help respondents recall which stations they had intended to use at the time of purchase (TOP) the survey provided maps of historical hydrogen station availability (**Figure 1)** using quarterly historical AFDC station data ("Alternative Fueling Station Locator" n.d.). All stations that eventually opened by the time of the survey were shown as planned from the beginning of the study period and therefore could have been chosen by respondents. Then respondents were asked to choose up to three reasons for considering each of the stations, a predetermined list that included perceived proximity to a variety of locations (home, work, shopping, school, a social or recreational destination, family or friends, or long distance travel), and station-level considerations (reliability, price, safety, station amenities (e.g., convenience store), hydrogen pressure, or a backup station). Respondents could also select "other," and expand with an open-ended response.

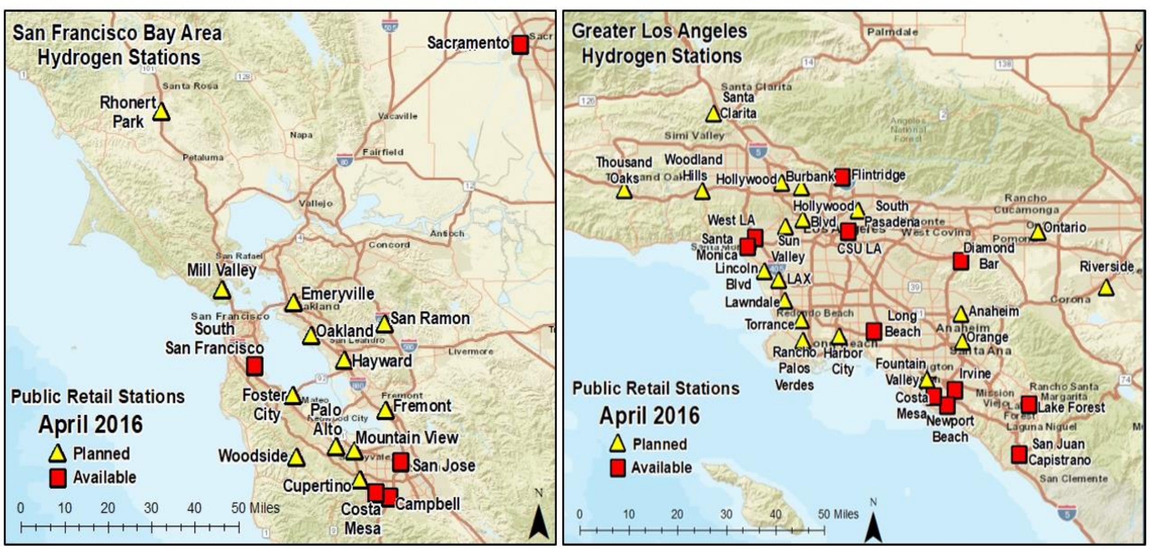

Figure 1 Modified example of a reference map of available and planned hydrogen refueling stations in San Francisco Bay Area and Los Angeles area, April 2016. Similar reference maps for each quarter since 2015 were embedded in the survey instrument, including versions that showed stations statewide not shown on these two maps.

The second section of the survey then prompted drivers to indicate which stations they "currently" used, that is at the time of the survey (TOS). Also if their list of stations *or* reasons for using them changed since they initially acquired their FCV. If so, respondents listed the stations they currently use and reasons for doing so.

Proximity Analysis

Using GIS network analysis, we analyzed the proximity of the stations listed by respondents to their homes and various destinations. All home locations and travel destinations were translated to point data in ArcGIS, along with the historical hydrogen station dataset from AFDC. Then, shortest travel time routes were estimated between all home locations and trip destinations and all available and planned stations, both at TOP and TOS using a detailed street network dataset and the Network Analyst extension. This analysis was automated using Python 2.7 to generate all routes and repeated for all respondents. All estimated routes and travel times were generated from the network analysis under the assumption of free flow travel speeds.

Then, based on the full list of shortest travel time routes to all available and planned stations at TOP and TOS, we evaluated if the stations listed by respondents (in terms of travel time) were 1) the closest station to their home, 2) closest to work, and 3) closest to other listed travel destinations. To account for the uncertainty of network travel assumptions such as congestion or delays, we then considered if their listed stations were one of the three closest to a listed trip destination.

Deviation Analysis

To assess the convenience of stations to respondents' driving routes, we computed the deviation that would be required to travel from home to a listed destination via all potential hydrogen stations. We first generated the direct shortest travel time paths between their home and their three given destinations. Then, each station in California that was either available or planned at TOP was inserted as a stop on a shortest travel time path between home and each given destination for all respondents. This analysis was repeated for all stations available at TOS. To calculate the deviation, we computed the difference in travel time in minutes between the estimated shortest travel time without the station stop and that for the route via the station. Similar to the proximity analysis, we then determined if the driver considered a station that was either the most convenient or among the most three convenient to one of their listed travel destinations at both time periods.

Respondent Station Changes

Of particular interest is the degree to which respondents changed the list of hydrogen refueling stations between TOP and TOS. We use the terms "Changed” and "No Change" to describe these two groups of respondents. No Change respondents have an identical list of stations at TOP and TOS (**Figure 2**). All other respondents are considered to have “Changed” their stations in some way. To focus on the effect of driving and refueling experience, we removed four respondents who moved to a different residence or changed their place of work. For changed respondents, we classified each change by a respondent according to the nature of the station change over time: 1) Added, 2) No Longer Uses, 3) Changed Importance, and 4) Never Opened, Never Used. As shown in Figure 2, the 46 respondents who changed their list of stations from TOP to TOS listed a total of 141 different changes. Examples of these categories can be seen in Figure 2’s Changed Respondent Example. Added stations were not listed by respondents at TOP, but are at TOS. The term “Added” conveys that the station was added by the respondent to their list at TOS rather than added to the network. “No Longer Uses” refers to any station that is not used at TOS, but was listed at TOP. "Changed Importance" stations refer to those that moved higher or lower in the respondent's list between TOP and TOS. Finally, some respondents listed planned stations that they intended to start using when they opened, but they were "Never Opened, Never Used" by these drivers. These ten stations are omitted from further analysis.

We computed summary statistics for the stated reasons why respondents listed these stations at TOP and TOS, along with the travel times and deviations required to reach them in the proximity and deviation analysis. Then, we compared differences in stated reasons for listing all stations between the Changed and No Change groups, along with differences in estimated travel times generated in the proximity and deviation analysis. We identified if any of the stations listed by a respondent were closest to their home, closest to their work or other listed trip destination, or required the least amount of deviation from an estimated shortest travel time path to one of their travel destinations. Commuting routes are classified as those between a respondent's home and any work location (some respondents listed multiple work locations). This analysis was conducted both for the primary station listed by the respondent and their secondary stations (2^{nd}-5^{th}). Based on the month and year of FCV acquisition provided by each respondent, we then compared length of experience with the vehicle, i.e., the amount of time from when the respondents' adopted their vehicle to when the survey was distributed, between the Changed and No Change respondent groups.

Several inferential statistics tested for significant differences among groups. First, a series of two-sample t-tests identified significant differences in stated reasons and estimated travel times and deviations between Changed and No Change groups of respondents (Figure 2) both for the primary station listed and the other stations listed. Then, we focus on stations added by Changed respondents over time. In contrast to other forms of stations changes shown at the bottom right of Figure 2, Added stations are unique in that they were not initially listed by respondents, but are now. We therefore analyze how these stations compare to these other classifications of station changes in terms of stated reasons for listing stations, and estimated travel times and deviations required to reach them. However, we distinguish whether the Added station was available both at TOP and TOS, or if the station was planned at TOP and then became available at TOS. If the Added station was both available when the respondents adopted their vehicle and at the time of the survey, this best indicates the effect of learned behavior based on driving experience. Adding a station that became available by the time the survey was taken may not send as clear of a signal of learned behavior but may simply be a result of the fact that the station was not available at the time the respondent adopted the vehicle. We assess differences in stated reasons and estimated proximity and deviations between Added stations and all other classifications of changed stations by specifying a binary logistic regression model for each of the above availability classifications of Added stations. In the station-level logit analysis, the sample size is the number of station changes listed by respondents. Given the emphasis on exploring the nature of differences of station changes, this part of the analysis focuses on listed changed stations as the unit of analysis. Therefore, a station listed at TOS by one Changed respondent that has been added may be one that another Changed respondent no longer uses at TOS, or has changed in order importance at TOS to another.

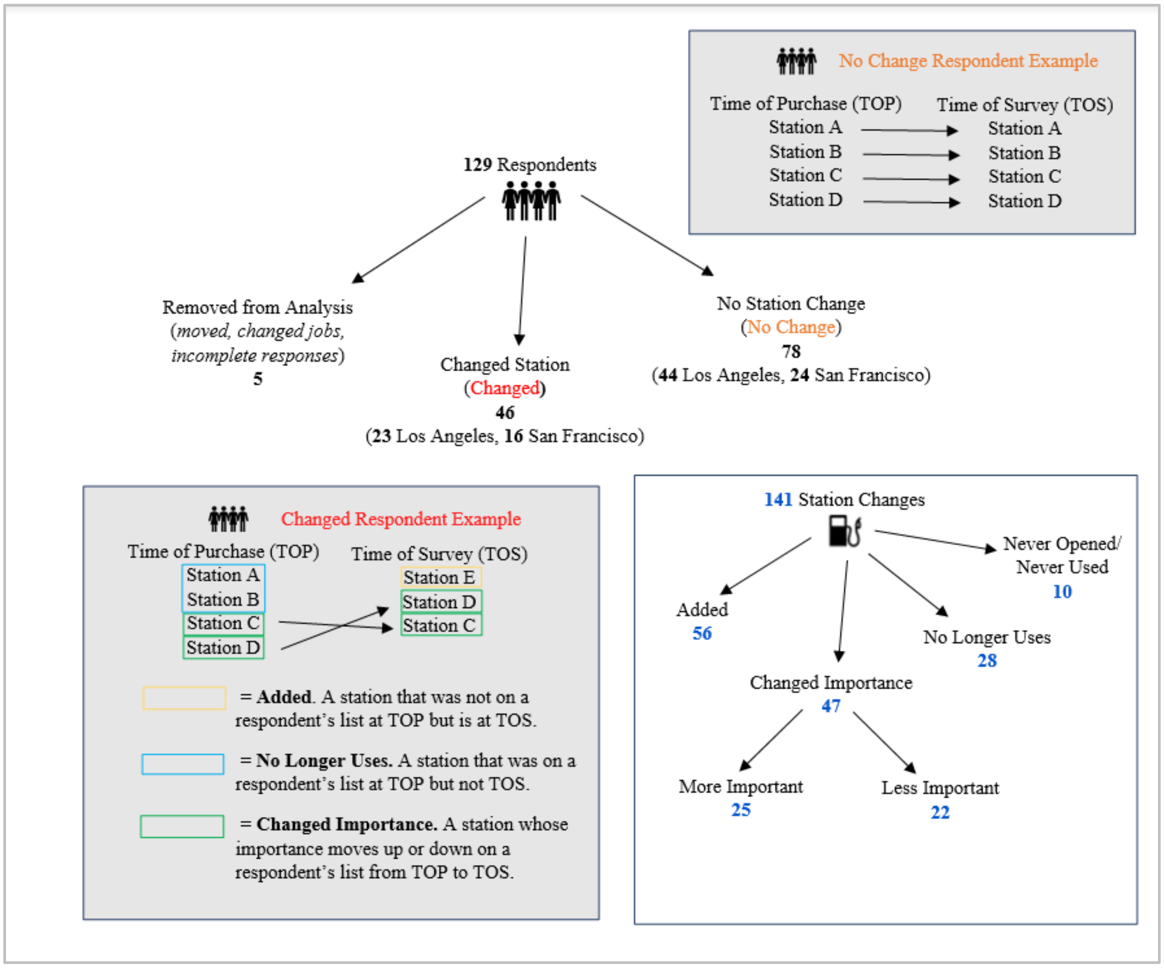

Figure 2 FCV respondent breakdown and station change classifications, with illustrative examples

Results

In total, 124 respondents completed valid surveys between January 1st and March 31st, 2019. Geographically, 67 respondents lived in the greater Los Angeles area, 40 in the San Francisco Bay Area, and the remainder in or near Sacramento and San Diego. The vast majority (80%) of respondents were either "extremely confident" or "very confident" in their recollection of the stations they had been planning to use when they decided to get their FCV. After filtering out respondents who indicated a change in home or work location and incomplete responses, there is a final sample of 46 Changed respondents (37%), while the remaining 78 (63%) represent no station changes (**Figure 2**). The ratio of Changed to No Change respondents is slightly higher for the San Francisco Bay Area but favors No Change respondents throughout California. Changed respondents listed 141 station changes: 58 of which respondents Added, 36 they No Longer Use, and 47 that Changed Importance. Changed respondents listed 141 station changes. Collectively, these respondents Added 56 stations, No Longer Use 38 of them, and had 47 stations that Changed Importance.

Length of Experience

Respondents had their FCVs for 3-37 months, and generally drivers who changed stations had their vehicles longer (**Figure 3**). For this sample of Changed respondents, the majority changed their list of refueling stations after 19 months of experience, though many drivers still use the same stations they planned to initially use after a year of experience. Of the No Change respondents, nearly 70% have had their vehicle for 19 months or less, while about 70% of Changed respondents have had their vehicle for 20 months or longer.

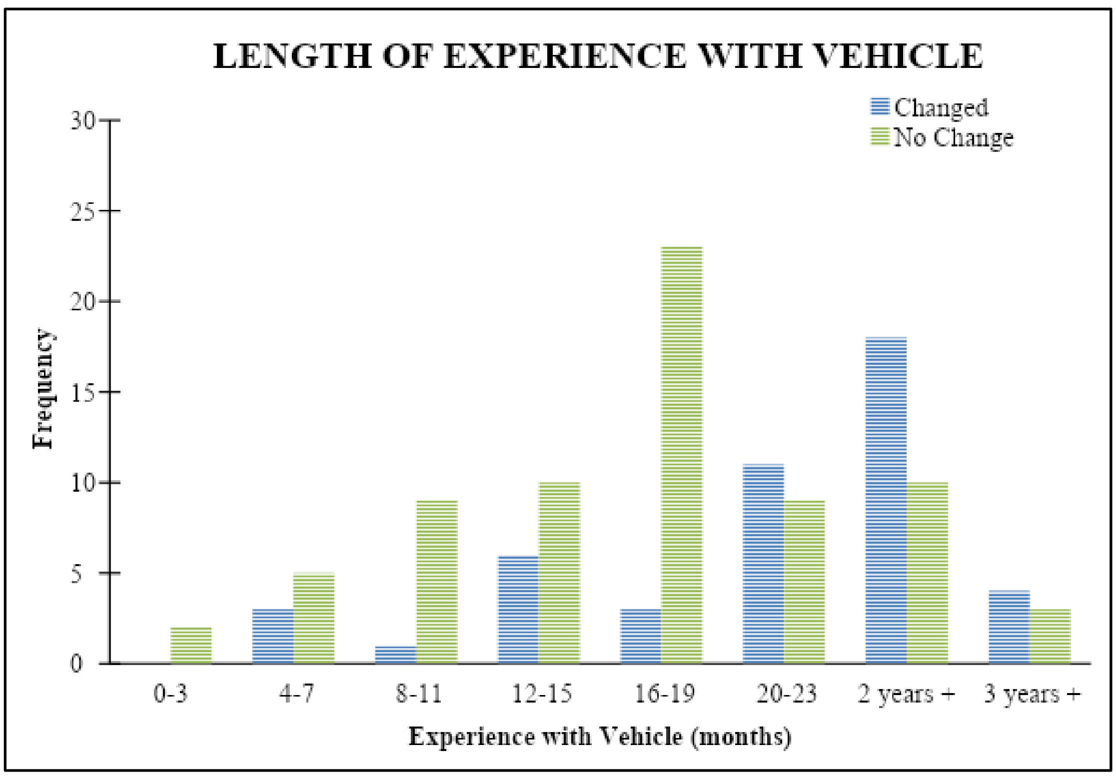

Figure 3 Length of FCV experience for Changed and No Change respondents

Comparison of Changed and No Change Respondents

Table 1 summarizes respondents' stated reasons for listing stations and the results of proximity and deviation analysis, both at TOP and TOS for Changed respondents. Table 1 omits the TOS columns for the No Change respondents because there is no difference across time periods. For all respondents, the factors are analyzed both for primary stations and for stations ranked 2^{nd} through 5^{th}. For the secondary stations, a reason only needs to be listed for one of the driver's secondary stations, not all. Respondents could give the same reason for multiple stations, or list multiple reasons for the same station, which is why neither rows nor columns add up to 100%. For the proximity and deviation analysis, percentages are the percent of respondents who listed a station that meets the criterion.

TABLE 2 Respondent and Station Classifications, by Stated Reasons and Revealed Estimated Travel Times, Including Comparison of Factors at Time of Purchase (TOP) and at Time of Survey (TOS) for Changed Respondents

	Changed (**n=46**)				No Change (**n=78**)	
	Primary Station		2^{nd} - 5^{th} Stations		Primary Station	2^{nd} – 5^{th} Stations
Factor	**TOP**	**TOS**	**TOP**	**TOS**	**TOP**	**TOP**
Stated Reasons for Considering Stations (% of respondents who listed the reason)						
Near Home	58	70	51	57	68	37
Near Work	35	37	33	44	35	32
Near School	11	11	4	7	9	5
On the Way	28	33	44	46	31	28^{+}
Near Shopping	17	15	17	22	14	21
Near Social/Recreation	7	11	24	30	18^{++}	15

Near Friends/Family	11	13	20	30	14	21
Long Distance Trip	7	4	17	26	10	17
Reliability	13	28*	20	17	24+	19
Price	7	4	11	9	9	8
Backup Station	11	11	41	44	12	46
Not Crowded	13	20	15	20	17	14
Pressure	7	11	9	9	8	6
Safety	7	4	7	7	8	6
Amenities	4	28**	9	17	9	6
Station Status						
Station available at TOP	77	--	70	--	93++	84++
Station planned at TOP	23	--	30	--	7++	16++
Proximity and Deviation Analysis (% of respondents who listed a station meeting the criteria)						
Closest Station to Home	31	28	29	31	58++	21
Closest Station to Work	12	19	12	12	40++	38++
One of Closest 3 Stations to Home	35	31	29	31	69++	78++
One of Closest 3	21	21	26	23	37++	40

Stations to Work						
Most on Way - Commute	17	19	44	29	37^{++}	35
One of 3 Stations Most on Way - Commute	37	27	67	50	69^{++}	60
Most on Way - Primary Destination	21	18	11	21	39^{+}	18
One of 3 Stations Most on Way - Primary Destination	42	34	34	50	71^{++}	45
Home to Closest Considered Station (minutes)	26	30	29	26	23	22

* significant (α=0.10), TOP vs. TOS, ** significant (α=0.05), TOP vs. TOS
$^{+}$ significant (α=0.10), Changed vs. No Change, $^{++}$ significant (α=0.05), Changed vs. No Change

Stated Reasons

"Near Home" was an important reason for choosing primary stations for all respondents and classifications, and was the only factor listed by more than half of both Changed and No Change respondents. This was also important for stations ranked 2nd-5th, but less for No Change respondents. For those who listed a work location, nearly one-third considered their primary station to be "Near Work" for both Changed and No Change groups. Nearly 30% indicated their primary station was on the way between important travel destinations. For the primary station, both reliability and station amenities became significantly more important to Changed respondents after experience with the FCV. While the term reliability may be open to some ambiguity among respondents, this term generally refers to stations having fuel and the drivers being able to receive that fuel, i.e. the system is working properly. Notably, the percentage of respondents who considered reliability at TOP for their primary station was 11% lower for the Changed respondents than the No Change respondents, which implies that by considering reliability at time of purchase, there was less need to change stations later. At TOS this relationship was reversed and reliability was noted more frequently by Changed respondents than No Change respondents. Fewer than half of Changed and No Change respondents listed any of their 2nd-5th stations as backup stations.

Revealed Reasons

There are more statistically significant differences between the Changed and the No Change groups for the proximity and deviation analysis than for the stated reasons above. For instance, the percentage of drivers whose primary station was the closest station to home is significantly lower for Changed respondents, both at TOP (31%) and TOS (29%) than No Change respondents (58%). We observed similar significant differences for one of the three closest stations to home. This is also the case for work location: 40% of No Change respondents list the closest station to work, while 12% of Changed respondents did, both at TOP and TOS. This finding implies that stations measurably nearer to home or work provided more lasting utility to drivers who did not change stations later.

When considering commuting routes between home and work locations for each respondent, a significantly higher percentage of No Change respondents listed a primary station that required the shortest possible deviation to reach. Nearly 70% of No Change respondents relied on a primary station with one of the three smallest deviations from their home-work commute route, while only about a quarter of Changed respondents did at TOS. We did not find strong evidence that Changed respondents switched to stations with shorter deviations. However, at TOS, Changed respondents list a primary station that is on average eight minutes farther away from their home than No Change respondents. This suggests that stations closer to their home become less important over time for this group. There is inconsistency between respondents' stated and revealed reasons for considering a station: the percentage of Changed respondents who list the actual closest station to home as their primary station decreased by 4% between TOP and TOS, but the percentage of respondents who stated "Near Home" as a reason for using their primary station increased by 11%. For both groups, the majority of primary and secondary stations were available at TOP.

Analysis of Added Stations

Table 2 compares the stations added by Changed respondents with all other station changes they made, which includes stations dropped after TOP and stations that changed importance after TOP, but not stations that were listed at TOP but which never opened. These station changes are then broken down into two further groupings. The first group consists of listed changed stations that were available for use at both TOP and TOS. Given that respondents could have used these stations when first acquiring their FCV but did not do so, adding such a station is more likely to be a result of learning from experience. Of the 77 station changes in this first group, 21 were added to the respondents' lists after TOP. The second group consists of listed changed stations that were planned but not yet available at TOP, and opened for operation between TOP and TOS. Adding such a station is less likely to indicate learning over time and more likely to result from a more convenient station becoming available. Of the 54 station changes in the second group, 35 were added to respondents' lists at TOS.

The primary hypothesis of the paper was that early adopters start out with more focus on locations near home but over time they begin to use stations farther from home but on their way. Table 2 shows that when looking at all station changes, the Added stations tend to be farther from home than all other stations that were changed after TOP. For both stations that were initially available and those that were initially still in the planning or construction phase, median travel time from home is 17 minutes longer for Added stations compared to the other changed stations that Changed respondents initially listed. Both groupings of added stations also exhibit a higher percentage of stations an hour or more away from home. It is important to note that the times reported for the Proximity analysis below are dependent on the use of average time and do not take in account rush hour times.

TABLE 3 Comparison of added stations vs. all other changed stations listed at TOP by Changed respondents, both for stations available at TOP and TOS, and those planned at TOP and available at TOS.

Factor	Available at TOP and TOS (n=77)		Planned at TOP, Available at TOS (n=54)	
	Initially Listed at TOP: Changed (n=56)	Added (n=21)	Listed at TOP: Changed (n=19)	Added (n=35)
Proximity and Deviation Analysis (median minutes)				
Lowest Home to Destination Deviation	8	14	4	4
Home to Station Travel Time	26[a]	43[a]	21	38
Proximity and Deviation Analysis (% of stations meeting the criteria)				
Shortest Home-Destination Deviation is < 3 Minutes	25[a]	33[a]	31[b]	49[b]
Station is > 60 Minutes from Home	16	33	16[b]	43[b]
Stated Reasons for Considering Stations (% of listed reasons)				
Near Home	15	13	7	18
Near Work	11	15	14	11
Near School	4	0	0	4
Near Shopping	6	0	0	5
Near Friends and Family	6	5	10	7

Near Social or Recreational	6	10	10	11
On the Way	7	13	10	11
Backup Station	13	5	7	8
Long Distance Trip	6	5	7	7
Not Crowded	6	8	10	7
Pressure	5	5	0	3
Station Amenities (e.g., convenience store)	4	0	0	1
Reliability	6[a]	18[a]	14[b]	5[b]
Price	4	3	7	3
Safety	4	0	3	1

[a]Descriptive statistics for independent variables in Table 3, Model 1. [b]Descriptive statistics for independent variables in Table 3, Model 2.

The deviations required to reach stations between respondents' homes and one of their three listed travel destinations present a more complicated picture. For the group of stations that were open from TOP to TOS, the median deviation of added stations is higher (14 minutes vs 8), contrary to our hypothesis, but the percentage of Added stations originally available at TOP with extremely short (< 3 minutes) deviations is also higher (33% vs 25%), consistent with our hypothesis. Of the 21 Added stations, ten have deviations less than 7 minutes, while ten have calculated deviations to one of the drivers' destinations ranging from 14 minutes to 39 minutes, plus one outlier with 74 minutes. The willingness of at least some drivers to add stations with very long deviations requires further research. It is unknown how many of the very long calculated deviations would involve a much shorter deviation to an unlisted travel destination, which is possible given that respondents were asked to list up to five stations but only three frequent destinations.

Table 2 reveals how drivers view planned stations when they are considering purchasing an FCV. Planned stations closer to home (median 21 minutes) and with short deviations to some destination (median 4 minutes, 31% under 3 minutes) tended to be on the driver's radar at TOP and they listed them as stations they were intending to rely on despite not being open yet.

Planned stations farther from home (median 38 minutes), despite even shorter deviations (median 4 minutes 49% under 3 minutes), were not initially on the driver's radar but were added after they opened.

Stated reasons for considering stations are relatively similar for Added stations and those initially considered in both availability classifications, with the exception of reliability. For the more telling category of stations available at both TOP and TOS, reliability was stated more often for Added stations (18%) than for Initially Considered stations (6%).

Given these differences between the two classifications of Added stations, we specified two binary logit models (**Table 3**) to assess differences between these stations and other changed stations initially considered by respondents. Separate models were specified for stations available at TOP and at TOS and for stations planned at TOP and available at TOS. The unit of analysis in each model are changed stations, where y_i =1 for added stations and y_i = 0 for stations initially considered that respondents no longer use or have changed in importance. Table 2 contains the comprehensive list of variables considered for the models in Table 3. A series of two-sample t-tests helped identify differences in key metrics between the two groups in each model. We also computed correlation matrices to avoid selecting multiple interdependent variables. Variables were then added iteratively to improve model fit to the point where no further improvement could be observed.

In each model, stations' being located farther from home was a positive and significant predictor of an Added station relative to one initially listed by a respondent. In these models, we added the variable that measured proximity to home that best improved model fit. In Model 1, in contrast, Added stations available both at TOP and TOS are positively influenced by listing reliability as a reason for using the station (OR = 3.83) while the station requiring a short deviation to reach is not a significant predictor. In Model 2, stations planned at TOP and now available at TOS are positively influenced by requiring a short deviation to reach (OR = 3.20) while listing a station for reliability reasons is not a significant predictor of adding these stations since TOP.

TABLE 4 Logit Model Results: Characteristics of Added Stations Relative to Changed Stations Initially Considered by Changed Respondents, by Station Availability Classification.

Model 1				***Model 2***			
Available TOP and TOS *DV:* y_i =1 for added stations and y_i = 0 for other initially listed changed stations				***Planned at TOP, Available TOS*** *DV:* y_i =1 for added stations and y_i = 0 for other initially listed changed stations			
Coefficients	**Est.**	**OR**	***p***	**Coefficients**	**Est.**	**OR**	***p***
Minutes from Home [a]	0.01	1.01	0.02*	Station is > 60 min. from Home [b]	1.60	4.93	0.03*
Deviation < 3 min. [b]	0.30	1.35	0.62	Deviation < 3 min.	1.16	3.20	0.08^{+}
Reliability [b]	1.34	3.83	0.03*	Reliability [b]	-0.51	0.60	0.55
Constant	-2.02	0.13	<0.01 *	Constant	-0.22	0.80	0.64
Model Diagnostics				**Model Diagnostics**			
Log Likelihood	-39.9			Log Likelihood	-31.1		
Likelihood Ratio Test (*p*)	<0.01 *			Likelihood Ratio Test (*p*)	<0.01 *		
AIC	87.7			AIC	70.3		
Hosmer-Lemeshow Test (*p*)	0.20			Hosmer-Lemeshow Test (*p*)	0.51		

* significant α = 0.05, +significant α = 0.10. [a] Continuous variable, [b] Dummy variable

DISCUSSION

Much of the AFV refueling station planning literature has focused on the need to place stations conveniently near home locations, work locations, or along commuting routes in order to encourage AFV adoption. These considerations do indeed appear to be prominent in this study at the critical moment when respondents decided to adopt their FCVs, and seem to influence whether or not respondents change stations and the nature of those changes. Notably, the percentage of No Change respondents who listed their primary station as the one closest station to their home at TOP is nearly identical to that of a larger sample in the recent AB8 Report on FCV drivers in California ("2018 Annual Evaluation", 2018). These respondents did not change their list of stations after some time with the vehicle which provides some evidence that, for them, the strategy that recommended aligning early stations with neighborhoods of potential early adopters allowed them to feel comfortable adopting the FCV without yet needing or desiring to change their initially intended stations. The No Change group generally had stations that were both *measurably* near their home, work, and commute route and *subjectively perceived* to be convenient to these locations. The discrepancies between stated perceptions of proximity to home and results of the proximity analysis between listed stations and home locations for Changed respondents warrants future attention. Subjective perceptions of how near is "near" exhibit some variability, but it appears that when subjective and objective measures align, drivers are more likely to continue relying on the same stations they originally planned to use.

A surprising finding was the willingness of some drivers to add some stations to their lists at TOS that are more than 60 minutes from home and in some cases requiring very long deviations requires further research. It is possible they assumed the nearest stations would be the most convenient at the TOP before taking their activity space and driving behavior into account after experience. We speculate that the long driving range of FCVs (over 300 miles) enables some drivers to refuel on other kinds of regular routes that they may not drive daily, and the addition of these stations to their list signals an expansion of travel activity from home and may reflect greater confidence and a greater degree of experience with the vehicle and refueling infrastructure. An analysis that also considers travel direction as a component of deviation required to reach a station relative to two given locations (e.g., between home and work), in combination with proximity, could warrant future analysis. In this study, the deviation analysis measures the amount of time a driver would have to travel out of their way to reach a station arranged in such a way, but direction could be an additional consideration by drivers that will become less tolerated by drivers over time as the refueling infrastructure matures and more stations are built along the way between frequently-traveled locations.

More broadly, these findings may also be a signal that once early adopters have a set of stations that they consider convenient enough to home locations, work locations, and commuting routes, other trip types become the next priority. There are some unique considerations that should be noted. Recent studies have shown that retirees have been among the early adopters of FCVs (Kuby & Lim, 2005), and these respondents would understandably prioritize non-work locations. However, the ratio of Changed and No Change respondents in this study who did not list a work location, which accounted for 20% of respondents, was nearly identical to the rest of the sample, so these results do not seem to be a function of behavior changes from this group. Some respondents listed multiple work locations, while still others may take advantage of recent policies in California that encourage employees to telecommute more often and are conducting different types of travel. We also did not ask how long respondents spent researching the station network, which may influence the degree to which respondents changed stations or not.

We do note that Changed respondents are not disproportionately located in either the San Francisco Bay Area or greater Los Angeles, and neither are Added stations. When considering the two availability classifications, the percentage of Added stations in the San Francisco Bay Area available at TOP and TOS is 15 %, with 70 % in the Los Angeles area, and the remainder adding the station at Harris Ranch (Coalinga) that facilitates travel between the two areas. For stations planned at TOP, but available at TOS, these percentages are 30% for Bay Area stations 42% for those in Los Angeles, with the remainder scattered between Sacramento, Coalinga (Harris Ranch), and Truckee. Planned stations that have been added to a respondent's list over time, then, appear to not be disproportionally added to one metropolitan area or the other, but instead, to stations that support longer-distance travel elsewhere in the state. This is reflected in the finding that Added stations tend to be further from home than those initially considered.

Reliability remains a key consideration with the fledgling hydrogen refueling infrastructure, and the results of this study reflect that consideration. Due to supply constraints and equipment failures, early FCV adopters have had to deal with station closures and reliability issues more frequently than they ever did for gasoline stations. Reliability clearly becomes important after experience for drivers who changed stations and is a significant predictor of adding a station over time that was available both at TOP and TOS. It is also possible that some drivers were more aware of this issue when they acquired their vehicles and did not end up changing stations for reliability-related reasons as a result of upfront planning. This could also be a function of the time of vehicle adoption and the ability to communicate with other drivers.

Our survey instrument did not explore interactions between respondents and other drivers prior to their purchase, which might account for the disparity in reliability import between Changed and No Change respondents. Information-sharing between current and prospective FCV drivers via online forums and in-person communication proves highly important to consumers’ understanding FCV technology and planning for its adoption (Lopez et al 2019). It is possible that Changed respondents added stations over time that had gained a reputation in these communities as being reliable. Backup stations, on the other hand, declined in importance over time, which may indicate that drivers who switched to more reliable stations had less need for a backup station after experience. Uncertainty remains, though, about how respondents interpreted the “backup” terminology.

Of relevance to the network analysis, we also did not ask respondents to indicate how factors such as the time of day of respondents' trips or congestion may have altered their travel routes to their three primary travel destinations or station considerations, which is a priority for future work. Expanding consideration to the three closest stations to home, work, or a frequently traveled route helped address this to a degree, though future specificity on these factors may help indicate which stations are considered more or less convenient as a function of nearby travel or traffic congestion. Additionally, we relied on respondents to provide their approximate home and trip destination locations using an interactive web map in the survey. Asking drivers for up to five stations but only up to three destinations may have introduced some uncertainty into the proximity and deviation analysis relative to the station locations, though given the sparse nature of the refueling infrastructure, it is unlikely such geographic uncertainty would dramatically influence the rank-order position of the listed stations relative to the others available both at TOP and TOS.

Finally, a larger sample in a future study would be helpful to verify these findings, alongside analysis with a more robust refueling network that is planned to be available for such a study in a few years. A more in-depth analysis of these drivers’ station choices at the time of adoption can provide insights into early adopters’ infrastructure criteria. Other follow-up opportunities include conducting semi-structured interviews to further analyze these drivers’ opinions of FCVs and the infrastructure, especially as they approach the 3 year re-lease period. This can provide more information on the continued use of these vehicles and deeper insight into their experiences.

Conclusions

Researchers have long anticipated the introduction of hydrogen FCVs into regional transportation systems and have developed a suite of station planning strategies that would encourage adoption when the vehicles came to market. This study addresses an understudied topic in the literature, which is how drivers prioritize station locations after purchasing the vehicle. Analysis of survey data collected from 124 FCV drivers in California demonstrates that if drivers can subjectively and objectively align station convenience with home, work, and commuting routes when they made the decision to adopt an FCV, they were less likely to change stations over time. This finding provides some evidence to support the notion of locating stations near the home and work locations of likely early adopters, and further, that drivers will continue to use these stations over time. For those who did change stations after experience, reliability becomes significantly more important, particularly for stations that they now use that they did not initially consider that were available both when they adopted the FCV and at present. It is a clear signal to station developers that this is a concern of early FCV adopters to facilitate wholesale changes to the list of stations they initially intended to use, even if it means adding stations far from home and less convenient to their routes between home and important travel destinations.

Of importance to future station planning is the finding that after experience, stations not initially considered by respondents at the time they got the FCV, are more likely to be farther from home regardless of whether they were available or planned at the time of adoption, and in the case of the latter, require minimal deviation to reach. This is an important first glimpse at how these stations allow drivers to begin to expand their travel activity with the FCV after an initial period of acclimating to the vehicle and refueling infrastructure, though to what extent these changes have been necessitated by desire or need remains an area of future inquiry. New station locations that are convenient to a number of different trip destination types that facilitate travel farther away from home and are conveniently near highways and freeway access may be appealing to drivers after they gain experience with the vehicle, so long as the station maintains a reputation for being reliable.

Chapter 3:
After Experience: California FCV Drivers' Considerations for Re-adoption

Introduction

The widespread adoption of alternative fuel vehicles (AFVs) provides an avenue for the reduction of greenhouse gas emissions in the transportation sector ("EPA Sources of Greenhouse Gas Emissions", 2019). Hydrogen fuel cell vehicles (FCVs) are classified as "zero-emissions vehicles", meaning no harmful air pollutants are generated at the tailpipe ("Fuel Cell Electric Vehicles", n.d.). There are currently three FCV models on the market: the Toyota Mirai, Honda Clarity, and the Hyundai Nexo. With the opening of the San Francisco Mission Street station in February of 2020, there are currently 44 public retail stations in California. From February 2019 to March 2020 there has been an increase of about 1,600 FCVs on the road in California and the total number of vehicles now exceeds 8,200 ("Fact of the Month", 2019; CAFCP, 2020). While the growth in vehicles has been facilitated by the expansion of the refueling station network, FCV drivers have expressed concern over the reliability and limited number of stations (Kurtz, 2019; Ramea, 2019), which align with long-understood barriers of adoption of AFVs in general. However, beyond serving as barriers for initial consideration of FCVs from the general public, these may also hamper the continued use of these vehicles by those who have adopted the vehicle, but find these concerns to be too problematic for continued use. Other factors that have been previously not considered as barriers for early adopters may be prominent for those considering whether or not to continue using the vehicle. This is a relatively unexplored research area, and is of interest to this study. Drivers' considerations for initial adoption of these vehicles, then, may not directly translate to their continued use considerations after they have had some experience with the vehicle, which is a priority consideration for the FCV adoption literature to address.

California's current FCV market offers the opportunity to gain insight from known early adopters on their considerations for the continued adoption of FCVs. These vehicles have been available to drivers since 2015, so some early adopters are reaching the point at which their initial 3 year leases are expiring, and they are evaluating whether or not to continue their leases. As such, their experiences to date can provide valuable information on their considerations for re-adoption. Assessing such considerations of new technologies can be accomplished through the use of semi-structured interviews, which have been found to be successful in facilitating exchange between interviewer and the participant (Galletta, 2012). This qualitative method allows new concepts to emerge while encouraging depth within the responses (Dearnley, 2005), and is useful in understanding how FCV adopters reflect on their initial period of experience, as they transition from early adopter to potential continued adopter. In this study, the general research question is: After experience, what are FCV drivers' top considerations for the continued use of this technology? To address this, 16 semi-structured interviews with FCV drivers in California were conducted in December of 2019. A final codebook was created with themes derived from existing literature and from initial codes. The interview transcripts were coded by the author to identify common factors and reveal patterns among the participants.

Literature Review

There is a vast amount of literature focused on the initial adoption of AFVs in comparison to their continued adoption. Previous studies have found that the decision to adopt an AFV depends on a multitude of different factors, including: price of vehicle and fuel, operating cost, infrastructure location and arrangement, travel behavior, incentives offered, and the performance and range of the vehicle (Carley et al., 2013; Caulfield et al., 2010; Dumortier et al., 2015; Egbue et al., 2012; Hoen & Koetse, 2014; Lopez Jaramillo et al., 2019.) Carley et al.

(2013) conducted a study about the stated intent of U.S. urban drivers to purchase plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs). The findings reported low public interest in both vehicle types, with factors such as recharging time, range limitations, and cost premium as barriers for adoption.

Alternatively, Hoen and Koetse (2014) also conducted a stated preference study of likely AFV adopters and found negative preferences for both electric and fuel cell vehicles relative to conventional technology. Barriers included long refueling times, limited availability of refueling infrastructure, and limited driving range, although more so for EVs than FCVs. Since then, Lopez Jaramillo et al. (2019) found that the shorter refueling time of FCVs proves to be an advantage of purchasing one over an battery electric vehicle (BEV). Limited refueling infrastructure has been found as a top concern for FCV adopters, which is especially important for FCV drivers relative to those of EVs, because they must solely rely on public stations (Ball & Wietschel, 2009; Lopez Jaramillo et al., 2019; Martin et al., 2009; Melaina, 2010; Roche et al., 2010). These studies provide important insight on the initial adoption considerations of AFV's, including FCVs, but may not translate to the continued use of the vehicles.

Many of the previously mentioned studies frequently used quantitative methods after the collection of survey data, to arrive at these findings. However, qualitative methods provide many different benefits. While a large part of transportation technology adoption literature utilizes quantitative research techniques, qualitative research approaches can capture a wider range of issues through open-ended inquiry and discussion. They have the ability to uncover underlying human beliefs, assumptions, and values (Choy, 2014). Avenues are available to explore areas of human behavior that cannot be quantified (Roshan & Deeptee, 2009). To preserve human behavior, these methods often take a holistic prospective addressing the "why" aspect of questions. Quantitative questionaries' and surveys are subject to respondents' misunderstanding questions and problems of recall (Lakshman et al, 2000). Survey data reliability is very dependent on the accuracy of the respondents' answers. While qualitative interviews are also subject to this, the chance for clarification and understanding of the questions is more readily available with the interviewer present (Queirós et al., 2017).

Qualitative methods have been used to understand respondents' meaning behind their actions, such as their values and beliefs (Clifton & Handy, 2003). Several studies within the transportation field have employed qualitative techniques that can provide a deeper look at decision making processes, barriers to vehicle adoption, drivers of and language surrounding vehicle use, public and private transit perceptions, and travel mode choices (Beirão & Cabral, 2007; Gardner & Abraham 2007; Guiver, 2007; Handy & Clifton 2001; Hardman, 2017 Lopez Jaramillo et al., 2019; Mann & Abraham 2006). For example, Gardner and Abraham (2007) conducted 19 interviews with commuters who traveled to work by personal vehicle. Findings from this study suggest that there are misconceptions about public transit in relation to the length of journey times and feelings of control regarding personal vehicle and public transit use. Mann and Abraham (2006) conducted 18 semi-structured interviews with personal vehicle owners and also identified control as a reason for personal vehicle use over public transit. Car use provides drivers with maintained autonomy and personal space.

Different variations of qualitative methods have been used to assess transportation choices and decisions, including semi-structured interviews, focus groups, and travel diaries (Baslington et al., 2008; Gardner & Abraham, 2007 Miralles-Guasch et al., 2014; Papinski & Doherte, 2009). Individual interviews allow the respondent privacy from a group setting and the flexibility for clarification and expansion when answering questions (Handy & Clifton, 2001), making it particularly useful when assessing respondents' interactions with new vehicle technologies. Using this approach, this study can provide in-depth information about the continued use considerations of FCVs through drivers' experiences.

Continued adoption of emerging transportation technologies may be influenced in part by the factors that were important to initial AFV adoption, and past qualitative work on this topic provides important insights on consumer decisions. Heffner et al. (2009) conducted interviews with 23 PEV early adopters regarding their experiences and motivations for converting from a hybrid electric vehicle (HEV) to a PEV. Through these interviews it was found that the drivers expressed interest in greater all-electric driving range and performance as motivating factors for switching vehicles. Kurani et al. (2018) held three workshops in California with hybrid vehicle owners, PEV owners, and internal combustion engine owners. The participants were provided information about PEVs and were allowed to ask questions of the current PEV drivers. Findings from the workshops include charging infrastructure and incentives as two important symbols for PEV drivers. The PEV drivers commonly explained these symbols, or signs of PEVs, to the non-PEV drivers. For the most part, at the end of the workshop, non-PEV owners were convinced that purchasing a PEV was sensible financially, contrary to previous beliefs about adopting the vehicle. Non-PEV owners also gained clarity on different PEV owners' access to both a dense re-charging infrastructure and those who rely on a sole few charging locations to meet their needs. Caperello and Kurani, (2011) conducted multiple in-home interviews with households that participated in a 4-6 week PHEV driving trial. Eight themes were identified from the interviews. For example, confusion regarding how a PHEV works and recharging habits and etiquette, such as creating a daily charging routine, were both themes identified. Continued adoption literature can provide avenues for information and education regarding the success of emerging technologies.

Two FCV interview studies laid groundwork for understanding initial FCV adopters' decision making considerations. Hardman et al., (2017), interviewed 39 Tesla BEV drivers' in Northern California and provided insights about reasons drivers decided not to lease a FCV. They uncovered 12 barriers to adoption, 5 being prominent: the lack of infrastructure, the source of hydrogen, not being able to charge FCVs from home, cost, and safety issues. Lopez et al., (2019), interviewed 12 FCV drivers in the Greater Los Angeles Area and offered insights on drivers' choices who adopted an FCV over other alternatives. Of importance was the development of 14 codes, with all participants taking into consideration the comparison to other vehicles, cost, and the refueling infrastructure.

The first wave of FCV leases are nearing their end, which provides an opportune moment to better understand the factors that these FCV drivers – who have moved from initial adopters and are now weighing continued use of these vehicles – primarily consider, and how these have changed since the time of vehicle adoption. An area of interest is what the common attributes of re-lease considerations and opinions of the vehicle technology and infrastructure are now that the drivers have had experience with both. Understanding these changes in considerations and opinions can be beneficial to encouraging FCV market growth beyond the initial adoption process.

Methods

For this research, 16 FCV drivers from California were interviewed. Six respondents indicated that they lived in the greater Los Angeles area, eight from the greater San Francisco area, with the remaining two from San Diego and central California. Semi-structured interviews were conducted over Skype and by phone from December 2nd -20th of 2019. Remote interviews allow contact with participants in a timely manner and financially affordable way (Iacono et al., 2016). A systematic sampling technique was used, choosing every 5th respondent, from a list of 80 participants who took part in the survey from the previous chapter (Krafft et al. 2020, in review). These respondents were originally recruited from these Facebook groups: Toyota Mirai Owners, Honda Clarity Fuel Cell Owners, Hydrogen Car Owners, and GM Project Driveway. The size of the groups range from about 603 to 3,200 members. As with the previous study, participants needed to live in California and either own or lease an FCV at the time of the interview. Literature suggests that 16 respondents is a representative sample size for this centralized topic study that focuses specifically on FCV drivers (Bertaux, 1981; Guest et al., 2006; Kuzel, 1992).

The majority of the respondents (56.25%) drive the Toyota Mirai, while 37.5% drive the Honda Clarity and 7.1% drive the Hyundai Nexo (Table 6). Fourteen (87.5%) of the respondents provided demographic information. The majority of their income and education demographics align with FCV drivers' demographics who took part in the California Vehicle Rebate Program (CVRP) (California Air Resources Board, 2018), which incentives FCV purchases and leases. According to the CVRP, about 48% of FCV drivers earned a post graduate degree, and this study's participant population reports 50%. Similarly, the majority of our respondents (51.7%) reflect a household income of <$199,000, and the CVRP reports 54.5% for this category.

Table 5 Characteristics of Interviewed Drivers

Category	**% of Respondents (n=16)**
Current FCV Leased/Purchased (n=16)	
Toyota Mirai	56.25%
Honda Clarity	37.5%
Hyundai Nexo	7.1%
Year of FCV Lease/Purchase	

2016	6.25%
2017	62.5%
2018	31.25%
Previous AFV Ownership	
Yes	50%
No	50%
Demographics	**% of Respondents (n=14)***
Gender	
Male	64.3%
Female	35.7%
Age	
30-39	14.3%
40-49	21.4%
50-59	33.3%
60-69	14.3%
70-79	14.3%
Income	
$75-99K	14.3%
$100-$149K	28.6%
$150-$199K	14.3%
>$200K	42.8%
Education	
High School	21.4%
University or technical training	28.6%
Graduate/professional school	50.0%
Drivers in Household	
1	42.9%
2+	57.1%

*Two of the respondents did not provide demographic information

The interviews focused on the driver's opinions of hydrogen fuel cell vehicles and the refueling infrastructure since vehicle adoption. The interviews were semi-structured and consisted of open-ended questions that allowed the respondent to elaborate on their FCV vehicle performance and infrastructure refueling experiences. Other topics were addressed, including if respondents would re-lease an FCV, recommend one to someone else, and if their experiences have matched their expectations. Also discussed was the location of the refueling infrastructure in relation to the respondents' current travel destinations. See Appendix A for the full list of interview questions. The respondents received $15 pre-paid Amazon gift cards for their participation. The interview questions, incentives, and recruitment techniques were approved by the University of Nevada, Reno's Institutional Review Board.

The interviews were audio recorded, transcribed verbatim by the author, and coded using NVivo 12 qualitative analysis software. The data and analysis process for these interviews follows Braun and Clark's (2006) framework for content analysis (Figure.

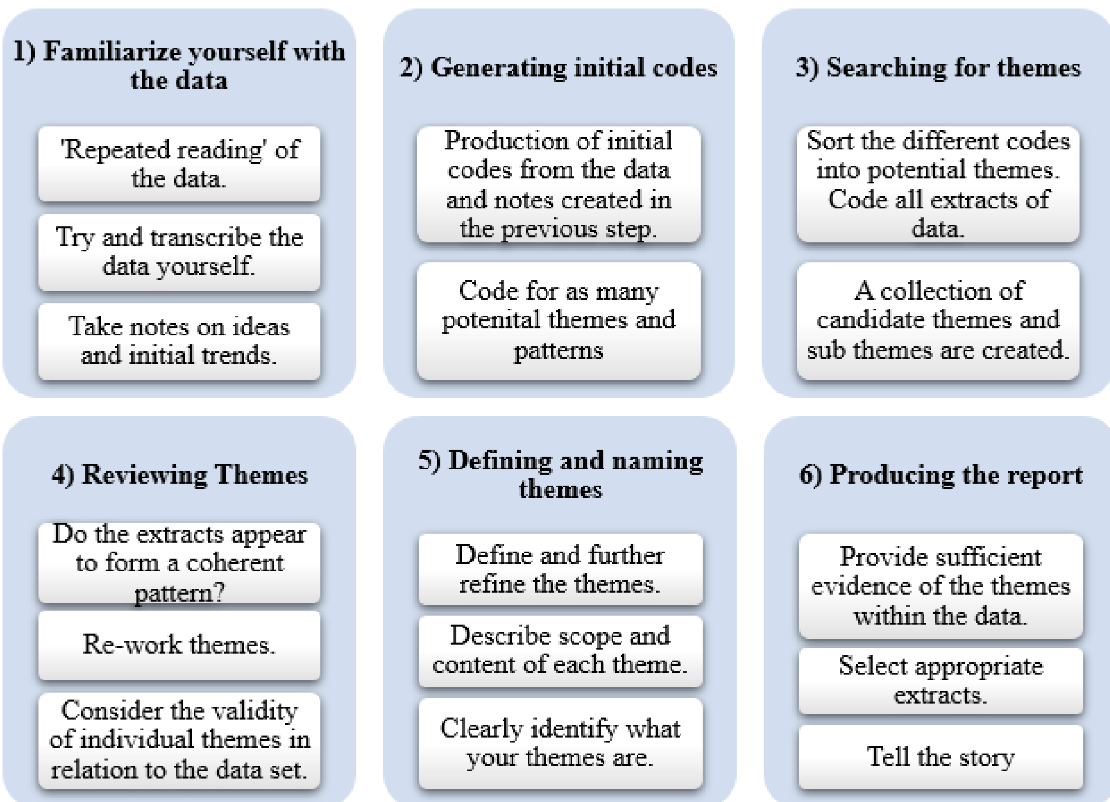

Figure 4 Braun and Clark's (2006) framework (modified by author).

This involves the production of initial codes by coding for as many patterns and potential themes as possible at the sentence level, then the creation and refinement of major themes from these codes. The detailed step process can be described as follows: 1) Familiarize yourself with the data, 2) Generate initial codes, 3) Search for themes, 4) Review themes, 5) Define and name the themes. Step 1 involves repeated re-reading of the data taking notes on initial ideas and trends. Step 2 is the production of initial codes from the data and using the notes taken during step 1. The process for step 3 involved sorting the different codes into potential themes and created a collection of candidate themes and sub themes. Step 4 is a process to refine the themes and check the validity of individual themes in relation to the dataset. During step 5, themes were further refined and then each theme was given a definition that describes the scope and context of the theme. It should be noted that the final "themes" were designated as the final codes by the author within the code book.

A final codebook which included 8 themes (Table 7) was derived and revised to achieve a sufficient interrater reliability. Within the codebook there are cited sources from which the individual themes were derived. A 10% sample of the interviews were coded with Dr. Rhian Stotts from the Arizona State University, until Cohen's Kappa > 0.8 was reached. Specifically, if a code did not reach a satisfactory Cohen's Kappa score, the code definition was revised and another interview was coded by both raters. Cohen's Kappa is a statistical measure used to assess the agreement between two raters that can be expected to have occurred due to chance. It is a widely used interrater index (Gisev et al., 2013). The themes that emerged during the analysis are discussed below.

Results

Table 7 is a brief synopsis of the final code book, which includes eight thematic codes. These codes provide insights for the continued use of FCVs and are considerations among this sample of FCV drivers.

Table 6 Code Definitions

Code	Definition	Example	Kappa
Number of and Arrangement of Stations	Drivers' considerations of hydrogen refueling stations in terms of their geographic distribution, convenience to destinations, and desire for more stations, desired station location destinations, and number of stations.	"Now the station that I go to is on my way to work so it's perfect. I knew that was coming, done the research to see where they were opening stations and sure enough this one did."	0.881
Station Considerations	Drivers' consideration of hydrogen refueling stations, in terms of their amenities, individual layout, crowdedness, and time of day refueling.	"I like to be able to fuel up at any time so the ones that have limited hours are kind of a pain in the neck."	1.000
Station Reliability	Drivers' consideration of the reliability of hydrogen refueling stations in terms of fuel availability and pump operation.	"…maybe their initial sort of growing pains with these new stations, but it's annoying to waste a bunch of time and not end up getting any fuel. So I would rather just go to one that I know will work."	1.000
Incentives/Cost	Drivers' aspects of incentives and costs, both at the time of initial purchase and as criteria for re-adoption.	"I'm leasing…I'm definitely interested in another hydrogen vehicle…I haven't had any problems getting around. And I like that it's claiming free fuel for the years and all of the manufacturers seem to be doing that. Free fuel deals so."	1.000

FCV Driver Community	This code focuses on the drivers' FCV community and resources of information.	"I participate in a couple of social media groups with other fuel cell drivers. So that's kind of how I stay up to date on what's happening."	1.000
Comparison to Other Vehicles	This code describes discussion of other vehicles in comparison to hydrogen fuel cell vehicles.	"And so it's kind of like the electrical the electric cars because I was having trouble charging if I couldn't charge at home so I hope the infrastructure expands in line with the demand I guess."	1.000
Vehicle Characteristics	This code covers characteristics and amenities of the vehicle itself that are important to the driver.	"I can listen to classical music while I'm driving at 70 miles per hour, and I can hear all the sections of it, it's really nice that's one of the things I absolutely love about it."	1.000
Alignment with Expectations	This code covers the interviewees expectations of their FCV in comparison to their experiences.	"Well, I guess in the sense that when I started I you know, I didn't know that much and I didn't have any experience and I hoped I was making a good decision for me and you know, now it's nearly four years later and it has been a good decision."	1.000

Amount of and Location of Refueling Stations

Hydrogen stations were framed by respondents in terms of their geographic distribution, convenience to destinations, desire for more stations, desired station location destinations, and safe neighborhood location.

Geographic Distribution

Drivers frequently discussed the stations in relation to their home, work, freeways, and/or along their commute path, although there was variation among the respondents. Stations in relation to work and commuting routes were referred to as "just a block off my commute", "a slight detour", and "on my way to work." Twelve participants mentioned having at least one station "near" their home. Five respondents discussed having a station near their work and four respondents mentioned having a station along their commute route. Five respondents specifically mention deviating from their route to refill. Proximity to home, work, the freeway, and frequently traveled routes appear to be the most common considerations among these drivers when describing the location of the station(s) they use which is consistent with previous station planning strategies (Nicholas & Ogden, 2011, Nicholas, 2010, Melendez & Milbrandt, 2008), but these are not the only considerations these participants discussed about the current refueling infrastructure.

Safe Location

Two respondents specifically mention the importance of a station being located in a safe area.

> "If it's in a populated area like not somewhere out in the middle of nowhere like there's a there's a station near LAX but it's not near any it's like near and it's part of a natural gas station for the LAX buses. So you can I've filled there before but sometimes you're all alone there and I would as a woman, I would not feel comfortable there like at night alone…I feel safe because lots of people." – Interviewee 5

> "It's a safe neighborhood. I don't have panhandlers approaching me and so like things like that, because I tend to go I guess, at night. So those are things that are that I take into consideration." -Interviewee 9

While 'safety' at hydrogen stations is commonly assumed to reference combustibility and concerns about hydrogen storage, it is clear that respondents are more concerned with personal safety when considering refueling locations. After these participants had experience with certain refueling stations, the importance of having a station to use that is considered to be in a safe location became more important to them over time. This is an important influence for the continued use of their vehicle.

Convenience

Out of the 16 participants, 15 (93.75%), stated the current layout of refueling stations is "convenient" to them. While convenience may vary from driver to driver, it was common for the discussion to be framed around stations becoming more convenient to them after some time with the addition of new stations opening. For example,

> "They are now I knew I would have a little bit of a challenge early on, because this station in downtown San Francisco was not open yet. But it just opened. My life is a lot easier now." – Interviewee 9

Desired Station Locations

When the respondents were asked if there was anywhere they would like to travel to but currently cannot, it was common for the discussion to be framed around long distance trip locations. Several respondents mentioned more than one location. Destinations within California include; Yosemite (2), Lake Tahoe (1), Palm Springs (1), Napa Valley (1), Sonoma (1), and the coast of California spanning from the North/South (3). Out of state destinations include; Las Vegas (5), Salt Lake City (1), national parks in Utah (1), Arizona (1), and New Mexico (2). A few drivers expressed their desire for generally for more stations nationwide, and in the neighboring states. While it was less common, two respondents mentioned having additional stations near themselves or other current stations become available. One stated:

> "Right now there's only one station in San Diego, I would like to see a second one. But there's a second one that's supposed to open I think early next year so that will be good, just in case that one's not online it's nice to have a backup." -Interviewee 16

While 13 of the respondents discussed a destination or location, two of the respondents feel that their travel needs are currently met. Furthermore, one respondent said no and explained they would just take their conventional vehicle if they need to go somewhere they currently can't.

Desire for More Stations

The majority of the drivers, 15 out of 16, (93.75%), discussed their desire for more stations. The phrase “more stations” was commonly used among the participants. However, instead of only talking about not having enough stations in order to travel around, respondents often framed their desire for more stations in context with too many cars on the road for the current hydrogen refueling station network. For example,

> “Probably more stations. Yeah, just because I think there's so many hydrogen cars on the road now that it's clogged up the station space.” – Interviewee 1

The sparse refueling infrastructure is a concern for the majority of these drivers and may be a potential barrier for the continued use of FCVs, especially if new adopters grow at a faster rate than stations do.

Station Considerations

Drivers often mentioned the crowdedness and individual layout of stations, the time of day they refuel, and the nozzles freezing. These were top considerations the drivers mentioned while detailing their experiences with certain stations Station amenities (such as a convenience store) were not mentioned as impactful to most respondents regarding their station considerations.

Crowdedness

Waiting in line at the hydrogen stations was a common topic during the interviews with most of the respondents. This is a main concern among this sample of FCV drivers. The drivers often framed the discussion as having to wait behind a few cars, but overall kept a positive attitude about it. One respondent noted:

> “It's been maybe max, I had like three or four cars. But overall great.” -Interviewee 8

Ten of the respondents discussed having to wait in line when they refuel. Several noted that with an increase of FCV drivers, there has been an increase of wait time at the stations. One respondent, while discussing the amount of FCVs on the road in comparison to the number of hydrogen stations mentioned:

> "At my favorite station I've never had to wait until the past 6 months." - Interviewee 1

Another respondent noted, in reference to having to wait at stations:

> "Originally we didn't… now we do. Three years ago, it was pretty smooth… now usually I do have to wait in line." -Interviewee 15

A desire for more hydrogen pumps at stations was also expressed by two of the drivers in reference to not having to wait in line. Several respondents mention a small line or no line at all when they go to refuel because of the time of day they plan to get their fuel, as discussed below under Time of Refueling.

Time of refueling

Seven of the respondents discussed the time of day they refuel as a significant reason for not having to wait in line at the stations. These discussions were often framed as having to plan their time accordingly to get fuel. One respondent mentioned:

> "So far it's been okay. I think the max line that I've seen is probably three cars. What I do is I fill up gas at 5am. So when no-one's there. I try and get a weekday or weekend like 5am, where probably no one is awake. And I fill up, and I'm usually I'm the only one. But then again, I had to I had to kind of create my own system to make sure that I'm able to fill up gas." – Interviewee 6

Freezing Nozzles

The occurrence of the hydrogen nozzles freezing was a common topic, with ten of the respondents stating they have had this experience. The stations with newer nozzles were mentioned as less likely to have this problem. Several of the drivers bring their own towels with them when they refuel to speed up the defrost process. The desire for standardization among the nozzles at the hydrogen stations was expressed. One driver mentioned:

> “Yes, I've used by at least three different nozzles at different stations. And so they're kind of problematic…sometimes they freeze to the car… yeah, that's kind of annoying.” – Interviewee 7

Stall Location

A few respondents specifically mention the location of individual hydrogen stalls at a station in terms of the stall being located in between gas station stalls. Therefore, the gasoline drivers block the hydrogen stall. These respondents mention a desire for a hydrogen stall separate from the gasoline stalls which provides some insight for future station design plans.

> “In terms of location, that location for the specific hydrogen stall…our hydrogen cars get cramped in right in between like two normal gas station stalls. And that’s a problem… and I'm trying to like squeeze in between and have to wait so I'd like it if they kind of put the hydrogen stall somewhere separate from a gas station.” -Interviewee 5

> “The one that I actually kind of like going to more often is the South San Francisco one, only because it's, you don't have to play Tetris to get in and out of it. The two Shell stations, you really have to, hope no one blocks you in or that no one's blocking the hydrogen station or that you pull in backwards like it's a whole Tetris situation.” – Interviewee 9

Amenities

The importance of station amenities (such as convenience stores and hours of availability) among the respondents was very low. Four of the respondents mention some consideration of the amenities provided in context to stations having limited hours, a car wash, and the desire for trash cans and squeegees. One driver mentioned:

> “The stations some of the stations as you probably know, have limited hours and I that that's pretty inconvenient sometimes you know…I'm lucky that the station is right around me are 24 hours…I think it's a probably going forward it's a bad idea to build new stations that have such limited hours.” – Interviewee 16

The majority of this sample of respondents did not consider amenities to be particularly important.

Station Reliability

Every respondent shared their experiences with the reliability of the hydrogen refueling stations they use. Overall, this sample of drivers is concerned about the future reliability of stations. Several respondents mentioned having to search for fuel, the need for a back-up car, and consideration of multiple stations. The mention of having experiences with stations being down or unavailable was common, along with the drivers expressing their desires for more reliable stations. One respondents said:

> “So we have to be a little more careful on you know when you need fuel go get it because you may have to find it.” -Interviewee 7

One respondent discussed the reliability of the stations in terms of a specific time period stating:

> “…for the first two years of my lease from 2017 to 2018, it was very reliable. For 2019 it's been awful, really, really, really bad.” -Interviewee 15

A few respondents considered the reliability of the stations they use, or at least one station they use as being reliable, and therefore they have very little problems refueling. The reliability of the station software and the dispenser itself was also mentioned by several respondents. For instance, in reference to a station:

> “When you go to it you maybe have a 60% chance of getting fuel, it crashes, the software is too complicated.” – Interviewee 3

In addition to their own experiences, several respondents shared reliability experiences in terms of what they’ve heard from other people. Specifically, mentions of the Northern California Bay Area hydrogen shortage in 2019 (roughly from June to October.) Two respondents specifically stated:

> **“**And the people in the North Bay that people live across the bay from San Francisco have had the worst luck with the station's being down.” – Interviewee 4

> "People in Northern California…had an outage like four or five months or something like that." – Interviewee 8

Two respondents shared their personal experiences during this shortage, one driver mentioned:

> "So I was without like so many other people without my primary car, which I can't tell you sucked so bad." -Interviewee 9

They had to place their car in "pseudo storage" while they used a rental because of the limited San Francisco street parking. The other driver stated:

> "I actually used Ubers so I went to and from work every day." – Interviewee 14

This respondent was very pleased with how Toyota "stepped up" during this hydrogen shortage. Two other respondents commented:

> "…I've never come to an empty station except during that June to October period." - Interviewee 5

> "You know, we've had they call them hydrogen apocalypses down here, you know, where you get shortages and stuff like that. But you know, that's part of that part of what you sign up for." -Interviewee 12

Despite some frustrations, the respondents had an overall positive attitude about the new technology but made it clear that station reliability is an issue that should be addressed moving forward with the addition of new stations and to support the continued use of FCVs.

FCV Driver Community and Resources

The respondents often discussed the FCV community in terms of other drivers, their resources of information, including both in person and online with other drivers, use of a website/app for vehicle and station updates, opinions of the vehicle sales staff, as well as communication with the hydrogen truck delivery drivers and station owners/employees. Several respondents referred to the station owners, employees, and hydrogen delivery drivers as, "very nice”, “very friendly”, and “very helpful”. A couple respondents referred to the vehicle salesman as unknowledgeable about the reliability of the stations. One respondent mentioned:

> “He literally had no knowledge… of what the future of the fuel cell market was. … didn't really know about the reliability of the stations around the area.” - Interviewee 6

It was common for the drivers to mention conducting their own personal research and checking the reliability of the stations from the California Fuel Cell Partnership Website, which provides real-time information on station status and availability. In-person communication among FCV drivers, including co-workers and friends was mentioned by a few respondents. Other sources of information include the online Facebook FCV group pages. Fourteen of the respondents mentioned participating on these groups to some extent.

Interestingly, it was common for several respondents to frame their discussions from the point of view of FCV drivers as a group as well as sharing other drivers’ experiences. One respondent mentioned:

> “We have people now saying ‘yeah I’m not gonna renew the lease on this because it’s been a challenge to get fuel.” -Interviewee 2

Another respondent mentioned:

> “…everyone is mostly happy with the car.” – Interviewee 12

While most of the respondents mention the Facebook groups as a great source for information, it was also evident that it is a place for the drivers to share their experiences with FCVs and each other, and these interactions in online communities may influence perceptions that in turn factor into how drivers evaluate stations and the vehicle technology when considering continued FCV use.

Incentives and Costs

Respondents discussed several incentives and costs that they evaluated at the time of adoption that are still important to them after some experience with their FCV, meaning that these incentives both attract new FCV adopters while also assisting continued adoption. Considerations were incentives such as HOV lane access, pre-paid fuel cards, low maintenance costs, and the vehicle rebate ($5,000), which is available to California residents who. Common phrases from the drivers about their FCVs include: "it is a really good deal", "it was almost like driving a free car", and "basically the car is almost free to me."

Five respondents mentioned the HOV lane access as an important initial consideration and talked about currently using the lanes on their commute routes. One respondent mentioned it as an important consideration at the time they leased their vehicle, but it is not a huge consideration now that they work from home. For the others it is a big consideration with one respondent stating:

> "I need to get a car next year as well around this time next year I need to get a new car and I'm only looking at cars that qualify for the sticker... if it doesn't qualify for the sticker, I'm not interested." – Interviewee 13

Receiving a pre-paid fuel card or "free fuel" as well as low maintenance cots was mentioned by eight of the drivers each. A few respondents stated their desire for the cost of hydrogen to come down in the future, while two mention their desire for the initial price of the vehicle to become lower.

Comparison to Other Vehicles

Several drivers compared their FCV to other AFVs such as BEVs in terms of their acceleration, vehicle technology, and refuel (recharge) time. They noted similar maintenance costs, BEVs having better acceleration and different technology features, the availability of super charging stations vs. hydrogen stations, and the fast refueling time of FCVs. One respondent mentioned being concerned about their previous electric vehicle's recharge time, while two drivers made comparisons between FCVs and gasoline vehicles mentioning FCVs having very little maintenance and gasoline cars as "ordinary".

The comparison between their current FCV vehicle type and other FCV vehicle types, as well as the future Toyota Mirai model was a common topic. The FCVs were often compared to one another in terms of their design, size and range. One respondent mentioned:

> "I'm not thrilled about the fact that there's only two seats in the backseat [referring to the Mirai]. So you could only have four people in the car ever. Looks like the new Mirai that's coming out next year is going to have room for five, that would be good...It's much more attractive, bigger, supposed to be peppier, more power, greater range." – Interviewee 12

When considering continued FCV use, seven drivers also often compared the FCV types to one another. One driver mentioned:

> "Our lease will be up in 2021 and Toyota's announced that they're going to have a revised Toyota Mirai which is much more desirable…and it also had a greater range…there's a considerable likelihood that we would get a re-lease at the end of ours and get a new model." – Interviewee 10

Once these respondents discussed a desire to continue to use another FCV when their 3 year lease ends, a comparison was drawn between their current model, the other two vehicle models, and the future Mirai model.

Vehicle Characteristics

Respondents shared the characteristics and amenities of the *vehicle itself* that are important to them. The drivers mentioned**,** range, speed, acceleration, handling, vehicle size, storage space, seating space, adaptive cruise control, physical appearance, road noise, range, Apple Car Play, and safety features. While describing the vehicle phrases such as, "I love it.", "It's been great", "fantastic vehicle", "It's fabulous", and "comfortable" were common. Two respondents stated:

> "I love the handling I love the drive, the comfort, the luxury, the amenities, the high-tech. I love all of that about it." -Interviewee 1

> "Oh, great performance. A very powerful engine. Very quiet ride. Very smooth ride. It was great. I would say five stars on performance." - Interviewee 7

The size of the vehicle was discussed by eleven of the respondents. A few respondents from San Francisco expressed a desire for a smaller vehicle due to the limited on street parking options. Others were very happy with the size, and a few respondents desire more trunk space. Adaptive cruise control was also mentioned by several of the respondents in terms of a feature they "love". The range of the FCVs was framed by the respondents in terms of a desire for a longer range in the future.

Alignment with Expectations

The respondents were asked about the experiences of their FCV in comparison to their expectations. Ten of the respondents mentioned that their experiences have been positive. Two of these ten respondents stated their experiences have met their expectations and three said they went above what they were expecting.

> "…maybe even a little higher." -Interviewee 4

> "…yes, or gone above." – Interviewee 1

> "They've been better than my expectations really, I think" – Interviewee 12

Other respondents mentioned planning a time to refuel in advance and how and where find fuel was more work than they expected. Five of the respondents stated they did not have very many expectations or did not know what to expect. One participant mentioned:

> "I didn't know what to expect. I was just hoping for the best. And, you know, it's been fabulous." – Interviewee 16

Overall, the drivers that participated in the interviews have an optimistic mindset about FCVs and the future potential of these vehicles.

Continued Use Considerations

The participants were asked whether or not they would continue to use another FCV. Twelve of the participants stated they would, with one of these twelve only saying "yes" to re-leasing under the condition that more stations become available. The four participants that were not sure if they would continue to use another FCV expressed concerns about the reliability, crowdedness, and amount of hydrogen stations available, as these were top common concerns expressed during the interviews.

The majority of these participants (15) stated they would recommend a FCV to someone else. Ten of these fifteen mentioned they would recommend the vehicle under certain conditions. These included: if additional stations become available, if the person lives near reliable stations, a structured life with time to plan to refuel, if you have a back-up car, and if you do not have to drive far. One participant would not recommend a FCV to someone else due to the crowdedness of stations, stating:

> "…we have a little more cars than we have fueling." – Interviewee 1

Overall, the majority of the drivers interviewed are willing to adopt another FCV and recommend one to someone else. This sample of drivers provides a promising outlook for the continued use of this new vehicle technology past drivers' initial 3 year lease period. While this does offer some optimism, it is important to recognize their views may not be representative of the entire FCV community.

Discussion

This sample of FCV adopters does appear to be generally satisfied with their vehicles and the refueling infrastructure, and the majority are willing to continue using an FCV to conduct personal travel. Some of the key themes uncovered in this analysis align with known considerations of initial adopters, though it appears sustained adoption will also require accommodation of different criteria. The key findings from known literature on importance of initial adoption that correspond with important aspects of continued adoption include: vehicle performance, price, range, station reliability and limited infrastructure (Caulfield et al., 2010; Dumortier et al., 2015; Hardman et al., 2017; Hoen & Koetse, 2014; Krafft et al., 2020 In Review; Kurtz & Bradley, 2019; Martin et al., 2009, Melania et al., 2013; Ramea, 2019; Roche et al., 2010).

Results revealed that drivers continue to value incentives such as HOV lane access, pre-paid fuel cards, low maintenance costs, and a $5,000 California rebate. These may need to implemented or ensured in other cities and regions interested in facilitating a transition to FCVs, both at the time of adoption and beyond.

An unexpected and important finding had to do with a common perception among interviewees: that the growth in FCV sales has gotten to the point where drivers felt the stations had become too congested and popular, and long refueling lines became an irritant of early adopters. While this is a signal that the market is maturing and that station developers should feel confident about usage of their stations, this finding indicates that the consideration of additional infrastructure from continued adopters may reflect a different desire than initial adopters.

Other insights from this study highlight new adoption considerations for FCV drivers. Ten of the respondents discussed having to wait in line to refuel at stations. To reduce time spent waiting, seven of the respondents plan to refuel at a time when they know the stations will not be crowded. These drivers made it clear that with the increase in FCVs on the road, there is now an increase in wait time at the stations. This correlates with a desire for more stations, which was expressed by 15 of the 16 respondents. A few respondents directly connected the increase of drivers with an increase of congestion at stations. The station locations in terms of safety was also revealed as an important consideration for station use. Stations located in a relatively safe area or neighborhood can provide drivers with a sense of security and more station options.

Another novel finding is, aside from the geographic location of the station, the individual hydrogen stall location is an important consideration as well. A few respondents expressed a desire for the stalls not to be located between gasoline pumps, as the hydrogen pump often is blocked by these drivers. Station layout may be a function of company policies or reflective of health and safety regulations, so adjusting these to better accommodate FCV drivers may take some time and vary from place to place.

Like previous studies have found (Hardman et al., 2017; Lopez et al., 2019), it was common for the participants to compare their FCVs to BEVs. In this case, FCVs were often highly regarded for having a faster refueling time than BEVs, although in several discussions with interviewees, there is a perception that FCV vehicle technology lags behind that of BEVs. Another new finding is the comparison of FCV types to each other, and identification of a community "favorite". The new Toyota Mirai 2020 and 2021 models emerged as a clear top choice, compared with the three current FCV models. This discussion of commonly-accepted FCV models when considering which type to re-adopt is a sign that the FCV market is maturing.

Vehicle characteristics among the models may play a role when considering which type to re-adopt. Two commonly mentioned characteristics are size and the vehicle technology, i.e., adaptive cruise control, and Apple Car Play.

The current FCV community relies on each other, predominantly through online forums, for sources of information about the FCV models as well as the reliability of stations. It is common for members of online Facebook groups to update each other on the status of stations as well as on their experiences with FCVs. Positive and negative experiences with the infrastructure are often shared in these forums, and some of our results may reflect what others have heard through this online community.

Ten of the drivers expressed that their overall experiences with the FCV have been positive and either matched their expectations or have gone above and beyond them. Their high opinions of FCVs and the excitement about the technology have not wavered. Interestingly, five respondents said they did not have any expectations when they adopted the vehicle. The majority of the sixteen drivers are willing to re-adopt and recommend an FCV, which provides a promising outlook for the future FCV market.

Uncertainties remain surrounding the extent to which drivers are influenced by online communication with other FCV owners and remains an area of inquiry for future research. It is unclear to what extent drivers were influenced by other FCV drivers in terms of station choices and vehicle types when they initially adopted their FCV. Another area of interest is these drivers' previous AFV experience. Half of the respondents indicated they have owned a previous AFV, but no questions directly asked respondents to what extent their previous experience may have influenced their consideration to re-adopt an FCV. This includes previous AFV vehicle type(s) and length of experience with them. According to the California Air Resources Board (2018), the study population was both representative of education and income levels of California FCV adopters. This may be transferable to other populations and regions within the U.S. but varied demographics by state should be taken into consideration.

Conclusion

Of the 16 drivers interviewed, this study finds that 12 FCV drivers (75%) are willing to transition beyond being an initial adopter and continue using their FCV, which is an important finding given that the first wave of adopters in the state of California are approaching the end of their 3 year lease. New insights from these semi-structured interviews with FCV drivers in California can provide avenues for future policy considerations that assist the widespread and sustained adoption of FCVs elsewhere. While this study revealed a strong signal for the re-adoption of FCVs, many drivers expressed their concerns, particularly related to the refueling infrastructure. With an increase of crowdedness at hydrogen stations, respondents attributed this to the increase of FCVs on the road. This finding indicates that adding new stations both encourages initial adopters to invest in an FCV, while also alleviating congestion and long refueling lines from stations heavily used by current drivers. Future infrastructure decision planning should consider travel desires and demands of both groups when locating new stations.

A few participants also indicated that station layout should be more carefully considered by station developers. The arrangement of fuel pumps relative to gasoline pumps made access difficult. Station developers should consider more accommodating layouts to FCVs as the market grows. Stations, therefore, with accommodating space for FCVs, sufficient lighting, and on-site personnel to help ensure driver safety may all help keep initial adopters in their FCVs while appealing to potential new drivers.

FCV drivers have also expressed a desire to expand their travel destinations. Within the state, this would include the addition of stations to allow more comfortable travel to and from Northern and Southern California. Current drivers feel the addition of new stations would help expand their activity space but improving the reliability of existing stations should also remain a top priority because it is an important criterion for the continued use of FCVs.

With a developing FCV market, there is now more competition between the different FCV model types. The new Toyota Mirai models were often discussed in terms of consideration for re-adoption. While the majority of drivers' "love" the vehicle itself, the continued advancement of updated features and design, based on this study, can be predicted to increase in importance as drivers gain experience with the vehicles. The vehicle incentives (HOV lane access & pre-paid fuel cards) and the price of the lease are highly important to drivers and new policy should take this into account when promoting the continued use and adoption of FCVs. This study revealed the importance of the addition of new reliable stations throughout California, as well as the development of the FCV market in terms of new vehicle models and the advanced technology associated with them. Another study of FCV drivers and their experiences over time that did not rely on an initial convenience sample may be beneficial for a comparison between other drivers' considerations and the findings from this sample of 16 drivers.

Future research is needed to determine how these new findings align with existing station planning methods from previous studies. For example, contrary to the cluster strategy (Nicholas & Ogden, 2011), which recommends station locations to initially encourage people to adopt FCVs, the findings from this study and the previous chapter support locating new stations further away from early adopters' home locations. Our results did show that FCV drivers value having a station near their home and work, but it may be beneficial for new stations to be located further from these two destinations to promote the continued use of these vehicles. Nicholas, 2010 proposed locating stations near residential areas just off the highway, which may coincide with our suggestions to help facilitate travel further away from early adopters home locations, while also ensuring that those nearby have a station convenient to them. Connecting results from this research with previous station planning models is beneficial for future station planning considerations as well as helping to promote the continued use of FCVs.

Chapter 4: Conclusion

Conclusion

This thesis addresses one key understudied topic in literature: how drivers transition from an initial FCV adopter to a continued one who has gained experience with the vehicle and the infrastructure, and how priorities shift for these drivers over time. Specifically, this thesis addresses: 1) how drivers prioritize station locations after adopting an FCV and gaining experience with it relative to when they first got it, and 2) how drivers consider FCVs and the refueling infrastructure after experience as criterion for re-adoption. The first study revealed that drivers are less likely to change stations over time if they have stations located conveniently to their home and work locations, both subjectively and objectively. This aligns with what were speculated to be important spatial relationships for initial adopters in the FCV adoption literature.

Respondents that did change stations after some experience indicated that reliability of the stations has become significantly more important, suggesting this is an important factor when changing the stations they typically use. Drivers that changed stations over time added stations farther from home and less convenient to their routes between home and common travel destinations. Combined with similar statements made by interviewees regarding the trade-off between reliability and convenience of the station location, this suggests drivers are willing to travel further to stations that are more likely to be reliable, and may also be an indication of expanding activity spaces. The second study revealed a promising indication of willingness to re-adopt an FCV, with 75% of respondents in agreement that they would do so. The decision to re-adopt relies on having a reliable network of stations, as well as the overall price of adopting the vehicle and using the infrastructure, which emphasized the importance of incentives that are offered (HOV lane access, pre-paid fuel card, and the $5,000 California rebate). New findings were revealed; crowded stations, difficult access to the hydrogen pumps, and safety regarding the location of stations are concerns among current FCV drivers. Future policy, then, that incorporates these considerations in future station location planning, coupled with adjusting policy to allow for better inclusion of FCVs and hydrogen pumps at existing shared stations while ensuring driver safety and security, would be helpful to the continued transition to a vehicle technology with substantially lower tailpipe emissions than traditional vehicles.

The California FCV market will benefit from the addition of new reliable stations throughout the state. This will help expand the activity space for current drivers who expressed a desire for more stations and coincide with the finding that drivers tend to use new stations further from home and their travel destinations. In addition, an expansion of the current hydrogen refueling network may make other drivers aware of FCVs which could help grow the current number of drivers. While it has been revealed that many FCV drivers communicated with each other on online forums – firsthand awareness may prove beneficial to FCV market sales.

Future research is needed to determine to what extent the expansion these driver's activity space is voluntary or necessary, i.e., the drivers now feel comfortable traveling further, or they feel they need to in order to find a trustworthy station. Another opportunity for inquiry is an in-depth analysis of how FCV drivers are influenced by other drivers (in-person and through online forums) in terms of station choices and vehicle re-adoption considerations.

With an increase in FCV drivers over the years, the need to alleviate congestion at stations has become apparent and additional stations would allow drivers to refuel at more convenient times. Future hydrogen infrastructure planning should consider an alignment of new reliable stations that 1) facilitate travel throughout the state, 2) are located in safe areas, and 3) provide easy entrance/exit and access to the hydrogen stall. This would be a wise investment to help promote the continued use of FCVs and in turn the success of the FCV market.

Appendix A

Interview Questions

1) When did you purchase or lease your FCV?

2) Which car do you currently drive?

3) Is this the vehicle you drive most often?

4) Is this your first alternative fuel vehicle? (If no, what else have you owned/leased or still do?

5) What were your initial considerations at the time of purchase?

6) Are the stations located conveniently to the places you currently travel to?

7) Describe your experiences with the reliability of the refueling stations.

8) Where would you like to travel to with your vehicle but currently can't?

9) What other aspects of stations have you found to be important to you after experience with them, such as things you find at normal gasoline stations? (station amenities, which ones?)

10) Are there any other experiences with the refueling stations you'd like to share?

11) Describe your experiences with the performance of the vehicle?

12) Have your experiences match your expectations?

13) Based on your experiences with the vehicle and infrastructure, do you think you would purchase or lease the vehicle again?

14) Would you recommend a FCV to someone?

15) What are your expectations and desires for the refueling infrastructure in the future?

16) What are your expectations and desires for the vehicle technology going forward? (in the future)

17) Is there anything else you'd like to add that would give me insight into your experiences with the vehicle and infrastructure?

References

Alternative Fuels Data Center: Maps and Data. (2020, January). Retrieved February 15, 2020, from https://afdc.energy.gov/data/

Alternative Fueling Station Locator. (n.d.). Retrieved March 10, 2019, from https://afdc.energy.gov/stations/#/find/nearest

Ball, M., & Wietschel, M. (2009). The future of hydrogen – opportunities and challenges. *The Hydrogen Economy*, 613–639. doi: 10.1017/cbo9780511635359.022

Beirão, G., & Cabral, J. S. (2007). Understanding attitudes towards public transport and private car: A qualitative study. *Transport Policy*, 14(6), 478–489. doi: 10.1016/j.tranpol.2007.04.009

Bertaux, D. (1981). From the life-history approach to the transformation of sociological practice. In *Biography and society: The life history approach in the social sciences, ed.* by D. Bertaux, 29–45. London: Sage.

Braun & Clarke. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3 (2). pp. 77-101. ISSN 1478-0887

Brey, J., Carazo, A., & Brey, R. (2014). Analysis of a hydrogen station roll-out strategy to introduce hydrogen vehicles in Andalusia. *International Journal of Hydrogen Energy*, 39(8), 4123–4130. doi: 10.1016/j.ijhydene.2013.06.087

Brey, J. J., Brey, R., Carazo, A. F., Ruiz-Montero, M., & Tejada, M. (2016). Incorporating refuelling behaviour and drivers' preferences in the design of alternative fuels infrastructure in a city. *Transportation Research Part C: Emerging Technologies*, 65, 144–155. doi: 10.1016/j.trc.2016.01.004

Carbon Pollution from Transportation. (2019, June 10). Retrieved 23, 2020, from https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation

California Air Resources Board. (2018) Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. *California Environmental Protection Agency.*

Caulfield, B., Farrell, S., & Mcmahon, B. (2010). Examining individuals preferences for hybrid electric and alternatively fuelled vehicles. *Transport Policy,* 17(6), 381–387. doi: 10.1016/j.tranpol.2010.04.005

Carley et al., (2013). Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. *Transportation Research Part D: Transport and Environment,* 18, 39-45. doi:10.1016/j.trd.2012.09.007

Caperello, N. D., & Kurani, K. S. (2011). Households' Stories of Their Encounters With a Plug-In Hybrid Electric Vehicle. *Environment and Behavior*, 44(4), 493–508. doi: 10.1177/0013916511402057

Chapman, L. (2007). Transport and climate change: A review. *Journal of Transport Geography*,15(5), 354-367. doi:10.1016/j.jtrangeo.2006.11.008

Choy, L. T. (2014). The Strengths and Weaknesses of Research Methodology: Comparison and Complimentary between Qualitative and Quantitative Approaches. *IOSR Journal of Humanities and Social Science,* 19(4), 99–104. doi: 10.9790/0837-194399104

Clifton & Handy, (2003). "Qualitative Methods in Travel Behaviour Research." In *Transport Survey Quality and Innovation*, edited by P. Jones and Peter R. Stopher, 283–302. Emerald Group Publishing Limited. https://doi.org/10.1108/9781786359551-016.

Dearnley, C. (2005). A reflection on the use of semi-structured interviews. *Nurse Researcher*, 13(1), 19–28. doi: 10.7748/nr2005.07.13.1.19.c5997

Dumortier et al., (2015). Effects of Providing Total Cost of Ownership Information on Consumers' 17 Intent to Purchase a Hybrid or Plug-In Electric Vehicle. *Transportation Research Part A*, 18 2015. 72: 81-86.

Egbue, O., & Long, S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy Policy, 48, 717-729. doi:10.1016/j.enpol.2012.06.009

EIA - U.S. Energy Information Administration - Independent Statistics and Analysis. (2019, August 2). Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=40752

EPA Fast Facts on Transportation Greenhouse Gas Emissions. (2019, July 16). Retrieved 23, 2020, from https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

EPA Sources of Greenhouse Gas Emissions. (2019, September 13). Retrieved from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Fact of the Month March 2019: There Are More Than 6,500 Fuel Cell Vehicles On the Road in the U.S. (2019). Retrieved March 8, 2020, from https://www.energy.gov/eere/fuelcells/fact-month-march-2019-there-are-more-6500-fuel-cell-vehicles-road-us

CAFCP - FCEV Sales, FCEB, & Hydrogen Station Data. By The Numbers (2020, March 1). Retrieved March 8, 2020, from https://cafcp.org/by_the_numbers

Fuel Cell Electric Vehicles. (n.d.). Retrieved March 6, 2020, from https://www.cecsb.org/fcev/

Gardner & Abraham. (2007). “What Drives Car Use? A Grounded Theory Analysis of Commuters’ Reasons for Driving.” *ScienceDirect*. Accessed January 15, 2020. https://www.sciencedirect.com/science/article/abs/pii/S136984780600088X.

Galletta, A. (2012). Mastering the semi-structured interview and beyond: from research design to analysis and publication. New York: New York University Press.

Gisev, N., Bell, J. S., & Chen, T. F. (2013). Interrater agreement and interrater reliability: Key concepts, approaches, and applications. Research in Social and Administrative Pharmacy, 9(3), 330–338. doi: 10.1016/j.sapharm.2012.04.004

Greene, D. L., James, B., Perez, J., Melendez, M., Milbrandt, A., Unnasch, S., … Hooks, M. (2008). Hydrogen Scenario Analysis Summary Report: Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements. doi: 10.2172/931163

Guerra, C. F., García-Ródenas, R., Sánchez-Herrera, E. A., Rayo, D. V., & Clemente-Jul, C. (2016). Modeling of the behavior of alternative fuel vehicle buyers. A model for the location of alternative refueling stations. *International Journal of Hydrogen Energy*, 41(42), 19312–19319. doi: 10.1016/j.ijhydene.2016.07.165

Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough? *Field Methods*, 18(1), 59–82. doi: 10.1177/1525822x05279903

Guiver, J. (2007). Modal talk: Discourse analysis of how people talk about bus and car travel. *Transportation Research Part A*: Policy and Practice, 41(3), 233–248. doi: 10.1016/j.tra.2006.05.004

Handy et al., (2005). "Driving by Choice or Necessity?" *Transportation Research Part A: Policy and Practice* 39 (2–3): 183–203. Accessed January 17, 2020. https://doi.org/10.1016/j.tra.2004.09.002.

Handy & Clifton. (2001). "Local Shopping as a Strategy for Reducing Automobile Travel." *SpringerLink.* Accessed February 2, 2020. https://link.springer.com/article/10.1023/A:1011850618753.

Hardman, S., Shiu, E., Steinberger-Wilckens, R., & Turrentine, T. (2017). Barriers to the adoption of fuel cell vehicles: A qualitative investigation into early adopters attitudes. *Transportation Research Part A*: Policy and Practice, 95, 166–182. doi: 10.1016/j.tra.2016.11.012

Heffner, R. R., Kurani, K. S., & Turrentine, T. S. (2009). Driving Plug-In Hybrid Electric Vehicles. *Transportation Research Record: Journal of the Transportation Research Board*, 2139(1), 38–45. doi: 10.3141/2139-05

Hodgson, M. J. (2010). A Flow-Capturing Location-Allocation Model. *Geographical Analysis,* 22(3), 270–279. doi: 10.1111/j.1538-4632.1990.tb00210.x

Hoen & Koetse. (2014). A Choice Experiment on Alternative Fuel Vehicle Preferences 18 of Private Car Owners in the Netherlands. *Transportation Research Part A*, 2014. 61: 19 199-215.

Hong, S., & Kuby, M. (2016). A threshold covering flow-based location model to build a critical mass of alternative-fuel stations. *Journal of Transport Geography*, 56, 128–137. doi: 10.1016/j.jtrangeo.2016.08.019

Iacono, V. L., Symonds, P., & Brown, D. H. (2016). Skype as a Tool for Qualitative Research Interviews. *Sociological Research Online*, 21(2), 103–117. doi: 10.5153/sro.3952

Jacobson, M. Z. (2005). Cleaning the Air and Improving Health with Hydrogen Fuel-Cell Vehicles. *Science*, 308(5730), 1901-1905. doi:10.1126/science.1109157

Kang, J. E., & Recker, W. (2015). Strategic Hydrogen Refueling Station Locations with Scheduling and Routing Considerations of Individual Vehicles. *Transportation Science*, 49(4), 767–783. doi: 10.1287/trsc.2014.0519

Kang, J.E., and W. W. Recker. (2014). Measuring the inconvenience of operating an alternative fuel vehicle. *Transportation Research Part D*, 2014. 27: 30-40.

Kang, J.E., T. Brown, W.W. Recker, and G.S. Samuelsen. 2014. Refueling hydrogen fuel cell vehicles with 68 proposed refueling stations in California: Measuring deviations from daily travel patterns. *International journal of hydrogen energy*, 2014. 39.7: 3444-3449.

Kelley, S., & Kuby, M. (2013). On the way or around the corner? Observed refueling choices of alternative-fuel drivers in Southern California. *Journal of Transport Geography*, 33, 258–267. doi: 10.1016/j.jtrangeo.2013.08.008

Kelley, S., & Kuby, M. (2017). Decentralized refueling of compressed natural gas (CNG) fleet vehicles in Southern California. *Energy Policy*, 109, 350-359. doi:10.1016/j.enpol.2017.07.017

Kelley, S. (2018). Driver Use and Perceptions of Refueling Stations Near Freeways in a Developing Infrastructure for Alternative Fuel Vehicles. *Social Sciences*, 7(11), 242. doi: 10.3390/socsci7110242

Kitamura, R. and D. Sperling. (1987). Refueling Behavior of Automobile Drivers. *Transportation Research A*. 21A(3):235-245.

Krafft, A., Kelley, S., Kuby., M., Lopez, J., Stotts, R (In Review 2020). Hydrogen Refueling Station Consideration and Driver Experience in California. *Transportation Research Record.*

Kuby, M. (2019). The opposite of ubiquitous: How early adopters of fast-filling alt-fuel vehicles adapt to the sparsity of stations. *Journal of Transport Geography*, 75, 46–57. doi: 10.1016/j.jtrangeo.2019.01.003

Kuby, M., Kelley, S. B., & Schoenemann, J. (2013). Spatial refueling patterns of alternative-fuel and gasoline vehicle drivers in Los Angeles. *Transportation Research Part D: Transport and Environment*, *25*, 84-92. https://doi.org/10.1016/j.trd.2013.08.004

Kuby, M., & Lim, S. (2005). The flow-refueling location problem for alternative-fuel vehicles. *Socio-Economic Planning Sciences*, 39(2), 125–145. doi: 10.1016/j.seps.2004.03.001

Kurani, K. S., Caperello, N., Tyreehageman, J., & Davies, J. (2018). Symbolism, signs, and accounts of electric vehicles in California. *Energy Research & Social Science*, 46, 345–355. doi: 10.1016/j.erss.2018.08.009

Kurtz, J., Sprik, S., & Bradley, T. H. (2019). Review of transportation hydrogen infrastructure performance and reliability. *International Journal of Hydrogen Energy*, 44(23), 12010–12023. doi: 10.1016/j.ijhydene.2019.03.027

Lakshman, M., Sinha, L., Biswas, M., Charles, M., & Arora, N. K. (2000). Quantitative Vs qualitative research methods. *The Indian Journal of Pediatrics*, 67(5), 369–377. doi: 10.1007/bf02820690

Lines, L., Kuby, M., Schultz, R., Clancy, J., & Xie, Z. (2008). A rental car strategy for commercialization of hydrogen in Florida. International Journal of Hydrogen Energy, 33(20), 5312–5325. doi: 10.1016/j.ijhydene.2008.05.102

Lopez Jaramillo, O., Stotts, R., Kelley, S., & Kuby, M. (2019). Content Analysis of Interviews with Hydrogen Fuel Cell Vehicle Drivers in Los Angeles. *Transportation Research Record: Journal of the Transportation Research Board*, 2673(9), 377–388. doi: 10.1177/0361198119845355

Lu, C., Rong, K., You, J., & Shi, Y. (2014). Business ecosystem and stakeholders' role transformation: Evidence from Chinese emerging electric vehicle industry. Expert Systems with Applications, 41(10), 4579–4595. doi: 10.1016/j.eswa.2014.01.026

Mann & Abraham, (2006). "The Role of Affect in UK Commuters' Travel Mode Choices: An Interpretative Phenomenological Analysis" *PubMed - NCBI*. Accessed February 1, 2020. https://www.ncbi.nlm.nih.gov/pubmed/16613647.

Martin, E., Shaheen, S. A., Lipman, T. E., & Lidicker, J. R. (2009). Behavioral response to hydrogen fuel cell vehicles and refueling: Results of California drive clinics. *International Journal of Hydrogen Energy*, 34(20), 8670–8680. doi: 10.1016/j.ijhydene.2009.07.098

Melaina, M., J. Bremson, and K. Solo. (2013). Consumer Convenience and the Availability of 1 Retail Stations as a Market Barrier for Alternative Fuel Vehicles. Technical Report No. 2 NREL/CP-5600-56898.

Melendez, M. (2006). Transitioning to a hydrogen future: learning from the alternative fuels experience, Technical Report No. NREL/TP-540-39423.

Miralles-Guasch et al., (2014). On user perception of private transport in Barcelona Metropolitan area: an experience in an academic suburban space. Journal of Transport Geography, 36, 24-31

Mirhassani, S. A., & Ebrazi, R. (2013). A Flexible Reformulation of the Refueling Station Location Problem. *Transportation Science*, 47(4), 617–628. doi: 10.1287/trsc.1120.0430

NEXO Fuel Cell. (n.d.). Retrieved from https://www.hyundaiusa.com/us/en/vehicles/nexo

Nicholas, M. A. (2010). Driving demand: What can gasoline refueling patterns tell us about planning an alternative fuel network? *Journal of Transport Geography*, *18*(6), 738–749. doi: 10.1016/j.jtrangeo.2010.06.011

Nicholas, M. A., & Ogden, J. (2006). Detailed Analysis of Urban Station Siting for California Hydrogen Highway Network. *Transportation Research Record*: Journal of the Transportation Research Board, 1983(1), 121–128. doi: 10.1177/0361198106198300117

Nicholas, M., G. Tal, and J. Woodjack, 2013. California Statewide Charging Survey: What Do Drivers Want? Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C.

Ogden, J., & Nicholas, M. (2011). Analysis of a "cluster" strategy for introducing hydrogaen vehicles in Southern California. *Energy Policy*, 39(4), 1923–1938. doi: 10.1016/j.enpol.2011.01.005

Philipsen, R., Schmidt, T., Heek, J. V., & Ziefle, M. (2016). Fast-charging station here, please! User criteria for electric vehicle fast-charging locations. *Transportation Research Part F: Traffic Psychology and Behaviour*, 40, 119–129. doi: 10.1016/j.trf.2016.04.013

Papinski & Doherte (2009). Exploring the route choice decision-making process: A comparison of planned and observed routes obtained using person-based GPS. *Transportation Research Part F*, 12, 347–35

Ramea, K. (2019). An Integrated Quantitative-Qualitative Study to Monitor the Utilization and Assess the Perception of Hydrogen Fueling Stations. *International Journal of Hydrogen Energy*, 2019. 44(33): 18225–18239.

Roche, M. Y., Mourato, S., Fischedick, M., Pietzner, K., & Viebahn, P. (2010). Public attitudes towards and demand for hydrogen and fuel cell vehicles: A review of the evidence and methodological implications. *Energy Policy*, 38(10), 5301–5310. doi: 10.1016/j.enpol.2009.03.029

Roshan, B. & Deeptee, P. (2009). Justifications for qualitative research in organisations: a step forward. *The Journal of Online Education*, 1, 1-7.

Stephens-Romero, S. D., Brown, T. M., Kang, J. E., Recker, W. W., & Samuelsen, G. S. (2010). Systematic planning to optimize investments in hydrogen infrastructure deployment. *International Journal of Hydrogen Energy*, 35(10), 4652–4667. doi: 10.1016/j.ijhydene.2010.02.024

Toyota Mirai – The Turning Point. (n.d.). Retrieved from https://www.toyota.com/mirai/fcv.html

Weyant, J. P. (2010, September 8). Accelerating the development and diffusion of new energy technologies: Beyond the "valley of death". Retrieved from https://www.sciencedirect.com/science/article/pii/S0140988310001295

Woodjack, J., Garas, D., Lentz, A., Turrentine, T., Tal, G., & Nicholas, M. (2012). Consumer Perceptions and Use of Driving Distance of Electric Vehicles. Transportation Research Record: *Journal of the Transportation Research Board*, 2287(1), 1–8. doi: 10.3141/2287-01

Wongpakaran et al. (2013). “A Comparison of Cohen’s Kappa and Gwet’s AC1 When Calculating Inter-Rater Reliability Coefficients: A Study Conducted with Personality Disorder Samples.” *BMC Medical Research Methodology* 13 (1): 61. https://doi.org/10.1186/1471-2288-13-61.

Queirós, A., Faria, D., & Almeida, F. (2017). Strengths and limitations of qualitative and quantitative research methods. *European Journal of Education Studies*, 0. Retrieved from https://oapub.org/edu/index.php/ejes/article/view/1017

Zhang, L., Yu, J., Ren, J., Ma, L., Zhang, W., & Liang, H. (2016). How can fuel cell vehicles bring a bright future for this dragon? Answer by multi-criteria decision making analysis. *International Journal of Hydrogen Energy*, 41(39), 17183–17192. doi: 10.1016/j.ijhydene.2016.08.044

2018 Annual Evaluation of Fuel Cell Electric Vehicle ... (2018, July). Retrieved July 28, 2019, from https://ww2.arb.ca.gov/sites/default/files/2019-11/AB8_report_2018_print_ac.pdf

2020 Honda Clarity Fuel Cell – Hydrogen Powered Car: Honda. (n.d.). Retrieved from https://automobiles.honda.com/clarity-fuel-cell