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Analysis of Fuel Cell Vehicle Customer Usage and Hydrogen Refueling Patterns – Comparison of Private and Fleet Customers

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Abstract

Honda has been leasing our fuel cell vehicle to numerous fleet customers, such as the City of LA, since 2002, and to individual customers since 2005. Honda is unique in having this combination of customer types. Because of their variety, our customers use the fuel cell vehicle in very different ways. As a result, we have learned a lot about the differences in driving habits and refueling patterns of fleet vs. individual customers. This paper will discuss these differences and show the importance of considering these different usage patterns for future vehicle and hydrogen infrastructure development toward an effective rollout of a fueling network, and to provide maximum vehicle utility to our early customers.

Keywords: fuel cell, hydrogen, infrastructure, market

1 Introduction

Honda began leasing our fuel cell vehicle, the world's first fully certified commercial FCV, to the City of Los Angeles in December of 2002. Since this time, we have delivered our fuel cell vehicles to many additional fleet customers and to the world's first private customer in 2005. Most recently, Honda announced it will deliver up to 200 newly developed fuel cell vehicles over the next few years, primarily to private individual customers. Honda is in a unique position of having years of driving / refueling experience to draw upon from both fleet and private customers for our hydrogen fueled fuel cell vehicles, as well as our compressed natural gas IC vehicles.

We are in the very early stages of introducing the fuel cell vehicle as a fully functional, alternative to conventional gasoline fueled vehicles, so there is much we can learn about the way our customers use and refuel these vehicles. We will show there are obvious differences in the driving and refueling patterns of fleet vs. individual customers, and will surmise the implications this has on vehicle design and hydrogen infrastructure.

2 Refueling Patterns

In examining the driving and fueling patterns of our customers, some of what we found was intuitive, while some was less obvious and provided some important insights. What we found was that there is a distinct difference in both the driving and refueling patterns of individual customers and fleet customers.

2.1 Hydrogen Remaining when Refueling

The first thing we examined was the level of hydrogen remaining in the tank at the time of refueling. This can be observed visually by looking at the histogram graphs in Figure 1, showing the frequency of refueling at various hydrogen remaining levels for three individual customers. Although there is variation from individual to individual, it is quite obvious that the majority of the time, these individual customers fuel their vehicles when the hydrogen remaining in the tank is quite low (less than ¼ tank full).

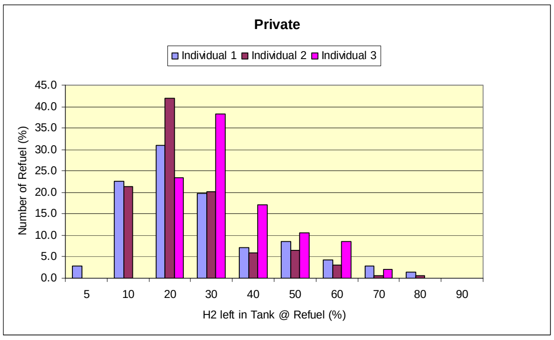


Figure1: Comparison of Refueling Level – Individual

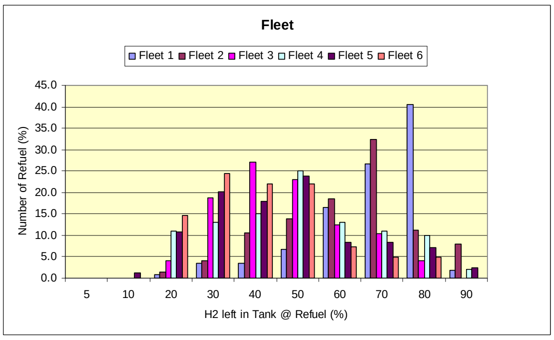


Figure2: Comparison of Refueling Level – Fleet

In contrast to the refueling patterns of the individual customers, Figure 2 show that fleet customers exhibit the exact opposite fueling behavior, with the highest frequency of fueling occurring above the 50% full level. Again, there is variation from fleet customer to fleet customer, but when comparing the general trend of individual customers vs. fleet customers, as shown in Figure 3, it is easy to see there is a distinct difference in this metric.

Since fleet vehicles are usually controlled by a vehicle manager, he will prepare the vehicle by refueling with hydrogen at their hydrogen station located nearby once a user finishes the use of the fuel cell vehicle. On the other hand, individual customers are likely to avoid refueling until they feel it is necessary. Opportunity fueling is much more difficult for them because the location of hydrogen stations is limited and often not as close to their residence as they are accustomed to with gasoline stations. Additionally, this pattern of refueling for individuals is consistent with other studies showing most (90% of) individuals refuel their gasoline powered vehicles with less than ¼ of a tank remaining [1].

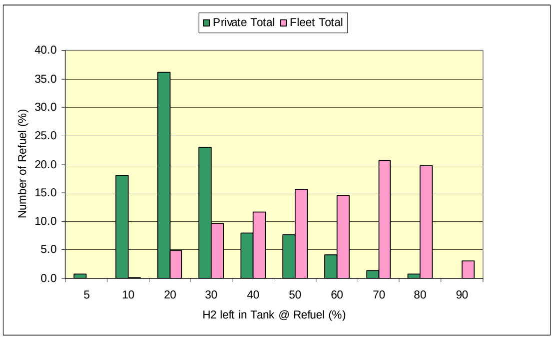
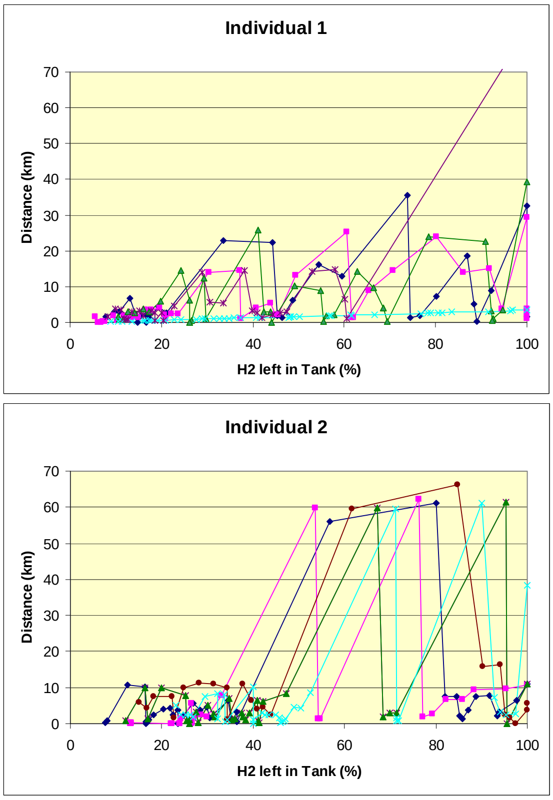


Figure3: Comparison of Refueling Level – Individual vs. Fleet Customers

2.2 Trip Distance as a Function of H2 Fuel Remaining

Another characteristic we considered for individual customers was the length of their drives (each time the car was turned on) in relation to the amount of hydrogen fuel remaining. What the data showed is that the trip distance gets progressively shorter as the fuel remaining level decreases. This can be seen in the graphs in Figure 4.



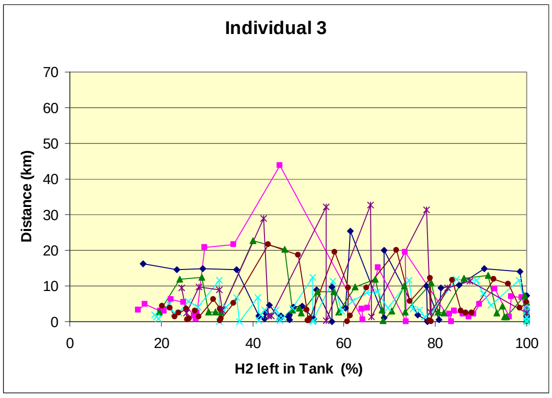


Figure4: Trip Distance as a Function of H2 Fuel Remaining

Again, this makes intuitive sense, but it is interesting to see the different characteristics of usage patterns by each customer. The phenomenon of much longer driving trips when the vehicle is above 50% fuel remaining is very clearly shown in the case of Individual 2. In contrast, Individual 3 shows much more consistent trip distance behavior, with trip distance noticeably dropping off when fuel remaining drops below 30%.

Although we must be careful not to draw definitive conclusions from such a small data set, the data, along with constructive reasoning does imply that a longer range would allow the number of trips per fill to increase, and additional hydrogen stations might allow the average distance trips to extend beyond the 30% fuel remaining level, which would more effectively utilize the hydrogen storage on-board the vehicle.

2.3 Driving Distance as a Function of Fuel Remaining

As we've already seen, individual customers generally refuel with less remaining fuel in the tank than fleet customers. But there are times when the individual customers refuel with a significant amount of fuel still remaining in the tank. Upon further investigation of these refueling events, we found that individual customers tend to drive longer distances directly after (within 24 hours of) refueling from a fuel remaining level of 45 to 70%. This is shown graphically in Figure 5.

Figure 5 shows that the majority of the time, when an individual user refuels at between 45 to 70% fuel remaining, their trip distance within the immediate 24hr timeframe exceeds 60km, the average being about 75km.

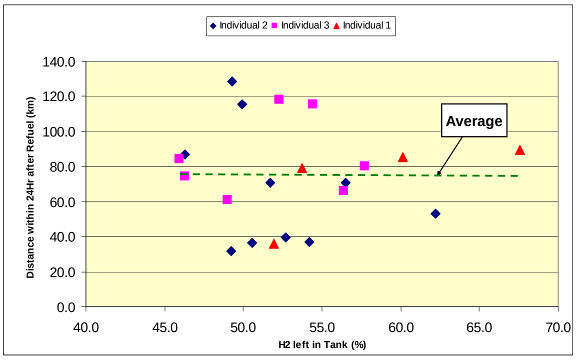


Figure5: Driving Distance as a Function of Fuel Remaining

This phenomenon, of course, makes intuitive sense, but it also highlights a couple of potential short comings of today's vehicles and infrastructure – namely limited range and limited availability of hydrogen stations, especially of those located outside the users home base. With a longer range, and/or with more available hydrogen fueling locations, the customer would feel more confident in their ability to get to their destination without having to first refuel. Increased range would allow them to reach their destination with enough fuel. Increased availability of hydrogen fueling locations would allow them to drive confidently to their destination, knowing they could refuel once there, or on their way back home.

3 Evolution through Learning

3.1 Infrastructure Learnings and Range Improvement

If we consider the current range of today's FCVs, one way to eliminate the inconvenience to the customer of fueling before prolonged driving would be to have fueling stations located within 30km of the customer's home location along key corridors. This would allow the customer to depart on their trip with confidence and without the inconvenience of first having to refuel. An example of this is shown in Figure 6, where three customer regions are identified, along with 30km radii circles that intersect the key corridor routes. A red star is placed at these intersections showing an approximate location that would facilitate travel to destinations beyond 30km (round trip of > 60km) without having to first refuel before the trip. Yellow circles are also drawn at the location of existing accessible hydrogen stations.

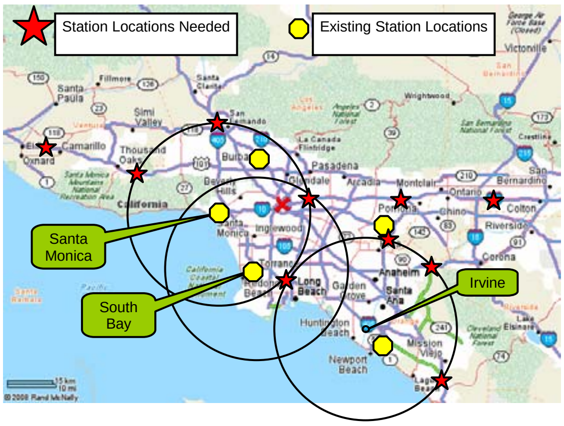


Figure6: Map showing strategic locations for H2 fueling stations along key corridors

Of course, another way to eliminate this inconvenience to the customer would be to increase the range of the FCV. The data shown is based on an FCV with an EPA rated range of 190 to 210 miles. Our newer model FCV has a comparative EPA rated range of 280 miles, which one would expect would shift downward the "H2 left in tank" level at which customers feel they must refill at before making a long distance trip. Also, we have implemented many additional technological improvements, discussed in later sections, that should work to increase the confidence our customers have in their ability to conveniently travel where they desire.

3.1.1 Infra Clusters and Networks

A challenge in developing a completely new fueling infrastructure is keeping a balance between supply and demand. Early customers understand that hydrogen is a completely new fuel and not commonly available, yet when paying for the lease of their fuel cell vehicle, they expect a commensurate level of utility. This means there must be enough well placed stations to adequately satisfy the majority of their driving demands. On the supply side, it's important to site stations where the demand is concentrated to ensure full utilization of the station's capacity. This is especially important given the economic challenges of building and operating a hydrogen station profitably. No one wants to see hydrogen stations that are underutilized, creating stranded assets.

Our current and future efforts are directed at establishing hydrogen communities containing clusters of hydrogen stations, and then establishing links from one community to the other through a series of networking stations that are readily accessible along key corridors. This concept is demonstrated in Figure 7. The clustering is important to establish a reliable, conveniently located set of stations our customers can access from their home base. Multiple stations provide utility and redundancy, much like consumers are used to with today's gasoline stations. Connecting these clustered communities together with a network of interconnecting stations is equally important in that it allows our customers to drive their vehicles to wherever they choose within the Southern California region, and as the infrastructure expands, to even further destinations.

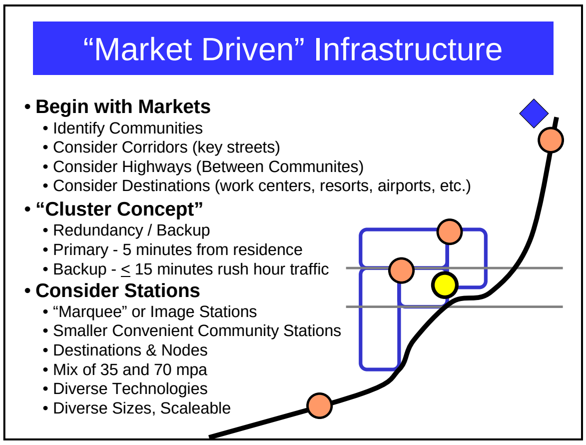


Figure7: Market Driven Infrastructure

Examples of early hydrogen communities include Santa Monica, Irvine, and the South Bay, as shown in Figure 6. These are the primary communities that the larger, fuel cell OEM community has chosen to market next generation fuel cell vehicles. Each of these communities has (or will soon have) a publicly accessible hydrogen station, with additional stations planned towards the development of clusters within these communities.

3.2 Improved Fueling Protocols

Honda learned many important lessons from its experience selling, marketing, and studying its customer experience of refueling its dedicated CNG vehicle. One of the lessons we learned is that a limited range gaseous fueled vehicle needs both consistent and complete fills. Because of the limited range and limited access to hydrogen infrastructure, it's especially important that customers get fast, convenient, and high quality fills. Early hydrogen stations have often been lacking in one or more of these areas, especially in quality, or state of charge of the fills. We have actively worked with infrastructure equipment suppliers and energy companies, as well as the California Fuel Cell Partnership, to measure and improve the fill quality of non-communication fueling for our customers [2].

Early stations only utilized ambient temperature for determining at what pressure to end the fill. An example of this is the California Fuel Cell Partnership *Fueling Interface Fueling Specification, Rev. 7.* However, recently, suppliers have developed "smart" fueling algorithms that, in addition to the ambient temperature, take into account such factors as the initial pressure in the tank, the tank volume, hydrogen supply pressure and temperature, etc. to determine end of fueling pressures that give SOCs in the high ninety percentage range. Most of the stations that our customers currently utilize have implemented an advanced fueling algorithm, allowing them to utilize the vehicle's hydrogen storage potential to the fullest. Figure 8 shows the increase in range available by this change in the fueling algorithm. Better, more consistent fills will have a two fold effect – not only 7% better range, but confidence to use more of the fuel before refueling, knowing that the range is greater, and the refueling amount is consistent.

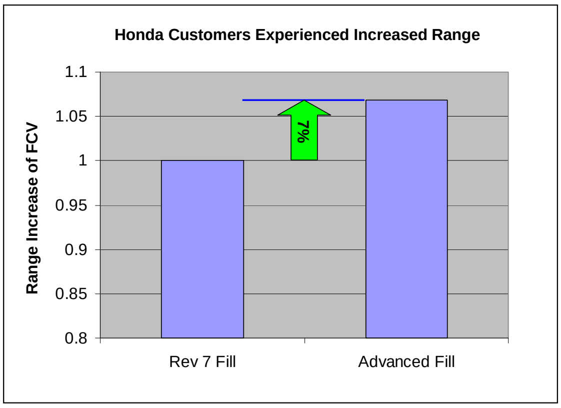


Figure8: An advanced fueling algorithm allows customers to drive 7% further on a fill

3.3 Vehicle Design

Consumers today increasingly have access to many new technologies that increase their driving pleasure, safety, and convenience, including GPS navigation systems, adaptive cruise control, real time fuel economy, and even accident avoidance systems. As well, with our latest generation fuel cell vehicle, we have included many of these features and more.

To help our customers gauge their driving efficiency, our latest generation fuel cell vehicle introduces an instantaneous hydrogen consumption meter utilizing a hydrogen ball to show energy consumption. The ball changes size and color based on driving and power output. A smaller size and blue color indicate maximum fuel economy.

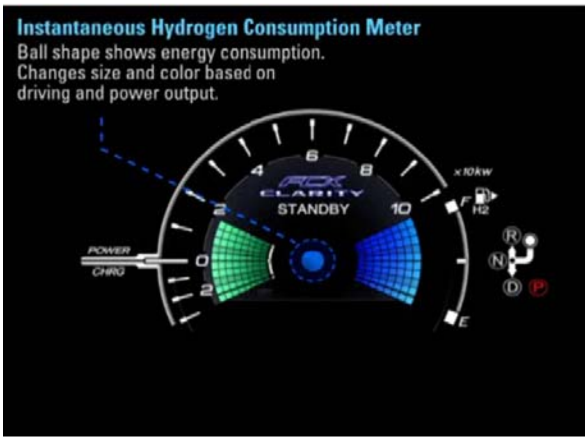


Figure9: Instantaneous Hydrogen Consumption Meter

Additionally, we've integrated an accurate "remaining driving range" indicator which indicates how many miles can be driven until the tank needs refueling. A sophisticated algorithm factors in both remaining fuel and actual driving conditions to accurately determine this number.

Figure10: Remaining Driving Range

Finally, to assist out customers in finding nearby hydrogen stations, we've integrated a feature into the on-board navigation system where the user can speak the words, "find nearest hydrogen station," and the navigation display will show a list of the nearest hydrogen stations. Once the user chooses a hydrogen station from this list, the navigation system will generate a route to this station.

4 Conclusion

In conclusion, we have shown there is a distinct difference in the refueling patterns of individual and fleet customers:

- Individuals tend to refuel at hydrogen remaining levels of less than 25%, while fleet customers exhibit the opposite behaviour with the majority of refueling at a level of greater than 50% hydrogen remaining.
- For individual customers the average trip distance tends to be correlated with the hydrogen remaining level of fuel, with trip distance getting progressively shorter as the fuel remaining level decreases.
- For individual customers, their driving distance within 24hrs of refueling tends to be much longer than normal when they refuel at hydrogen remaining levels between 45 to 70%.

We have also shown how we have learned from these findings and applied improvements to our latest generation fuel cell vehicle, as well as developing our marketing plans. From an infrastructure standpoint, we have learned that developing clusters of stations within "hydrogen communities," along with linking stations along key corridors will allow our customers to drive their fuel cell vehicles as they are accustomed to.

The development and implementation of advanced fueling protocols give our customers consistent and complete fills, maximizing their driving distance between fills. And on-board vehicle technology allows them to gauge their fuel economy and remaining miles, as well as to find the nearest hydrogen stations when needed.

Although hydrogen fuel cell vehicles are in their infancy stage, the technology and infrastructure we are developing now is building the foundation necessary to bring these vehicles to market as environmentally friendly and commercially viable products.

Acknowledgments

We would like to acknowledge our FCV customers as being the forerunners of this new technology and paradigm change in transportation.

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Authors

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