Barriers to the adoption of fuel cell vehicles

Hardman, Scott; Shiu, Eric; Steinberger-Wilckens, Robert; Turrentine, Tom

DOI:
10.1016/j.tra.2016.11.012

License:
Creative Commons: Attribution-NonCommercial-NoDerivs (CC BY-NC-ND)

Document Version
Peer reviewed version

Citation for published version (Harvard):
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*, vol. 95, pp. 166–182. https://doi.org/10.1016/j.tra.2016.11.012

Barriers to the adoption of fuel cell vehicles: A qualitative investigation into early adopters attitudes

Scott Hardman[*1], Eric Shiu[2], Robert Steinberger-Wilckens[3] & Tom Turrentine[4]

[*]scott@bluevineconsultants.com

[1]Blue Vine Consultants, Birmingham Research Park, Edgbaston, B15 2SQ

[2]Birmingham Business School, University of Birmingham, Edgbaston, Birmingham, B15 2TY

[3]Chemical Engineering, University of Birmingham, Edgbaston, B15 2TT

[4]Institute of Transportation Studies, University of California Davis, Davis, California, 95616

Abstract

Fuel Cell Vehicles (FCVs) are now approaching wider spread consumer adoption, with some of the largest OEMs having released or about to release commercial products. However, research into consumer perceptions of FCVs has been extremely limited to date. This paper investigates automotive early adopter attitudes toward FCVs by performing interviews with high-end BEV owners. This sample was chosen as based on a preceding study it was expected that these adopters would have a greater level of awareness and knowledge of FCVs compared to the general population. It was expected that this would lead to more insightful results. In this study 5 consumer barriers to FCV adoption emerge. These are; the lack of hydrogen infrastructure, the source of hydrogen, the inability of FCVs to be recharged from home, cost issues and also concerns about hydrogen safety. This paper goes on to make recommendations on how to solve these consumer barriers stating that; hydrogen infrastructure needs to be pre-developed, hydrogen should be sustainably generated, FCVs should have the ability to be partially charged at home, hydrogen fuel will need to be subsidised in the early market, vehicles need to be positioned in the correct markets, and safety concerns can be mitigated partly through education and outreach. Finally this paper finds that consumers do desire the range of a FCV and there is also consumer demand for FCVs ability to provide emergency back-up power.

1. Introduction

Fuel Cell Vehicles (FCVs) are approaching market entry, with recent developments by automotive companies meaning there are now commercial products on the market. 1,500 orders have been made for the Toyota Mirai in Japan and 331 FCVs are deployed in California at present (California Air Resources Board, 2016). Yet to date, research into consumer attitudes towards FCVs has been limited, which is potentially detrimental to their successful market entry. The purpose of this study is not to build a representative sample of what the market for FCVs is. The purpose is to understand what some of the potential barriers to their adoption by consumers are. By understanding these barriers policy makers, academics and automotive OEMs will be able to work towards solving them.

FCVs have some specific challenges. The most commonly cited technological barriers are high purchase prices and lack of hydrogen refuelling infrastructure. The vehicles are expensive mainly due to the high cost of fuel cells, hydrogen tanks and balance of plant components. All of which are more expensive than their incumbent counterparts. This high cost is due to lack of economies of scale and the specialised materials used in their construction (Hardman et al., 2015). FCVs also have a unique infrastructure challenge. When internal combustion engine vehicles (ICEVs) were introduced to the market in the late 1800s there was already an existing distribution network for petroleum. This existed for farm equipment, machinery and lighting (Geels, 2005; Melaina, 2007). In these early days it was relativity easy to access petroleum to refuel ICEVs. Even early adopters of Battery Electric Vehicles (BEVs) were able to charge their vehicles off existing electrical grids, albeit at a slow charge rate (Hardman et al., 2013; Hardman and Steinberger-Wilckens, 2014). For FCVs there is no existing infrastructure that consumers have access to. This lack of infrastructure is often cited as a barrier to their adoption. These two barriers, high costs and lack of infrastructure, are cited by academics and researchers (Cheng et al., 2007; Offer et al., 2011; Park et al., 2011; Schoots et al., 2010; Thomas, 2009; US DOE, 2013). They are not based on empirical evidence from consumers.

The interviewees within this sample are all early adopters of Alternative Fuel Vehicles (AFVs), specifically BEVs. The sample is adopters of Tesla BEVs. These adopters have previously been referred to as high-end BEV adopters (Hardman et al., 2016b). This sample was chosen for a number of reasons. Firstly the general population has been shown to have a low awareness of FCVs and BEVs (Campbell, 2014; O'Garra et al., 2005), and also a low willingness to adopt the technology (Campbell, 2014). Members of the general population are also not representative of early adopters (Rogers, 2003). The sample of BEV early adopters was therefore chosen because they are more likely than later adopters to buy new technologies. Something which they have clearly demonstrated this with actual purchase behaviours. Therefore these consumers are likely to be the first buyers of future innovations within the sector (Rogers, 2003). This idea of early adopters explained in more detail in the literature review. Furthermore, Tesla BEV adopters were chosen because the preceding study found that high-end adopters are more representative of typical early adopters than low-end BEV adopters (Hardman et al., 2016b). They have high incomes, high-educations and a high number of household vehicles. FCVs are expected to be expensive in initial market entry which is a shared trait with Tesla BEVs (Hardman et al., 2013; Toyota, 2015). It was therefore hypothesised that high-end BEV adopters would have good awareness and knowledge of FCVs and would be similar to the types of people that will adopt FCVs in the future.

Making comparisons between the Tesla Model S which has a 285 mile range and FCVs is also valuable. When FCVs become more commercially viable BEVs with ranges of 200 miles and above will be more numerous. Tesla, Ford, Audi, Porsche, BMW, VW and Nissan have all indicated that they will introduce BEVs with ranges of 200 miles by 2018 (Car Magazine, 2015a, 2015b; Chevrolet, 2015; Green Car Reports, 2015a, 2015b). Renault and GM have already launched vehicles with ranges of more 200 miles (Chevrolet, 2015; Renault, 2016), both of these were released for sale at the end of 2016. Therefore, FCVs are likely to be compared to BEVs with higher ranges than they are compared to at present. This will clearly have implications for their success as one of the key benefits of a FCV is its long range, along with faster refuelling. If consumers have adopted 200 mile BEVs will these attributes of FCVs still be valued? It should be noted that there are some differences between high-end BEVs such as the Tesla Model S and FCVs such as the Toyota Mirai. Both vehicles have high purchase prices, are zero emission, have electric drivetrains, use different infrastructure to ICEVs, are a new technology and so on. They do have different driving characteristics with the Tesla Model S being a high performance BEV and the Toyota Mirai having performance closer to that of a standard ICEV. This means that preferences around how the vehicles perform will differ between high-end BEVs and FCVs.

The outline of this paper is as follows. First this paper reviews current literature relevant to this study. The first set of literature is on diffusion of innovations or Rogers theory. The second is literature that explores the adoption of AFVs. This literature includes research into BEVs and hybrid electric vehicles (HEVs). The review then moves on to literature that investigates the adoption of FCVs along with literature that explores the barriers to adoption of FCVs. Finally, the literature review highlights the shortcomings of the existing research in this area. The methods used in this study are then outlined, including how respondents were recruited, the interview procedure and an explanation of grounded theory analysis. Then the results are presented, the results section first outlines the socio-economic profile of the adopters in this study. This is followed by a brief discussion around the reasons for purchasing and the benefits of owning a BEV. This discussion helps build context for the main body of results which explore the barriers to adoption of a FCV, which discusses each barrier in detail. Next recommendations for FCVs are made and finally the conclusions of this study are presented.

2. Literature Review

2.1. Diffusion of Innovations

Diffusion of Innovations theory was first published in 1962, it is commonly referred to as 'Rogers Theory' after its author. The book was published in its 4th edition in 2003 (Rogers, 2003). Rogers theory has come to be the most widely cited innovation theory. The theory explains how and why some new technologies become adopted by consumers and eventually become market leaders. Two specific aspects of the theory are relevant for this study. These are the idea of innovators and early adopters and also relative advantage.

Innovators and early adopters are collectively referred to as early adopters. These people are the first to adopt a new technology and are different to the general population or majority. Early adopters are highly educated, have high incomes, positive attitudes towards science and technology, and are willing to accept change amongst other things. These people are significantly different from the general population and in order for any new technology to diffuse through the market it first needs to be purchased by early adopters. Later adopters, people who make up the majority of the market, do not purchase new technologies. They follow the purchase decisions of early adopters. When considering the market entry of new technologies it is crucial to survey people who are likely to be the first buyers of the technology. If later adopters are surveyed their opinions will not be correlated to the opinions of the people who are likely to buy the technologies.

Relative advantage is the degree to which a new technology is perceived as superior to the technology that it is looking to replace or is competing with. Rogers states that in order for innovations to be purchased by early adopters they need to have relative advantage. This means that they must be perceived as having benefits compared to the incumbent technology and any competing technologies. If the new technology is perceived as having no benefits early adopters will not be motivated to buy it. The idea of relative advantage is supported by an abundance of researchers who find that in order for new technologies to succeed they must have beneficial attributes (Brockman and Morgan, 1995; Freeman, 1995; Hardman et al., 2013; Ryan and Gross, 1950; Summer and Agarwal, 1997).

2.2. AFV Consumer Adoption Research

Studies investigating consumer responses to AFVs have been on-going for over two decades (Brownstone et al., 1996; Bunch et al., 1993; Golob et al., 1997; Kurani et al., 1994; Tompkins et al., 1998). The vast majority of this research investigated HEVs (Caperello and Kurani, 2012; Graham-Rowe et al., 2012; Heffner et al., 2007) and BEVs (Campbell, 2014; Caperello et al., 2015; Egbue and Long, 2012; Hardman and Tal, 2016; Hidrue et al., 2011; Plötz et al., 2014; Skippon and Garwood, 2011; Turrentine et al., 2011). Some studies investigated ICEVs fuelled with natural gas or biofuels (Brownstone et al., 1996; Golob et al., 1997; Tompkins et al., 1998). Research by (Bunch et al., 1993) investigated demand for clean vehicles and their attributes by surveying 700 people in a stated preference study. The study conducted this research in the context of BEVs and methanol, ethanol, compressed natural gas or propane fuelled vehicles. Further studies from this time also used quantitative methods to explore the issue of consumer adoption of AFVs including research from (Brownstone et al., 1996; Kurani et al., 1996). A study by (Kurani et al., 1994) used a qualitative methodology in an attempt to understand household vehicle choice. Since the early 1990s research efforts in this areas have continued. A particular focus has been on BEVs. Studies that investigate the adoption of BEVs have used quantitative (Axsen and Kurani, 2013; Krause et al., 2013; Kurani et al., 1996; Tal et al., 2014), and qualitative methodologies (Caperello et al., 2013; Caperello and Kurani, 2012; Hardman and Tal, 2016; Turrentine and Kurani, 2007). Further studies have conducted trials where consumers are allowed to use a BEV for a limited period of time. During a 9 month trial in the US participants were surveyed before, during and after the study in order to assess their perceptions towards BEVs (Turrentine et al., 2011). None of these studies considered FCVs in their investigations though the results are insightful as to how consumers make decisions regarding purchases of new vehicle types.

2.3. FCV Consumer Adoption Research

The body of research investigating consumer perceptions of FCVs is far more limited. The majority of studies assess the attitudes of members of the general public who have no experience of a FCV or even an AFV. Some studies investigate consumers who have been on a FC powered bus or taxi. Two studies assess the perceptions of consumers who have driven in an FCV in a vehicle trial (Hardman et al., 2016a; Martin et al., 2009). The earliest studies considering consumer barriers to FCVs were based on case studies or the opinion of the authors. These studies state cost to be a barrier to adoption (Chalk et al., 1996), along with lack of refuelling infrastructure (Chalk et al., 2000). An early study by (Schulte et al., 2004) drew on lessons from the introduction of other technologies and then made recommendations for FCVs. The authors found that successful market introduction is dependent upon consumer acceptance and infrastructural development. They also suggested that the publics' opinions of FCVs are likely to be different from the scientific communities. They believed that for this reason the general public might have safety concerns, which may hinder acceptance. They suggest that education and marketing activities could increase consumer acceptance. A study by (Hardman et al., 2013) conducted historical case studies. This study found that the success of FCVs is dependent upon developing a targeted market entry strategy. A further study found that speeding up the development of a hydrogen infrastructure would increase FCVs chances of market success (Hardman and Steinberger-Wilckens, 2014).

Literature that gathers data from consumers, rather than from case studies, can be more insightful in understanding consumer perceptions. A study by Altman et al (Altman et al., 2004) looked to assess the perception of hydrogen and FCVs in three different countries. The researchers administered surveys in locations where FC bus trials were underway. The findings from Luxembourg, the UK and Australia indicated that in general there is support for FCVs. They found no objections to FCVs and consumers believed hydrogen to have positive environmental impacts. A UK study assessed consumer attitudes toward FCVs through the use of a survey, which yielded 400 responses. An initial finding was that less than 20% of the population had heard of hydrogen and fuel cells (O'Garra et al., 2005), but that perceptions of the technology were positive. Two German studies found that consumer attitudes toward hydrogen were generally positive and there were not safety concerns amongst the public (Altman et al., 2004; Dinse, 2000). A study based in Stockholm, which gathered data from people who had ridden on a FC bus, came to the same conclusion (Haraldsson et al., 2006). A study of London Taxi drivers by (Mourato et al., 2004) found that they did not have any safety concerns about hydrogen as a vehicle fuel. A study by (Campbell, 2014; Campbell et al., 2012) in the UK found that intent to adopt was low and that only 8% of people have good knowledge of FCVs.

Within the literature there are two studies that sample people who have actually experienced a FC passenger vehicle. The study by Martin et al (Martin et al., 2009) allowed consumers to drive a FCV and witness how the vehicles are refuelled. The study recruited 182 participants and held pre and post-drive interviews. Consumers did not have safety concerns and the ride and drives were found to improve consumer's opinions about FCV performance. The authors acknowledge that there is limited published research in this area. They highlight the need for more studies working towards understanding consumer perceptions of FCVs. The second study (Hardman et al., 2016a) allowed 30 people in the UK to drive a FCV. These people were surveyed after their trials. It was found that drivers have concerns about the high price of FCVs and the current lack of refuelling infrastructure.

2.4. Barriers to Adoption

The term 'barriers to adoption' is without an academic definition. However it is used in a wide number of fields in exploring what the potential difficulties are with the introduction of a new technology or innovation from a consumer perspective (Aggarwal et al., 1998; Browne et al., 2012; Diamond, 2009; Egbue and Long, 2012; Parente and Prescott, 1994; Stephens, 2014). (Diamond, 2009) suggests that the adoption of a new vehicle type has similar barriers as experienced by any new innovation, namely high costs, low consumer knowledge and low risk tolerance by potential adopters. (Aggarwal et al., 1998) suggests that perceptions of risk, understanding the benefits of a new technology, and lack of information can be barriers to market entry for new technologies. A white paper by (Stephens, 2014) explored non-financial barriers to the adoption of new light duty vehicle technologies. The study found that potential barriers are limited vehicle ranges, lack of refuelling infrastructure, long refuelling times, limited number of vehicle models, unfamiliarity with the technology and risk perceptions.

For FCVs the literature identifies three specific barriers to adoption. These are the development of infrastructure, cost reductions and perceptions of safety (Ball and Wietschel, 2009; Chalk et al., 2000; Hardman et al., 2016a; Huijts et al., 2012; Keles et al., 2008; Martin et al., 2009; Melaina et al., 2012; Roche et al., 2010). Research by (Schulte et al., 2004) also identifies 'consumer acceptance' as a barrier, the authors do not expand on what consumer acceptance entails. It is a potential shortcoming of the literature that only three barriers to FC adoption have been identified. The automotive sector is a large and complex socio-technical system. It contains a diverse array of consumers who are likely to have differing attitudes toward FCVs. It is therefore likely that more than three barriers to the adoption of FCVs exist.

2.5. Limitations of the Current Literature

Table 1 shows a summary of the literature exploring barriers to adoption using consumer data. These studies either use questionnaires or telephone surveys to gather the data. The literature is limited because it samples members of the population and not early adopters. This means that the perceptions of the consumers will not be indicative of the perceptions of consumers who might actually adopt the vehicles.

Author	Sample Size	Sample Characteristics	Methodology
(Dinse, 2000)	Not Stated	Employees of BMW Group	Questionnaire Surveys
(Altman et al., 2004)	Not Stated	Members of the general public in cities with FC bus trials	Telephone Administered Surveys
(Mourato et al., 2004)	99	Drives of conventional (ICEV) Taxi's in London	Questionnaire Survey
(O'Garra et al., 2005)	420	Members of the general public in London	Telephone Administered Surveys
(Haraldsson et al., 2006)	518	Members of the general population in Stockholm who have ridden on a fuel cell bus	Questionnaire Surveys
(Martin et al., 2009)	182	Participants in "ride and drive" of an FCV in California.	Pre and post ride and drive questionnaire surveys
(Hardman et al., 2016a)	30	Participants in a FCV vehicle trial in the UK	Post-trial questionnaire surveys

Table 1: Outline of fuel cell vehicle literature that gathers empirical evidence to support their findings from consumers, who are mostly members of the general public.

As was previously mentioned Rogers' theory (Rogers, 2003) makes it clear that the first adopters of new technologies are remarkably different to the general population. This is supported by an abundance of research (Allan and Wolf, 1978; Brockman and Morgan, 1995; Dickerson et al., 1983; Fliegel et al., 1966; Freeman, 1995; Saaksjarvi, 2003; Summer and Agarwal, 1997). There is also a large body of automotive adoption literature that finds that the first buyers of new automotive technologies differ from later adopters (Campbell et al., 2012; Caperello and Kurani, 2012; Carley et al., 2013; Gnann et al., 2015; Hardman and Tal, 2016; Heffner et al., 2005; Hidrue et al., 2011; Kurani et al., 1996; Lane and Potter, 2007; Plötz et al., 2014; Turrentine et al., 2011; Williams and Kurani, 2007). Therefore studies investigating consumer attitudes toward FCVs should sample consumers who are actual early adopters, rather than members of the general population.

The lack of relevant literature is detrimental for the growth of the FCV market. In the past, poorly planned market introductory strategies have hindered the diffusion of new technologies (O'Garra et al., 2005; Schulte et al., 2004). Based on the current literature it appears that consumers would be willing to adopt a FCV if costs come down, safety concerns are addressed and infrastructure is developed. There may however be additional barriers that the current literature has been unable to detect due to the limitations of quantitative research methods. A further limitation of the literature is that FCVs are considered in the context of ICEVs. Despite ICEVs being the incumbent they are not the only automotive technology currently within the market place. BEVs are now taking market shares from ICEVs, and in some nations are taking up to 13% of all new vehicle sales, with around 1.2 million now deployed worldwide (International Energy Agency, 2016). Therefore, FCVs need to be viewed as superior to ICEVs and BEVs in order to be adopted. Indeed, it has previously been suggested that FCVs be considered in the context of other AFVs and not just ICEVs (Roche et al., 2010).

3. Methods

The methodology used in this paper is qualitative research in the form of in-depth face to face interviews. Qualitative research was selected over quantitative research for a number of reasons. First in order to build a quantitative questionnaire survey a certain level of understanding of the topic in question is needed. This information is needed to build an effective questionnaire. In the case of FCVs the literature is not rich enough to allow this, therefore a quantitative method would miss important topics that could not be anticipated with foresight. Second qualitative research is able to provide more in-depth information. This is because during in-depth interviews more time can be spent exploring topics. Interviewers can ask follow-up questions to draw more information out of the interviewee. This results in richer data and uncovers topics and themes that may be missed in a quantitative investigation. The qualitative method utilised in this paper is one of semi-structured interviews using the approach of grounded theory analyses. This is outlined below along with the recruitment method.

3.1. Recruitment

Between the months of March and June 2015 interviews took place with 39 owners of Tesla BEVs. Prior to the study it was expected that an appropriate number of interviews would be 30. At this point it was expected that theoretical saturation would occur and no new themes or topics would emerge. Therefore the sample of 39 early adopters is a sufficient sample size and is similar to previous qualitative studies (Caperello et al., 2013; Graham-Rowe et al., 2012; Kurani et al., 1996). Interviewees were recruited via word of mouth and through electric vehicle clubs. Once an interviewee had been interviewed they were asked if they knew any other person who would be willing to participate. They were asked if they would forward a participant information letter to them. This same letter was sent to a number of electric vehicle clubs, who circulated it around their members. This methodology is commonly referred to as snowball sampling, as over time the number of interviews grows in an almost exponential fashion. This resulted in 39 interviews all in the San Francisco Bay and the Sacramento Valley areas in Northern California. Interviews typically lasted 1 hour, with some lasting up to 1 hour 30 minutes and some only lasting 30 minutes due to time constraints on the interview day. For this reason some of the results in this paper are based on 36 of the interviews as 3 interviewees were not asked a particular question. This is indicated where the data is presented. The majority of the data is based on all 39 interviews.

The interview location was selected as Northern California due to the high number of BEVs registered there. San Francisco for example has the highest proportion of new vehicles that are electric in the United States, with 6% of new vehicles being BEVs or PHEVs (Lutsey et al., 2015). Therefore it would be easier to access interviewees in this area as opposed to an area with a low BEV market share. The area was also chosen as it is a region where FCVs are being rolled out, with 179 FCVs already being registered in California at the time of undertaking this research (California Air Resources Board, 2015). There is a hydrogen refuelling station located in the sample area. This region therefore was selected due to the strength of the BEV market and because it is a potential future market region for FCVs.

3.2. Interview Procedure

All interviews were undertaken by the same interviewer to prevent any inter-interviewer variability. Firstly the interviewees' education, careers, current employment, household vehicles and other topics related to their background were explored. This allowed an understanding of the interviewees' socio-economic status. Interviewees were then asked about their reasons for purchasing their current BEV in order to understand the motivational factors for adoption. Then the benefits of ownership were explored in order to understand the advantages of owning a high-end BEV. Exploring both reasons for purchase and benefits of owning a BEV is important, as there may be differences between answers to each question. Motivational factors are something that consumers will consider in a pre-purchase situation. These factors result in adoption. Benefits of ownership are what consumers experience post-purchase. They are important in the confirmation stage and can influence future purchases and ideally cause repeat purchases.

The interviews then moved on to discuss FCVs. Interviewees were asked if they were aware of FCVs, and then in order to ascertain what level of knowledge the interviewees had of FCVs they were asked what they knew about the vehicles. They were then asked what the barriers to them adopting a FCV would be. Finally interviewees were asked two questions which related to specific attributes of FCVs. First interviewees were asked what range they currently get from their BEV, if they would desire more range, and what range they would desire. This was in order to understand if there is consumer demand for the range of a FCV. Finally, consumers were asked if they would want their vehicle to be able to provide home power. They were first asked if they would desire the feature, then they were asked how much they would be willing to pay for such a feature.

3.3. Grounded Theory Analysis

Grounded theory is a systematic methodology that can be used to guide data analysis and collection for qualitative studies. Grounded theory analysis can cause confusion amongst researchers who believe that it is a 'theory'. It is not a theory it is a methodological approach to collecting data. This approach can lead to the development of a new theory or theories. Often the result of using this methodology are new insights or results in a given research area. The benefit of using grounded theory analysis is that results more accurately represent real world phenomenon. This method was chosen due to it providing a systematic approach that can be followed and because the results would be free from bias. The way in which the study was carried out is outlined below. When formulating questions for the study all language was kept neutral so that the way in which questions are asked does not influence the results of the study. Further to this all questions are asked to each interviewer using the same language to prevent any difference between interviews.

Grounded theory analysis is described in detail in (Bryman and Bell, 2015). Throughout the data collection process research notes are kept, and some limited data from the interviews is recorded. This allows researchers to keep track of trends and be aware of when theoretical saturation has occurred. After all interviews were complete they were transcribed and imported into the qualitative analysis program NVivo. All transcripts were reviewed and common themes were analytically coded using nodes. After all transcripts had been analysed it is possible to group different nodes into categories with other nodes that are related to the same issue. The codes and categories are developed from the data and not by any pre-existing conceptualisations. This allows the discovery of basic social processes in the data. The advantage of using this approach is that it allows underlying issues to emerge without any preconceptions influencing the researcher. Thus allowing themes to arise on their own and not due to any expectancy bias or confirmation bias. This methodology has previously been used in a qualitative study involving 40 consumers who had taken part in a Hybrid Electric Vehicle (HEVs) trial (Graham-Rowe et al., 2012). In order to support the validity of the data presented in this paper quotes are presented along with the interviewee's reference number. This prevents any scepticism emerging from the reader and makes the results more transparent.

4. Results & Discussion

4.1. Sample Characteristics

Most interviewees are director or executive level within their respective companies, or are retired now and were previously in these positions. The ones not in these positions are university professors or medical doctors. Of the 39 interviewed, 19 work in the software or computing industries, mostly in the Silicon Valley area. 4 work in jobs related to the environment, 3 are professors at universities, 4 work in the medical sector, 2 work in the electric vehicle industry and 2 work in engineering. 5 high-end BEV owners do not have careers with any tangible link to the environment, technology or electric vehicles. In the sample level of education is high with 18/39 having completed an undergraduate degree, 11 a masters degree and 7 a doctorate or medical degree. Therefore only 3 had not obtained a university level degree, with 1 of these starting an undergraduate degree but not completing it. 33 males were interviewed in this study, and only 6 females. This is a low representation of females, but is still higher than previous studies (Hardman et al., 2016b). Age of interviewees is spread widely. The youngest interviewee was 35 and the oldest 80. Most interviewees were middle aged with 8 aged 40-49, 10 aged 50-59 and 11 60-69.

Car ownership is high at 2.5 cars per household, which is in alignment with (Hardman et al., 2016b), and is higher than the US average of 1.9. What is interesting in this sample is that 11 households have 2 BEVs and 1 household has 3 BEVs. 11 households do not own any ICEVs, these households have fully transitioned to BEV ownership. A further 5 households don't have any conventional ICEVs, but have HEVs in addition to their BEVs. There are 52 electric vehicles in this study, 41 of these are Tesla BEVs meaning two households have 2 Tesla's. The most common Tesla BEV in the study is the Model S 85, of which there are 18. The non-Tesla BEVs that adopters also own include 4 Nissan Leafs, 5 Toyota Rav4 BEVs, 1 Smart BEV and 1 THiNK City. Table 2 shows the socio-economic profile of the individual interviewees.

Interviewee Number	Gender	Number of Household Cars	Number of Household BEVs	Primary Vehicle	Highest Level of Formal Education	Age	Profession
1	Male	3	1	Tesla Model S P85	Bachelors	65	Electric Auto Industry
2	Male	2	1	Tesla Model S 60	Masters	35	Electric Auto Industry
3	Male	2	1	Tesla Model S 85	Masters	45	Software or Computing
4	Female	5	2	Tesla Model S 85	Masters	45	Law
5	Male	1	1	Tesla Model S 85	Bachelors	70	Engineering
6	Male	2	2	Tesla Model S P85	Bachelors	50	Coffee Shop Owner
7	Male	1	1	Tesla Model S P85D	Doctorate or Equivalent	70	Professor
8	Male	2	2	Tesla Model S 85	Doctorate or Equivalent	65	Professor
9	Female	3	1	Tesla Model S 60	Masters	50	Environmental
10	Male	3	1	Tesla Model S P85	Doctorate or Equivalent	50	Professor
11	Male	1	1	Tesla Model S 85	Masters	70	Medicine
12	Male	2	1	Tesla Model S P85	Doctorate or Equivalent	50	Medicine
13	Male	2	1	Tesla Model S P85	Masters	65	Environmental
14	Male	4	1	Tesla Model S 85	Masters	60	Software or Computing
15	Female	3	1	Tesla Model S 85	Bachelors	45	Business Consultancy
16	Male	3	2	Tesla Model S P85	Bachelors	50	Software or Computing
17	Male	3	1	Tesla Model S P85	Doctorate or Equivalent	45	Medicine
18	Male	2	1	Tesla Model S P85	Bachelors	65	Bio-technology
19	Female	2	2	Tesla Model S 85	Bachelors	60	Environmental
20	Male	4	1	Tesla Roadster	Masters	55	Environmental
21	Male	3	2	Tesla Roadster	Some Undergraduate	65	Software or Computing
25	Male	3	2	Tesla Roadster	Masters	65	Software or Computing
26	Male	3	3	Tesla Model S 85	Masters	75	Engineering
22	Male	2	1	Tesla Model S P85	Bachelors	50	Software or Computing
23	Male	3	2	Tesla Model S P85	Bachelors	35	Software or Computing
24	Male	2	2	Tesla Model S 85	Bachelors	80	Software or Computing
27	Male	3	2	Tesla Model S 85	High School	60	Software or Computing
28	Male	1	1	Tesla Model S 85	Bachelors	35	Software or Computing
29	Male	2	1	Tesla Model S 85	Doctorate or Equivalent	60	Software or Computing
30	Male	2	1	Tesla Model S 85	Bachelors	75	Software or Computing
31	Male	2	2	Tesla Model S P85	Doctorate or Equivalent	65	Venture Capitalist
32	Male	3	1	Tesla Model S P85	Bachelors	40	Software or Computing
33	Male	2	1	Tesla Model S 85	Bachelors	50	Software or Computing
34	Female	3	1	Tesla Model S P85	Masters	40	Medicine
35	Male	1	1	Tesla Model S P85	Bachelors	55	Software or Computing
36	Male	2	1	Tesla Model S P85D	Bachelors	40	Software or Computing
37	Male	4	1	Tesla Model S 85	Bachelors	40	Software or Computing
38	Male	3	1	Tesla Model S 85	Bachelors	50	Software or Computing
39	Female	2	1	Tesla Model S 85	High School	35	Software or Computing

Table 2: Gender, number of household cars, number of household BEVs, primary vehicle, level of education, age and profession of all 39 interviewees.

4.2. Reasons for Purchase

Adopters of high-end BEVs are characterised by an enthusiasm for performance vehicles, new technologies or the environment. These three attributes were observed during the 39 interviews. There is some overlap between performance, technology and environmental motivations for purchase, with some interviewees being enthusiastic about all three. Interviewee 7 uses his Model S for drag racing. He has a smart watch and smart phone but is also interested in the environment.

They have solar panels and had previously owned a Nissan Leaf and Chevy Volt. Their motivation is threefold, however most interviewees have an affinity to just one or two of these areas. A further result of this study is that these consumers are not cost conscious consumers. This is contrary to some existing studies (Caperello et al., 2015). For these interviewees performance and technological or environmental motivations are far more important than cost savings.

4.2.1. High performance adopters

The most prominent reason for adoption of a Tesla is the vehicles high performance, mainly the acceleration. This was mentioned by 69.2% (27/39) of interviewees as being a reason for purchasing the vehicle. Adopters mentioned this frequently and with much enthusiasm;

"It was fast, and it was fun to drive."
Interviewee 7

"It was good performance which again fit with the [Dodge] *Viper"*
Interviewee 18

These adopters previous vehicles include; a Ferrari 360, a Dodge Viper GTS, a Chevrolet Corvette, a Lotus Exige, a BMW M3 and a BMW 550i amongst others. These performance oriented consumers are enthused about the acceleration, speed and road handling of their vehicle.

4.2.2. Technological adopters

Some adopters are motivated due to technological reasons. Of particular note is the household with three BEVs. The interviewee is eager to note that he is a climate change sceptic. His reason for adoption was because he liked the technology of the vehicles. There are more interviewees whose reason for adoption is technology-related. Many of these interviewees worked in Silicon Valley for software or computing companies. The high-technology nature of the vehicle was mentioned by 48.7% (19/39) of interviewees.

"I'm a geek at heart, so I just appreciate the technology of this."
Interviewee 3

"I'm an early adopter of all new technologies, I stayed up last night and hit buy on a Apple Watch at 12:01am."
Interviewee 12
(On the day of the release of the new Apple Watch)

4.2.3. Environmental adopters

There are adopters whose motivations are related to environmental concerns. In total 58.9% (23/39) interviewees cited such reasons during the interviews. 7 adopters however had to be given a cue in order to get them to talk about this subject. When asked further questions about the environment these 7 interviewee's answers are without complexity or depth, suggesting that it is not a primary motivator. 16 mentioned environmental reasons without a cue, these people exhibited strong motivation toward environmental protection along with a good understanding of the issue. This therefore suggests that 41% (16/39) have environmental motivations. Another 16/39 interviewees indicated that they didn't have any environmental motivations. Most stated that it was something that they had not given much thought to, or that they were not interested in the environment.

4.2.4. Non-cost conscious adopters

Financial savings due to low running costs are often cited as motivation for purchase of a BEV (Caperello et al., 2015; Hidrue et al., 2011). This was not observed in this study. An emergent theme was that cost savings do not constitute a motivation for these adopters. Only 12/39 (30.7%) of interviewees believed that low running costs were a reason for purchasing a high-end BEV. The remainder of interviewees do not see this as a motivation for adoption. Many indicated that their incomes are high meaning that running costs are not of consequence. Adopters also stated that the Tesla BEVs cost significantly more than their previous vehicle meaning they would not see a financial pay back. As was mentioned in (Hardman et al., 2016b) the difference in purchase price between early adopters' high-end BEV and previous vehicle was between $37,614-41,575. It is unreasonable to expect this kind of investment to be offset by running cost savings.

"It's a nice sweetener to run the car at 3 cents a mile or something like that. But its not like it's going to pay for the car."
Interviewee 19

4.3. Benefits of Ownership

Again three trends emerged as the most significant benefits of owning a high end BEV, however only one of these benefits was the same as one of the reasons for adoption, this was performance. The remaining benefits of owning a high-end BEV are due to their low running costs and the ability to be recharged at home. Again there is some overlap in these areas with some consumers stating all three as a benefit; most respondents stated two of these areas as a benefit.

4.3.1. Home Refuelling

Surprisingly, 31/39 (79.4%) interviewees mention home refuelling as a benefit of owning a high-end BEV. This is unexpectedly high and has been previously mentioned as a 'convenient feature' by (Turrentine et al., 2011). In that study it was not found to be a significant benefit. This is perhaps due to the vehicles in the study having ranges of around 100 miles. In this study of high-end BEVs with EPA estimated ranges of up to 285 miles it is a significant benefit. Interviewees perceive this refuelling method as very convenient. They are aware that the recharging time of a BEV is longer than the time it takes to refuel an ICEV. Interviewees believe that they save time in other ways. First they do not have to take detours from their normal driving routes to refuel their car. Second they believe plugging in a BEV is quicker than waiting for an ICEV to refuel at a petroleum station. Interviewee's explained this;

"Its incredibly convenient having a power cord right outside the door of my house, just spending all of 1 minute to plug it in and have 250 miles ready to go, it couldn't be any easier."
Interviewee 18

"The home use is better because it takes 30 seconds to get out of the car grab the charger and plug it in and in the morning it's the same thing."
Interviewee 14

4.3.2. Performance

With performance being the leading reason for purchasing a high-end BEV it is not surprising that this is also a significant benefit of owning the vehicle; 30/39 (76.9%) interviewees mention this. When talking about the performance of the vehicle, interviewees state that the acceleration and good handling make their vehicle fun to drive.

"The driving of it is so much fun."
Interviewee 19

"I love the way it drives, it is fun to drive."
Interviewee 31

4.3.3. Running Costs

Despite only 12 interviewees stating that running costs are a reason for purchase, 29/39 (74.35%) mention this as a benefit of owning the vehicle. Interviewees mostly spoke about the benefit of low refuelling or recharging costs. Some interviewees had accurate knowledge of their recharging costs. These people had smart meters that they regularly monitored. Low maintenance costs also contribute to the low running costs. Interviewees state that the service costs were much lower compared to what they had experienced with ICEVs. The maintenance costs of BEVs are lower than ICEVs mainly due to the drive train having far fewer moving parts and components that need replacing regularly.

"There is no moving parts; you've got to replace tires that's about it."
Interviewee 19

4.4. Barriers to the Adoption of Fuel Cell Vehicles

All 39 interviewees are aware of FCVs, out of these, 35 have good knowledge. This is due to the interviewee's high level of education, careers in technical professions and because they are involved in AFVs, having adopted a BEV. Additionally, adopters are located close to areas where FCVs are being rolled out. Interviewees are aware of some of the current FCVs being developed. They are aware of hydrogen infrastructure roll out in California. They are also aware of issues related to FCVs such as hydrogen generation. This high level of knowledge means that exploring the barriers to their adoption resulted in insightful data. In total 12 different barriers emerged, these can be seen in Figure 1. Whether or not these are technical barriers to FCV market introductions is not important, these are what consumers themselves perceive to be barriers. Of the 12 barriers, 5 emerged as prominent themes during the interviews. These were related to infrastructure, the source of hydrogen, home charging, cost, and safety issues. The highest number of barriers mentioned by a single interviewee was 8. Most mention far fewer and the average number of barriers mentioned by each respondent is 3. Only 1 interviewee did not state any barriers to adopting a FCV, this was due to a low level of knowledge of the vehicles.

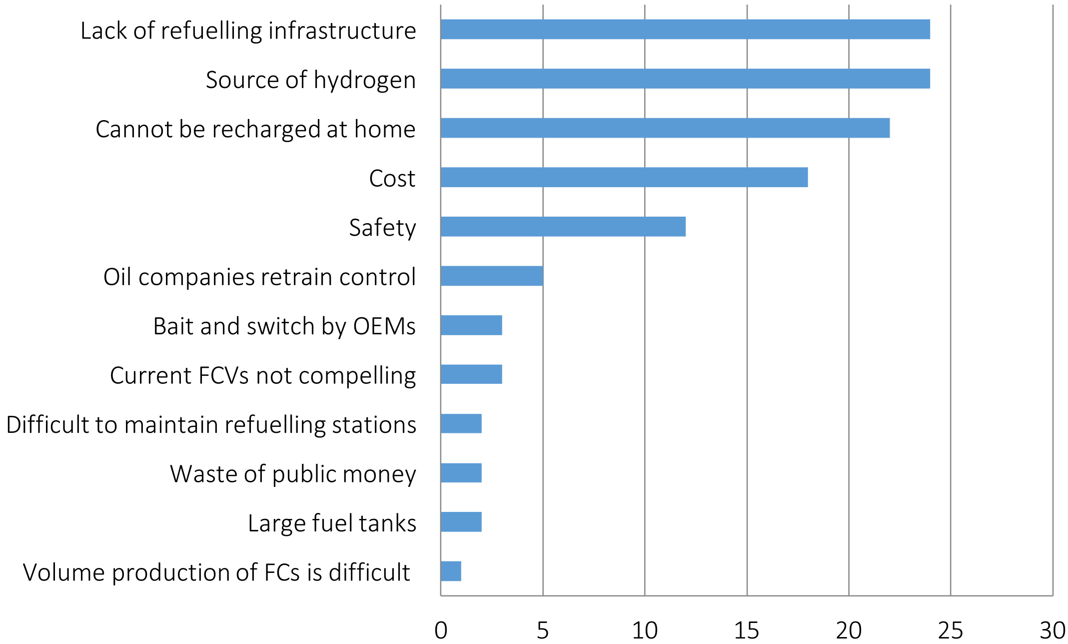

Figure 1: Early adopter barriers to the adoption of a fuel cell vehicle as reported by interviewees of this study (N=38).

4.4.1. Infrastructure

The most common barrier mentioned by 24 interviewees is related to the lack of hydrogen refuelling infrastructure. 23 of these people state that there is no refuelling infrastructure, and 4 state that there is no distribution infrastructure. Therefore 3 interviewees highlight both lack of refuelling infrastructure and lack of distribution infrastructure. The lack of refuelling infrastructure is a barrier as consumers would be unable to conveniently refuel their vehicles. At the time of undertaking this study there were 8 operational hydrogen-refuelling stations in the state of California. Some interviewees make comparisons between the abundance of petroleum refuelling stations, or the ease of access to electric outlets for BEV recharging. Interviewee 11 makes a comparison between hydrogen infrastructure and the ease of locating an electrical outlet for a BEV; *"They* [hydrogen refuelling stations] *are not everywhere, and electricity, electric outlets are."* They therefore believe that owning a FCV would be less convenient than owning a BEV. Interviewees state that for early adopters of FCVs it will be more challenging to refuel a FCV than it was for the early adopters of BEVs. They believe that the adoption of a FCV would lead to having range anxiety, as they would be unsure of where they will be able to refuel their vehicle.

"For the early adopters it's going to be just as hard as it was, worse than it was for electric cars, because there is very little infrastructure. I saw a presentation from

someone who was building out the hydrogen refuelling infrastructure, and I said that's back to worrying about range and everything else."
Interviewee 14

Interviewee 33 makes a comparison between a FCV and a natural gas vehicle. Their brother currently drives a natural gas vehicle, and observations of their brother's experience lead them to believe that it would not be convenient.

"I am not interested in searching out anything. Finding charge points is bad enough right now, I am not interested. And I also didn't consider getting a natural gas vehicle just because there are so many fewer choices for refuelling."
Interviewee 33

Other interviewees didn't make any comparisons between different fuelling infrastructures; they simply state that there was currently a lack of infrastructure.

"When you run out of hydrogen where are you supposed to get your car filled up, there are virtually no places to go hydrogen up your car."
Interviewee 16

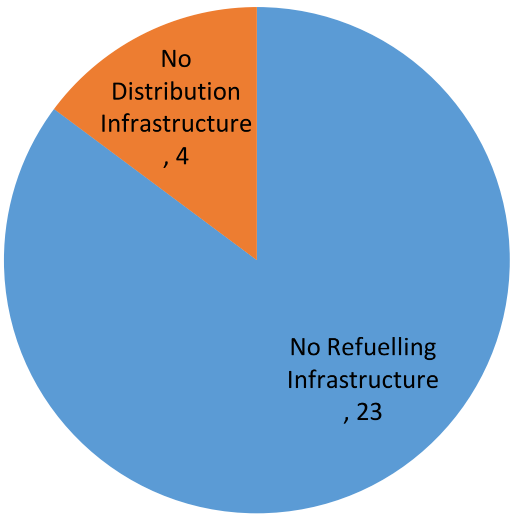

Figure 2: Count of infrastructural barriers to fuel cell vehicle adoption (N=24).

4.4.2. Hydrogen Source

24 interviewees mention the way in which hydrogen is sourced as a barrier, a breakdown of which can be seen in Figure 3. The most common reason is because hydrogen is mostly generated from fossil fuel sources. 16 interviewees believe that hydrogen being generated from fossil fuels is negative.

"If you are going to have a fuel cell powered by a hydrocarbon then you're not really advancing the ball sustainability wise. How many dinosaurs are you burning to get that hydrogen?"
Interviewee 33

15 interviewees believe that the conversion of fossil fuels or water to hydrogen via steam reformation or electrolysis is inefficient. Interviewees believe that even when electrolysis of water is used to generate hydrogen there are significant energy losses during the process. 9 interviewees state that sourcing hydrogen from fossil fuels doesn't make sense. They believe that CO2 emissions are released during the production of hydrogen. They also disagree with the use of fossil fuels for ecological reasons such as oil spills. Interviewee 14 mentions these issues, stating that hydrogen is worse for the environment than recharging of a BEV, and that is has an inferior well to wheel efficiency;

"Most of the hydrogen comes from refined natural gas and so we're actually finding that its more detrimental to the environment than people were thinking, there is a lot of gaseous emissions during the drilling and everything else, so when you count the wheel to well effect you could almost fill up [a BEV] *with coal fired electricity and be better off."*
Interviewee 14

3 interviewees believe that using hydrogen as an energy carrier for the transportation sector is inflexible. Their perception is that hydrogen can only be generated from a small number of sources, but electricity can be generated using any energy source. Interviewee 39 stated *"electricity is fungible hydrogen isn't".* 2 interviewees believe that using hydrogen as a fuel may consume water, which at the time of undertaking this study was in short supply in California due to a multi-year drought.

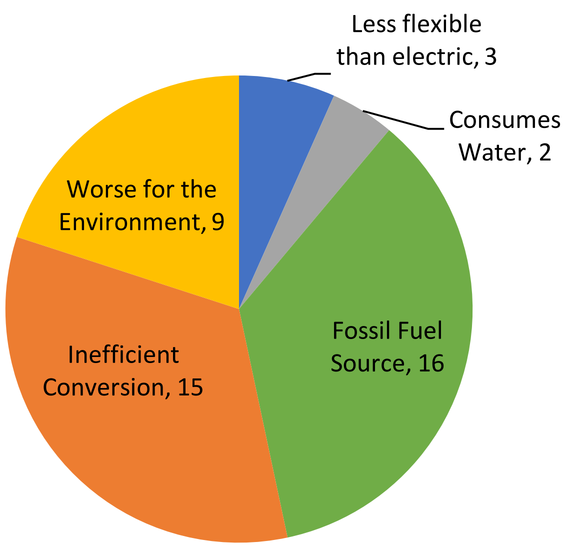

Figure 3: Count of Hydrogen source related barriers to fuel cell vehicle adoption (n=24).

4.4.3. <u>Home Charging</u>

22 interviewees mention the inability of FCVs to be recharged at home as a barrier. Interviewees are unwilling to go back to a refuelling style that means they will be required to take a detour to a filling station, and then stand there for 5 minutes to

refuel. Interviewees believe that the benefit of FCVs being refuelled in 5 minutes is not advantageous in comparison with home charging and that all that is needed is for consumers to get used to the idea of charging at home. Interviewee 1 made the comparison between plugging in a mobile phone at night and recharging a BEV;

"My view is that people will revise their view of what is normal, just like they have with the phone, and they have accepted it, it wasn't easy for people early on, you had to remember to plug in your phone. I think before fuel cells get their momentum people will have accepted the new fuelling model. So I don't think fuel cell vehicles will make it. I think home charging will win over fuel cells."
Interviewee 1

The reason for people preferring home charging is related to convenience. Interviewee 4 did a verbal calculation of how many times a week they would have to visit a hydrogen station. They state; *"For me you know that would be maybe every 3-4 days or so. It would certainly be more of an inconvenience."* Home refuelling did not emerge as a reason for the adoption of a BEV. It is a benefit which consumers only realise once they have experienced the vehicle. This may not be a barrier for ICEV drivers as they haven't experienced the convenience of being able to recharge a vehicle at their home. It is however a barrier for people who have adopted a BEV.

It should be noted that in some cases BEV adopters will charge away from home. These recharging events will last longer than it would for an ICEV or an FCV, however the frequency of these events is low. A study by Tal et al investigated the charging behaviour of owners of BEVs with less than 100 miles of range. They found that adopters of BEVs charge away from home less than 2% of the time (Tal et al., 2014). A driver of a BEV with more than 200 miles of range would charge away from home even less than this. Charging events away from home is not perceived as a disadvantage due to the low number of times that they occur.

4.4.4. <u>Cost</u>

18 interviewees believe that there are cost issues related to FCVs. A breakdown of each reason related to cost is shown in Figure 4. The most prominent of these is due to interviewee's perception of the cost of hydrogen fuel. This is because hydrogen refuelling would be more expensive than refuelling a BEV. Currently in the US, the cost of hydrogen is $13.60/kg meaning it would cost $68 to refuel a FCVs 5 kg hydrogen tanks. The cost to refuel a Tesla Model S is $0 from a supercharger or around $8.18 when refuelling from home (based on electricity cost of 8.67 c/kWh (SMUD, 2015), the 85 kWh Tesla Model S with a charge efficiency of 90%). Despite the fact that they did not adopt a BEV to save money the fact that an FCV would cost more to run is a shortcoming and a deterrent. Again this may not be a barrier for ICEV drivers. The cost of hydrogen filling may be similar to that of an ICEV. However, unless hydrogen refuelling is cheaper than petroleum refuelling it won't emerge as a benefit of the vehicles. 6 interviewees believe that it will be expensive to build a hydrogen infrastructure. Interviewees do not believe that this expenditure is necessary. They are concerned that infrastructure is being constructed with financial support from the state of California. 5 interviewees perceived FCVs as being too expensive. 3 interviewees

believe that it is expensive to generate hydrogen. Interviewee 1 mentions all of these cost related issues;

"The fuel is more expensive, its much more expensive to produce than to just use electricity from the grid. And the vehicle is more expensive, and the stations are going to cost a couple of million each. Economically it makes no sense."
Interviewee 1

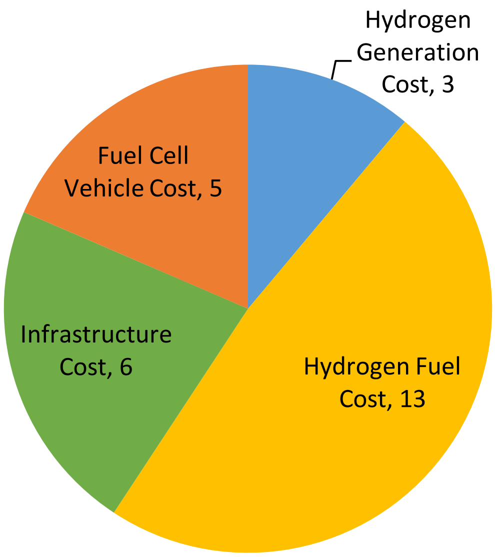

Figure 4: Cost barriers to the adoption of a fuel cell vehicle.

4.4.5. Safety

Safety is mentioned as a concern by 12 interviewees. Safety concerns are related to hydrogen being combustible or due to the 700 bar (10,000 PSI) hydrogen tanks. One respondent who raised safety concerns states that it is just an image related problem; *"Its probably no more dangerous than a normal car. All cars have various safety issues. But the image will scare off quite a few people"*. Most of the concerns, though, were related to the tanks storing hydrogen within the vehicle;

"I am a little bit worried about having a very high-pressure tank in the car."
Interviewee 38

Interviewee 11 and 14 are concerned that hydrogen is explosive at a wide range of gas mixtures, both had heard that if hydrogen leaks when parked in an enclosed space it has the potential to be explosive if exposed to an ignition source.

"From what I've heard you really shouldn't park it in your garage. At least I read that you were supposed to keep it parked outside."
Interviewee 14

4.4.6. Other Barriers

The remaining 7 barriers to adoption were less prominent, they are only discussed in brief. Some interviewees are opposed to the idea of a refuelling infrastructure that is dominated by oil companies. They believe that if they were to drive a FCV they would still have to refuel at stations owned by oil companies, something which they are opposed to for personal reasons. 3 interviewees have experience with a FCV, these interviewees perception after driving one is that they don't have any compelling features over a BEV. 3 interviewees believe that FCVs are just a marketing tool, know as 'Bait and Switch'. They believe FCVs are being used to distract consumers' attention away from BEVs by promising FCVs that will be launched in the future. This means consumers will continue to purchase ICEVs until FCVs become more widely available, thus allowing OEMs to continue with their most profitable business which is selling ICEVs. 2 interviewees believe that hydrogen fuel tanks would be large and compromise internal space of a vehicle. 2 interviewees believe that hydrogen infrastructure and FCVs are a waste of public money. They are aware of investments by the State of California into hydrogen infrastructure. Finally 2 interviewees believe that stations are difficult to maintain and had heard reports of refuelling stations being out of order for example (Green Car Reports, 2015c). Finally one respondent thought that high-volume production of FCVs would be difficult. They had heard that Toyota had planned on producing 3000 vehicles per annum. The interviewee believed that this was too low to achieve a mass market.

4.5. Demand for Novel Fuel Cell Vehicle Attributes

4.5.1. Vehicle to Home Power

One of the novel features of a FCV is its ability to provide vehicle to home power. It has been proposed that the vehicles can provide power in the event of a power outage or blackout. With full tanks 150 kWh of hydrogen can be stored on-board the vehicles. This is enough energy to power a house for around 3-7 days depending on demand (Toyota, 2015). Interviewees are interested in this feature. 15 out of 36 interviewees (41.6%) said they would purchase this feature on a vehicle. A further 14 (38.9%) would maybe purchase this feature, but want to know more before they could make a decision. 7 interviewees are not interested in this feature. Interest in this feature came about for a number of reasons. Some interviewees live in remote coastal or inland areas where they experience blackouts frequently, sometimes as often as every 2 weeks. Interviewees report power outages that lasted from a few hours to durations longer than a day. Some respondent's interest comes about due to them anticipating a natural disaster in the future. The most common reason is due to the risk of a major earthquake. Interviewees believe that if this does occur they could be without power for a number of days. In these cases the ability of the vehicle to provide emergency home power is viewed as valuable.

The 7 interviewees with no interest in this feature either report no power outages in as long as they are able to remember or that any power outages they do experience occur when they are not at home. These interviewees said that they are only aware of these power outages because *"the clock on the oven was flashing".* These interviewees also make no mention of the potential for a natural disaster causing the electricity grid to go down. 2 interviewees are not interested in this feature for another reason. They believe that an emergency power system should be 100% available. If the feature is installed in a vehicle it is possible that the vehicle could not be home when the power outage occurs.

The interviewees who are interested or maybe interested in this feature are willing to pay between $500-$10,000, the mean is $2,895 and the median value $2,250. Interviewees calculated these values in two ways. Firstly they made comparisons between the cost of an existing ICE generator and stated that they would be willing to pay the same amount of what that would cost. Secondly interviewees calculated the amount they believed that such a system could cost to install on a vehicle, and suggested values based on their assumptions.

4.5.2. Range

Another attribute of a FCV that is being promoted by OEMs is its range. The range of a FCV is greater than the range of a BEV at between 300-360 miles (Toyota, 2015). Interviewees in this study report that the BEVs they own achieve ranges of between 150 and 275 miles. These figures are reported range and not the suggested range based on US EPA calculations, or manufacturers calculations. Mean reported range is 232 miles and the medium 237 miles. 38 interviewees were asked if they would like more range, of which 16 (42.1%) indicated that they would. 4 (10.5%) maybe would like more range and 18 (47.4%) believe the current range of their vehicle is enough and they do not desire any more range. The 20 interviewees who want or maybe want more range desire ranges of between 225 and 500 miles. The ones who desire ranges of 225 miles currently have reported ranges of close to 200 miles. The mean desired range is 330 miles and median 325 miles. These ranges are in the same region of the range of a FCV.

4.6. Recommendations for FCVs

The data in this paper has enabled the identification of consumer barriers to FCV adoption. If these barriers to consumer adoption remain, the implications for FCVs will be negative and rates of adoption will likely be low. However, it is possible to solve these barriers in part or full. Recommendations for FCVs are now discussed for the 5 most significant barriers in the following paragraphs.

The first and most prominent barrier is the lack of hydrogen infrastructure. The development of a hydrogen infrastructure was discussed in (Hardman and Steinberger-Wilckens, 2014). In that paper it was suggested that pre-developing infrastructure prior to launching FCVs was the best strategy that would lead to successful adoption. Without there being some infrastructure early adopters will be unwilling to accept the technology. Infrastructure needs to be pre-developed in order for consumers to adopt FCVs. All stakeholders, including OEMs, policy makers, fuel suppliers, fuel producers and gas companies should invest in this development, as they will all benefit from successful market entry of FCVs.

The second most prominent barrier is due to concerns about how hydrogen is sourced. This can be addressed by firstly using the most energy efficient method for hydrogen generation. Education and outreach will help consumers understand how the well to wheel efficiency of FCVs compares to that of ICEVs or BEVs. The worse well to wheel efficiency of FCVs compared to BEVs can be addressed by targeting FCVs to specific regions. In regions where the electrical grid is still coal based driving a BEV is less beneficial than driving a vehicles such as HEVs (Onat et al., 2015; Tamayao et al., 2015). In these areas FCVs will be more beneficial, as it is possible for them to have greater efficiencies compared to their competitors.

Conversely in areas where the electricity grid is low carbon, due to the use of wind, solar and hydroelectric power, FCVs will be less beneficial than BEVs. Hydrogen infrastructure and FCVs should be placed in regions where they have the most significant benefit over BEVs due to there being a carbon intensive electrical grid.

The barrier of home charging can only be partially overcome, but it is possible to increase the convenience of FCV refuelling. Drivers of plug-in hybrid electric vehicles (PHEVs) which have ranges of around 40 miles are able to drive 67.5% of all vehicle miles travelled using the electric range (Tal et al., 2014). This means that visits to refuelling stations occur at a rate of around 1/3 compared to driving a standard ICEV. Therefore, if a FCV were to be a plug-in hybrid FCV with a plug-in range of 40 miles it would be possible to achieve the same benefit. This would also mean that the requirements for a hydrogen infrastructure are slightly reduced, as refuelling events would occur less frequently. Furthermore car buyers have previously been shown to be most interested in vehicles that are PHEVs (Axsen and Kurani, 2013). This may help in increasing early market demand for FCVs.

The fourth most prominent barrier is cost. The cost of building a hydrogen infrastructure and generating hydrogen cannot easily be reduced. Therefore it may have to be continually subsidised in the early stages of market development. The running costs in terms of fuel costs should be lower than that of an ICEV, and close to that of a BEV. This will increase the competitiveness of hydrogen as an automotive fuel. Low running costs did not emerge as a reason for adoption of a high-end BEV, but high running cost might lead to consumers being dissuaded from adoption of FCVs. The cost of a FCV cannot easily be reduced. Correct market positioning of a vehicle with desirable attributes will ensure FCVs are compared to similarly priced vehicles. This was previously explored in (Hardman et al., 2014), where it was suggested that a FCV should be introduced to high-end markets through developing a vehicle with attributes that consumers value. This is in a way similar to what Tesla has achieved.

Finally, safety was found to be a barrier. Scientists and engineers generally agree that FCVs are safe. However there does appear to be some consumer concern. Education and outreach may help in addressing this issue. Crash testing FCVs in line with IIHS (Insurance Institute for Highway Safety), NHTSA (National Highway Traffic Safety Administration), and Euro NCAP (European New Car Assessment Program) standards will help. These are organisations and crash test regimes which consumers are familiar with.

5. Conclusion

From interviews with 39 high-end adopters it has emerged that the reasons for adoption of AFVs are either due to performance, technological or environmental motivations. This supports literature that has previously indicated that these are potential reasons for adoption (Carley et al., 2013; Hidrue et al., 2011; Lane and Potter, 2007; Seebauer, 2015; Turrentine et al., 2011). What was surprising in this study was that running costs are not a reason for adoption, which is contrary to some previous studies (Caperello et al., 2015; Dumortier et al., 2015; Hardman et al., 2016b; Tal and Nicholas, 2013; Turrentine et al., 2011). It was found that the main benefits of owning a high-end BEV are the high performance and low running costs, agreeing with findings from (Hardman et al., 2014; Hardman et al., 2016b; Tal and Nicholas, 2013; Turrentine et al., 2011). Being able to charge BEVs at home is a benefit this has not been mentioned as a significant benefit prior to this study.

This paper has revealed more barriers to the adoption of FCVs than any previous studies. This is due to the use of in-depth qualitative interviews allowing all possible barriers to be uncovered. 12 barriers emerged in total and 5 of these emerged as prominent. These barriers are due to the lack of infrastructure, the source of hydrogen, not being able to charge FCVs from home, cost, and safety issues. Lack of infrastructure, safety concerns and cost have been previously mentioned in the literature (Ball and Wietschel, 2009; Chalk et al., 2000; Huijts et al., 2012; Keles et al., 2008; Melaina et al., 2012; Roche et al., 2010). Home refuelling and the source of hydrogen have not been previously mentioned. The barriers to adoption can be addressed through the pre-development of a hydrogen infrastructure and by sourcing hydrogen from the greenest source. In order to solve cost issues, government subsidies will be needed, but also the correct market positioning of a FCV can help with this. Safety concerns can be addressed through education and outreach. The barrier of not being able to recharge or refuel at home can be partially solved through developing plug-in hybrid fuel cell vehicles, with plug-in ranges of 40 miles or more.

There are some positive results. This study finds that there is consumer demand for the range of an FCV, with consumers desiring ranges of 330 miles on average. Furthermore, 80.5% of interviewees were interested in vehicle to home emergency power and 40.67% were willing to pay between $500-10,000 for this feature. These two benefits alone do not outweigh the current barriers to the adoption of a FCV, which need to be overcome prior to successful market entry.

5.1. Policy Implications

In order to address the barriers to FCV adoption significant investments will be needed. These investments will need to come from automotive OEMs but also public funds. Investments into new automotive technologies are needed in order to avoid the societal costs that will inevitably occur if the automotive sector remains to be dominated by ICEVs using petroleum. Furthermore the purpose of FCVs is to solve the problems of oil dependence, carbon emissions and urban air pollution. It is possible that the investments that would be required to develop the market for FCVs could result in a greater benefit if invested into other automotive technologies that tackle these problems, for example PHEVs and BEVs. Indeed, BEVs have greater well-to-wheel efficiencies compared to FCVs, which could result in lower emissions and less import dependency (Stimming and Ramachandran, 2015). If policy makers, fuel suppliers and OEMs do decide that investments into hydrogen and FCVs are worthwhile activities, they should be targeted to regions where average daily vehicle miles travelled are high so that consumers demand the range of an FCV. Further to this they should target regions with unreliable grid power supply. This would mean that the benefit of vehicle to home emergency power is highly valued by consumers. Prior to all undertake a joint effort that sees all stakeholders investing in the development of a hydrogen infrastructure will be needed.

5.2. Limitations Further Research

One possible limitation of this study on consumer responses to FCVs is that the data is gathered from owners of only 1 type of BEV. These BEVs are Tesla BEVs, this sample was selected due to them being early adopters. This meant they would be able to provide deeper insights into attitudes toward FCVs compared to the general population. These adopters may have some bias's towards FCVs. One such bias could be choice supportive bias. This would mean that adopters of BEVs will hold preferential views of the vehicles they have adopted and perhaps negative views towards vehicles they have not. In order to address this future studies should look to gather a sample of early adopters of a wider range of vehicles including PHEVs, low-end BEVs and ICEVs powered with alternative fuels (e.g natural gas or biofuels). It may also be possible in time to gather information from adopters of FCVs if they have been adopted in greater numbers.

The body of research investigating the adoption of FCVs is extremely limited, more research is needed in order to understand consumer demand for FCVs. This study concentrated on high-end adopters of BEVs. A future study should target low-end BEV adopters. These adopters may have different views of FCVs, due to different ownership experiences and personality profiles, as explored in (Hardman et al., 2016b). The most significant barrier explored in this paper is the lack of hydrogen infrastructure. More research is needed to understand how much infrastructure is needed in order to support the early market. More research is also needed that samples people who have actually experienced a FCV. There are only two such studies at the moment (Hardman et al., 2016a; Martin et al., 2009). One of these studies is now 6 years old and predates many recent developments. The second does not investigate people who are actual early adopters, rather a sample of people who are expected to be early adopters.

An interesting finding of this paper was that home charging is a beneficial attribute of a BEV. This has not emerged in previous studies, perhaps due to the vehicles in these studies having ranges of close to 100 miles. The vehicles in this study have EPA ranges of 285 miles. Therefore at what range does charging the vehicle at home become a benefit? This is an important question as is has implications for both the BEV and FCV market. This would impact the market for FCVs. With 200 mile BEVs from many automotive OEMs expected in 2018 the market for FCVs might become diminished if larger number of consumer adopt BEVs with these ranges.

6. Acknowledgements

The authors would like to acknowledge the College of Engineering and Physical Sciences at the University of Birmingham for funding the research visit to UC Davis. Much gratitude goes to Tom Turrentine at the Plug-in Hybrid & Electric Vehicle Research Centre of the ITS UC Davis for facilitating this research project. EPSRC and UKERC provided funding for this research.

7. References

Aggarwal, P., Cha, T., Wilemon, D., 1998. Barriers to the adoption of really-new products and the role of surrogate buyers. J. Consum. Mark. 15, 358–371.

Allan, G.S., Wolf, W.C., 1978. Relationships between perceived attributes of innovations and their subsequent adoption. Peabody J. Educ. 55, 332–336.

Altman, M., Schmidt, P., O'Garra, T., Hard, D., Mourate, S., Rohr, C., Contestabile, M., Saynor, B., Garrity, L., Graesel, C., Beerenwinkel, A., Kurani, K., Miller, M., Levin, J., Whitehouse, S., 2004. Public Perception of Hydrogen Buses in Five

Countries.
Axsen, J., Kurani, K.S., 2013. Hybrid, plug-in hybrid, or electric-What do car buyers want? Energy Policy 61, 532–543.
Ball, M., Wietschel, M., 2009. The future of hydrogen - opportunities and challenges. Int. J. Hydrogen Energy 34, 615–627.
Brockman, B.K., Morgan, R.M., 1995. The evolution of managerial innovations in distribution : what prospects for ECR ? Int. J. Retail Distrib. Manag. 27, 397–408.
Browne, D., O'Mahony, M., Caulfield, B., 2012. How should barriers to alternative fuels and vehicles be classified and potential policies to promote innovative technologies be evaluated? J. Clean. Prod. 35, 140–151.
Brownstone, D., Bunch, D.S., Golob, T.F., Ren, W., 1996. A transactions choice model for forecasting demand for alternative-fuel vehicles, Research in Transportation Economics. Elsevier Ltd.
Bryman, A., Bell, E., 2015. Business research methods. Oxford university press, Oxford.
Bunch, D.S., Bradley, M., Golob, T.F., Kitamura, R., Occhiuzzo, G.P., 1993. Demand for Clean-Fuel Vehicles in California: A Discrete-Choice Stated Preference Pilot Project. Transp. Res. Part A Policy Pract. 27, 237–253.
Burgess, M., King, N., Harris, M., Lewis, E., 2013. Electric vehicle drivers' reported interactions with the public: Driving stereotype change? Transp. Res. Part F Traffic Psychol. Behav. 17, 33–44.
California Air Resources Board, 2015. Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development.
California Air Resources Board, 2016. Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development 73.
Campbell, A., 2014. Identifying the reasons for consumers' non-adoption of zero-emissions vehicles, in: UTSG Newcastle 2014. pp. 1–12.
Campbell, A.R., Ryley, T., Thring, R., 2012. Identifying the early adopters of alternative fuel vehicles: A case study of Birmingham, United Kingdom. Transp. Res. Part A Policy Pract. 46, 1318–1327.
Caperello, N., Kurani, K.S., TyreeHageman, J., 2013. Do You Mind if I Plug-in My Car? How etiquette shapes PEV drivers' vehicle charging behavior. Transp. Res. Part A Policy Pract. 54, 155–163.
Caperello, N., Tyreehageman, J., Davies, J., 2015. I am not an environmental wacko! Getting from early plug-in vehicle owners to potential later buyers. Transp. Res. Board 2015 Annu. Meet.
Caperello, N.D., Kurani, K.S., 2012. Households' Stories of Their Encounters With a Plug-In Hybrid Electric Vehicle. Environ. Behav. 44, 493–508.
Car Magazine, 2015a. Audi Q6 E-tron (2018) revealed: Audi's first EV is a crossover! [WWW Document]. URL http://www.carmagazine.co.uk/spy-shots/audi/audi-q6-e-tron-2018-revealed-audis-first-ev-is-a-crossover/ (accessed 8.12.15).
Car Magazine, 2015b. BMW i5/i7 scoop: target Tesla Model S [WWW Document]. URL http://www.carmagazine.co.uk/spy-shots/bmw/bmw-i5i7-scoop-target-tesla-model-s/ (accessed 8.12.15).
Carley, S., Krause, R.M., Lane, B.W., Graham, J.D., 2013. Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cites. Transp. Res. Part D Transp. Environ. 18, 39–45.

Chalk, S.G., Miller, J.F., Wagner, F.W., 2000. Challenges for fuel cells in transport applications. J. Power Sources 86, 40–51.
Chalk, S.G., Patil, P.G., Venkateswaran, S.R., 1996. The new generation of vehicles: market opportunities for fuel cells. J. Power Sources 61, 7–13.
Cheng, X., Shi, Z., Glass, N., Zhang, L., Zhang, J., Song, D., Liu, Z.-S., Wang, H., Shen, J., 2007. A review of PEM hydrogen fuel cell contamination: Impacts, mechanisms, and mitigation. J. Power Sources 165, 739–756.
Chevrolet, 2015. The Future of EV [WWW Document]. URL http://www.chevrolet.com/culture/article/bolt-ev-concept-car.html (accessed 7.24.15).
Diamond, D., 2009. The impact of government incentives for hybrid-electric vehicles: Evidence from US states. Energy Policy 37, 972–983.
Dickerson, M.D., Gentry, J.W., Dickerson, M.D.E.E., 1983. Characteristics of Adopters and Non-Adopters of Home Computers. J. Consum. Res. 10, 225–235.
Dinse, G., 2000. Acceptance of hydrogen vehicles—A study on the use of a new and unusual fuel.
Dumortier, J., Siddiki, S., Carley, S., Cisney, J., Krause, R.M., Lane, B.W., Rupp, J. a., Graham, J.D., 2015. Effects of providing total cost of ownership information on consumers' intent to purchase a hybrid or plug-in electric vehicle. Transp. Res. Part A Policy Pract. 72, 71–86.
Egbue, O., Long, S., 2012. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy Policy 48, 717–729.
Fliegel, F.C., Kivlin, J.E., Fliegel, C., 1966. Attributes of Innovations as Factors in Diffusion. Am. J. Sociol. 72, 235–248.
Freeman, C., 1995. The ' National System of Innovation ' in historical perspective. Cambridge J. Econ. 19, 5–24.
Geels, F.W., 2005. The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technol. Anal. Strateg. Manag. 17, 445–476.
Gnann, T., Plötz, P., Funke, S., Wietschel, M., 2015. What is the market potential of plug-in electric vehicles as commercial passenger cars? A case study from Germany. Transp. Res. Part D Transp. Environ. 37, 171–187.
Golob, T.F., Torous, J., Bradley, M., Brownstone, D., Crane, S.S., Bunch, D.S., 1997. Commercial fleet demand for alternative-fuel vehicles in California. Transp. Res. Part A Policy Pract. 31, 219–233.
Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., Stannard, J., 2012. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. Transp. Res. Part A Policy Pract. 46, 140–153.
Green Car Reports, 2015a. Nissan Leaf With 250-Mile Range: Ghosn Shows R&D Car, Video At Annual Meeting [WWW Document]. URL http://www.greencarreports.com/news/1098870_nissan-leaf-with-250-mile-range-ghosn-shows-rd-car-video-at-annual-meeting (accessed 8.12.15).
Green Car Reports, 2015b. Ford May Show A 200-Mile Electric Car This Year To Counter Chevy Bolt: UPDATE [WWW Document]. URL http://www.greencarreports.com/news/1097103_ford-may-show-a-200-mile-electric-car-this-year-to-counter-chevy-bolt (accessed 8.12.15).

Green Car Reports, 2015c. CA Fuel-Cell Car Drivers Say Hydrogen Fuel Unavailable, Stations Don't Work (UPDATED) [WWW Document]. URL http://www.greencarreports.com/news/1099082_ca-fuel-cell-car-drivers-says-hydrogen-fuel-unavailable-stations-dont-work (accessed 8.12.15).
Haraldsson, K., Folkesson, a., Saxe, M., Alvfors, P., 2006. A first report on the attitude towards hydrogen fuel cell buses in Stockholm. Int. J. Hydrogen Energy 31, 317–325.
Hardman, S., Chandan, A., Shiu, E., Steinberger-Wilckens, R., 2016a. Consumer attitudes to fuel cell vehicles post trial in the United Kingdom. Int. J. Hydrogen Energy 41, 6171–6179.
Hardman, S., Chandan, A., Steinberger-Wilckens, R., 2015. Fuel cell added value for early market applications. J. Power Sources 287, 297–306.
Hardman, S., Shiu, E., Steinberger-Wilckens, R., 2014. Changing the fate of fuel cell vehicles: Can Lessons be Learned from Tesla Motors? Int. J. Hydrogen Energy 40.
Hardman, S., Shiu, E., Steinberger-Wilckens, R., 2016b. Comparing high-end and low-end early adopters of battery electric vehicles. Transp. Res. Part A Policy Pract. 88, 40–57.
Hardman, S., Steinberger-Wilckens, R., 2014. Mobile phone infrastructure development: Lessons for the development of a hydrogen infrastructure. Int. J. Hydrogen Energy 39, 8185–8193.
Hardman, S., Steinberger-Wilckens, R., van der Horst, D., 2013. Disruptive innovations: The case for hydrogen fuel cells and battery electric vehicles. Int. J. Hydrogen Energy 38, 15438–15451.
Hardman, S., Tal, G., 2016. Exploring the decision to adopt a high-end battery electric vehicle: The role of financial and non-financial motivations. Transp. Res. Rec. J. Transp. Res. Board 16–1783.
Heffner, R., Kurani, K.S., Turrentine, T., 2005. Effects of Vehicle Image in Gasoline-Hybrid Electric Vehicles. Inst. Transp. Stud.
Heffner, R.R., Kurani, K.S., Turrentine, T.S., 2007. Symbolism in California's early market for hybrid electric vehicles. Transp. Res. Part D Transp. Environ. 12, 396–413.
Hidrue, M., Parsons, G., Kempton, W., Gardner, M., 2011. Willingness to pay for electric vehicles and their attributes. Resour. Energy Econ. 33, 686–705.
Huijts, N.M. a, Molin, E.J.E., Steg, L., 2012. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. Renew. Sustain. Energy Rev. 16, 525–531.
International Energy Agency, 2016. Global EV Outlook.
Keles, D., Wietschel, M., Most, D., Rentz, O., 2008. Market penetration of fuel cell vehicles – Analysis based on agent behaviour. Int. J. Hydrogen Energy 33, 4444–4455.
Koetse, M.J., Hoen, A., 2014. Preferences for alternative fuel vehicles of company car drivers. Resour. Energy Econ. 37, 279–301.
Krause, R.M., Carley, S.R., Lane, B.W., Graham, J.D., 2013. Perception and reality: Public knowledge of plug-in electric vehicles in 21 U.S. cities. Energy Policy 63, 433–440.
Kurani, K.S., Turrentine, T., Sperling, D., 1994. Demand for electric vehicles in hybrid households : an exploratory analysis. Transp. Policy 1, 244–256.
Kurani, S., Turrentine, T., Sperling, D., 1996. Testing electric vehicle demand in

"hybrid households" using a reflexive survey. Transp. Res. Part C Emerg. Technol. I, 131–150.
Lane, B., Potter, S., 2007. The adoption of cleaner vehicles in the UK: exploring the consumer attitude-action gap. J. Clean. Prod. 15, 1085–1092.
Lutsey, N., Searle, S., Chambliss, S., Bandivadekar, A., 2015. Assessment of leading electric vehicle promotion activities in United States cities. International Council on Clean Transportation.
Martin, E., Shaheen, S., Lipman, T., Lidicker, J., 2009. BEHAVIORAL RESPONSE TO HYDROGEN FUEL CELL-VEHICLES AND REFUELING--RESULTS OF CALIFORNIA DRIVE CLINICS. Int. J. Hydrogen Energy 34, 8670–8680.
Melaina, M.W., 2007. Turn of the century refueling: A review of innovations in early gasoline refueling methods and analogies for hydrogen. Energy Policy 35, 4919–4934.
Melaina, M.W., Steward, D., Penev, M., Mcqueen, S., Jaffe, S., Talon, C., 2012. Hydrogen Infrastructure Market Readiness : Opportunities and Potential for Near-term Cost Reductions Hydrogen Infrastructure Market Readiness : Opportunities and Potential for Near-term Cost Reductions. NREL.
Mourato, S., Saynor, B., Hart, D., 2004. Greening London's black cabs: A study of driver's preferences for fuel cell taxis. Energy Policy 32, 685–695.
O'Garra, T., Mourato, S., Pearson, P., 2005. Analysing awareness and acceptability of hydrogen vehicles: A London case study. Int. J. Hydrogen Energy 30, 649–659.
Offer, G.J., Contestabile, M., Howey, D. a., Clague, R., Brandon, N.P., 2011. Techno-economic and behavioural analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK. Energy Policy 39, 1939–1950.
Onat, N.C., Kucukvar, M., Tatari, O., 2015. Conventional, hybrid, plug-in hybrid or electric vehicles? State-based comparative carbon and energy footprint analysis in the United States. Appl. Energy 150, 36–49.
Parente, S.L., Prescott, E.C., 1994. Barriers to Technology Adoption and Development. J. Polit. Econ. 102, 298.
Park, S.Y., Kim, J.W., Lee, D.H., 2011. Development of a market penetration forecasting model for Hydrogen Fuel Cell Vehicles considering infrastructure and cost reduction effects. Energy Policy 39, 3307–3315.
Plötz, P., Schneider, U., Globisch, J., Dütschke, E., 2014. Who will buy electric vehicles? Identifying early adopters in Germany. Transp. Res. Part A Policy Pract. 67, 96–109.
Renault, 2016. THE 100 PER CENT ELECTRIC RENAULT ZOE: A NEW RECORD DRIVING RANGE OF 250 MILES (NEDC).
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, 5301–5310.
Rogers, E.M., 2003. Diffusion of Innovations, 5th Editio. ed. Free Press, New York.
Ryan, B., Gross, N., 1950. Acceptance and Dissusion of Hybrid Corn See in Two Iowa Communities. Research Bulletin, Iowa State College of Agricultural and Mechanic Arts.
Saaksjarvi, M., 2003. Consumer adoption of technological innovations. Eur. J. Innov. Manag. 6, 90–100.

Schoots, K., Kramer, G.J., van der Zwaan, B.C.C., 2010. Technology learning for fuel cells: An assessment of past and potential cost reductions. Energy Policy 38, 2887–2897.
Schulte, I., Hart, D., Van der Vorst, R., 2004. Issues affecting the acceptance of hydrogen fuel. Int. J. Hydrogen Energy 29, 677–685.
Seebauer, S., 2015. Why early adopters engage in interpersonal diffusion of technological innovations: An empirical study on electric bicycles and electric scooters. Transp. Res. Part A Policy Pract. 78, 146–160.
Skippon, S., Garwood, M., 2011. Responses to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. Transp. Res. Part D Transp. Environ. 16, 525–531.
SMUD, 2015. SMUD Rates 2016-17 [WWW Document]. URL https://www.smud.org/en/residential/customer-service/rate-information/rates-2016-2017/ (accessed 8.12.15).
Stephens, T., 2014. Non-Cost Barriers to Consumer Adoption of New Light-Duty Vehicle Technologies.
Stimming, U., Ramachandran, S., 2015. Well to Wheel Analysis of Low Carbon Alternatives for Road Traffic. Energy Environ. Sci. 8, 3313–3324.
Summer, I., Agarwal, R., 1997. The Role of Innovation Characteristics and Perceived Voluntariness in the Acceptance of Information Technologies. Decsion Sci. 28, 557–582.
Tal, G., Nicholas, M., 2013. Studying the PEV Market in California: Comparing the PEV, PHEV and Hybrid Markets, IEEE. Electric Vehicle Symposium and Exhibition 2013.
Tal, G., Nicholas, M.A., Davies, J., Woodjack, J., 2014. Charging Behavior Impacts of Electric Vehicle Miles Traveled- Who Is Not Plugging in? J. Transp. Res. Board 10.3141/24.
Tamayao, M.-A.M., Michalek, J.J., Hendrickson, C., Azevedo, I.M.L., 2015. Regional Variability and Uncertainty of Electric Vehicle Life Cycle CO2 Emissions across the United States. Environ. Sci. Technol. 49, 8844–8855.
Thomas, C., 2009. Transportation options in a carbon-constrained world: Hybrids, plug-in hybrids, biofuels, fuel cell electric vehicles, and battery electric vehicles. Int. J. Hydrogen Energy 34, 9279–9296.
Tompkins, M., Bunch, D., Santini, D., Bradley, M., Vyas, A., Poyer, D., 1998. Determinants of Alternative Fuel Vehicle Choice in the Continental United States. Transp. Res. Rec. J. Transp. Res. Board 1641, 130–138.
Toyota, 2015. Hydrogen fuel cell vehicles could change mobility forever [WWW Document]. URL http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/ (accessed 8.20.15).
Turrentine, T., Dahlia, G., Lentz, A., Woodjack, J., 2011. The UC Davis MINI E Consumer Study. Institute of Transportation Studies, University of California, Davis, Research Report.
Turrentine, T.S., Kurani, K.S., 2007. Car buyers and fuel economy ? Energy Policy 35, 1213–1223.
US DOE, 2013. Accomplishments and Progress [WWW Document]. URL https://www1.eere.energy.gov/hydrogenandfuelcells/accomplishments.html (accessed 10.7.13).

Williams, B.D., Kurani, K.S., 2007. Commercializing light-duty plug-in/plug-out hydrogen-fuel-cell vehicles: "Mobile Electricity" technologies and opportunities. J. Power Sources 166, 549–566.