

EVS24
Stavanger, Norway, May 13-16, 2009

An Overview of Automotive Home and Neighborhood Refueling

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Abstract

Home refueling helped address the fuel availability issue for gasoline vehicles a century ago; it may still have important implications for alternative fuel vehicles today. The positive consumer response and lessons learned about home refueling for compressed natural gas vehicles, battery electric vehicles, and plug-in hybrid vehicles demonstrate its potential and warrant further research. This paper presents a historical review and comparison of home refueling methods for a wide range of motor vehicles; the home refueling experience of these vehicles and consumer preferences and response to these methods are discussed as well. A description of neighborhood refueling is also provided. Furthermore, the important questions, challenges, and opportunities of adopting a home and neighborhood refueling strategy for alternative fuel pathways are summarized. The paper intends to help us understand the potential of home and neighborhood refueling and the difference between home refueling for different alternative fuel pathways, and help facilitate further exploring of the implications.

Keywords: home refueling, neighborhood refueling, alternative fuel vehicles

1 Introduction

This paper presents an historical review and comparison of home refueling methods for a wide range of motor vehicles; the home refueling experience of these vehicles and consumer preferences and response to these methods are discussed as well. Furthermore, the important questions, challenges, and opportunities of a home and neighborhood refueling strategy for alternative fuel pathways are summarized. Home refueling for private vehicles is not a new idea; between 1900 and 1915, a variety of home refueling options were introduced to early

gasoline vehicle owners. These early home refueling outfits addressed the concern of gasoline-vehicle drivers for fuel availability and featured convenience and reduced trips to public refueling facilities [1, 2]. Home refueling methods played an important role during the introduction of gasoline vehicles before large, public gasoline stations became dominant. Neighborhood refueling—intermediate in scale between home and commercial refueling—has less history. In addition to gasoline, the history of home refueling for automobiles also includes compressed natural gas (CNG) vehicles, battery electric vehicles (BEV),

plug-in hybrid vehicles (PHEV), and hydrogen fuel cell vehicles (FCV).

2 A Historical Review of Home Refueling Methods

2.1 Home Refueling for Gasoline Vehicle

Because large, public gasoline stations have been the dominant refueling method for gasoline vehicles for a long time, it is easy to forget that home refueling once helped address concerns for fuel availability. Early home refueling outfits removed driver's concerns about fuel availability, reduced trips to refuel vehicles, and offered convenience, freedom, and security of refueling at home to early vehicle owners, before a convenient network of large, public gasoline stations became available.

Early gasoline home refueling outfits typically included a private pump located in the garage and connected to an underground tank. A number of home refueling configurations were introduced between 1900 and 1915. The large variety of models supplied suggests that there was a significant clientele [1, 2]. Gasoline home refueling outfits exited the market once convenient, public stations offering cheaper gasoline became available. The reasons for gasoline vehicle owners to switch to large, public gas stations might have included the cost and difficulty of installation and maintenance, risk of fire or spills, and the relatively higher fuel cost associated with each driver maintaining their own home refueling [2].

Home refueling played an important role in facilitating gasoline vehicles during early market penetration. Home refueling together with other small capacity, dispersed, non-station refueling methods, addressed the concerns for fuel availability and made widespread use of gasoline vehicles possible before a convenient network of large, public gasoline stations became available. As pointed out in [2], the takeoff period for large, public gasoline stations occurred between 1915 and 1925, after the takeoff period for gasoline vehicle mass production, around 1910.

An important analogy from the early development of the gasoline station network is that innovative, small volume, widely available, refueling methods including home and

neighborhood refueling may be necessary during the introductory periods of alternative fuel vehicles (AFVs). Furthermore, home refueling offers many attractive features other non-station refueling methods and a sparse public station network could not offer including reduced trips to refuel vehicles, convenience, freedom, and security of refueling at home, which may be appealing to many consumers.[3] Consumer preference and response will be discussed in more detail in section 3.

2.2 Home Refueling for Compressed Natural Gas Vehicles

In early 1980's, there was a push for the use of CNG vehicles in North America due to environmental and energy security concerns and the economic viability of using natural gas as a transportation fuel. Although a dramatic change in natural gas to oil price ratio in 1987 stopped the push, the number of CNG vehicles on the road continued to grow slowly [4]. In 2006, more than 116,000 CNG vehicles were operating in the U.S [5], and around 9,548,400 CNG vehicles were operating worldwide by 2008 [6].

Lack of refueling infrastructure was one of the biggest barriers to the commercialization of CNG vehicles. Under a collaborative endeavor of the government and private sector, there has been some investment in creating a CNG infrastructure system. CNG is currently available at approximately 1,300 refueling stations in 46 states in the U.S. This is less than 1% of the 170,000 gasoline stations [7]. Further, the CNG refueling locations tended to not be at commercial gasoline stations, but to be located in fenced facilities that each required users to have an account. With this low of service and convenience, it is not surprising that drivers of CNG vehicles in southern California in the early 2000s uniformly complained of access, billing, and location problems related to refueling their vehicles [8]. As with gasoline vehicles a century ago, home refueling systems entered the market to partially solve the problem of fuel availability for CNG vehicles. CNG vehicle owners can now refuel their cars at home by installing a home refueling appliance, which consists of a small compressor connected to the home's natural gas supply, and dispensing equipment [9].

Beyond partially solving the problem of CNG availability; home refueling can provide the convenience and security of refueling at home, which may be an attractive feature to many

consumers. The potential of home refueling has drawn some attention from public decision makers as well. Recognizing the potential of home refueling for facilitating CNG vehicles, in 2005 the South Coast Air Quality Management District (AQMD) and the California Mobile Source Air Pollution Reduction Review Committee (MSRC) announced and provided financial incentives to assist consumers in covering 57% of the cost of purchasing a new CNG home refueling appliance. An incentive is also offered for leasing a home refueling appliance. The program was recently renewed due to positive response and high demand [10]. Studies of consumer response to these incentives and the impact of them on home refueling for CNG would provide valuable data and analogies for other alternative fuel pathways. However, very few (if any) such studies are underway.

2.3 Home Refueling for Battery Electrical Vehicles

Since the late 1980s, BEVs have been promoted in the U.S. through a number of incentives including tax credits and state level mandates such as the Zero Emission Vehicle mandate. In 2006, there were more than 55,730 battery powered vehicles (including neighbourhood BEVs) in use in the U.S. excluding demonstration and concept vehicles not ready for delivery to end users [5].

Current charging stations for BEVs are primarily located at residences, businesses, public parking lots, and fleet facilities where vehicles may be parked for long periods each day. Even with current fast charging stations, BEVs cannot be recharged in minutes, due to required high power and constraints on the battery side. The limited charging rate, along with the charging equipment requirements and other charging characteristics make home refueling a natural fit to BEVs. Drivers need to charge their vehicles where they park their vehicles for long periods each day, and home is most often a convenient place. Additionally, some electric utilities have offered time-of-day rates to BEV customers for charging their cars at night when electricity demand is typically at its lowest. The lower electricity cost at night makes home refueling more attractive to consumers. Based on consumer surveys and utility observations, 95% of California's current BEV drivers charge at home, mostly through overnight charging [11, 12].

Furthermore, because BEVs can be plugged into an electrical outlet, home refueling appears to be fundamental to BEVs at least for the time being. Although upgrading of recharging facility is most likely required in the US (with 110 volt outlets), capital costs for home recharging equipment may be much less compared with capital costs of home refueling equipment for other AFVs such as CNG vehicles and fuel cell vehicles (FCV). The cost for upgrading a residential garage recharging system is estimated at \$870 - \$2,200 [13], and the cost for providing a home refueling system for FCVs can easily exceed \$6,000 [14, 15]. Cost and other concerns such as safety may have significant impact on consumers' purchasing decisions, which may make the marketing strategies fundamentally different between BEVs (and PHEVs) and other AFVs of interest.

2.4 Home Refueling for Plug-in Hybrid Vehicles

With a few companies announcing their production plans in the coming years, PHEVs have drawn considerable public attention. With existing gasoline stations, fuel availability is not a concern. However, for consumers to be able to drive the vehicle dominantly with electricity to realize the multi-faceted benefits of PHEVs, recharging methods matter. Most current PHEV models are designed such that they can be simply plugged into a conventional outlet, and it is recognized by many that home recharging will play a major role for refueling these PHEVs at least in the near term.

Recharging for PHEVs is similar to BEVs in that conceptually they both can be recharged wherever parking and an electrical supply coincide. However, there can be differences between PHEVs and BEVs depending on the size of the battery in a PHEV. The charger cost can be less for PHEVs than for BEVs, and upgrading of recharging infrastructure may not be required for PHEVs. But an electrical infrastructure upgrade may be required for a PHEV with long charge depleting range (and thus, a large battery). [13]

Similar to the discussion in sub-section 2.3, home refueling is regarded by many as fundamental to PHEVs as well. Further research on PHEV infrastructure standards is imperative, since a consensus on the basic operational abilities has not been reached. [16-18]

2.5 Home Refueling for Fuel Cell Vehicles

Although some companies have made FCVs available to selected consumers, they are not commercially available. The number of FCVs in use in the US was 223 in 2007 excluding demonstration and concept vehicles not ready for delivery to end users [5]. While announcing their near term plans for small scale pre-mass production of FCVs, major automobile companies acknowledge there still are barriers on the commercialization of FCVs. Among other barriers, lack of a hydrogen infrastructure system is probably the most daunting.

Convinced that home refueling can help evade the “chicken and egg” infrastructure-vehicle problems, several companies including major automobile and FC system manufacturers are in partnerships to develop and test their home hydrogen refueling outfits to partially solve the fuel availability problem. Current solutions these companies are exploring can be separated into two categories. The first category is an electrolysis unit to split water to hydrogen and oxygen and feed hydrogen to a vehicle. The second category is a small-scale tri-generation system, which can produce electricity, heat and hot water simultaneously by converting fossil fuels such as natural gas. Compressors, dispensers, and storage are typically integrated in the system.

Among the aforementioned AFVs, providing home refueling for FCVs is the most challenging. These systems are costly and complex. Technology advances may make low-cost electrolyzers available. The tri-generation configuration is designed to improve the economics, giving more motivation to consumers to adopt such systems. First, it spreads out the capital costs among three types of energy needs, electricity, hot water and transportation. Second, the economics of operating the system can be improved by providing the three types of energy rather than providing only transportation fuel, if designed properly. A possible configuration of such a tri-generation system is shown in figure 1.

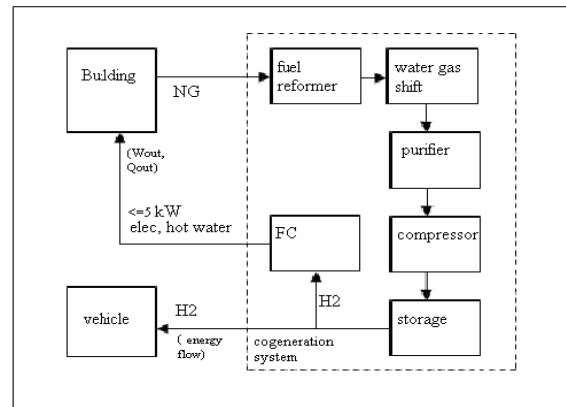


Figure 1 the schematic of a typical tri-generation system (source: [14])

Cost and consumers’ perceived safety concerns are still two major barriers to the commercialization of home refueling technologies for FCVs. A number of companies are investing in hydrogen home refueling systems and they occasionally announce improving performance and lower costs, but provide few details. Independent studies to evaluate the technical and economic performance of these systems are needed to better inform policy makers and the public about their potential.

2.6 A Comparison of Home Refueling for Different Types of Vehicles

The history of home refueling for gasoline vehicles still has important implications for home refueling for AFVs. Home refueling for AFVs can alleviate concerns for fuel availability when easy access to an extensive network of public fueling stations is not available, as well as provide convenience, and security of refueling at home. Presently, home refueling is used by a few CNG vehicle drivers. Their preferences and responses to home refueling systems provide valuable information for home refueling for other AFVs. There has not been any real world end-user experience of home refueling for FCVs so far, though a number of companies are investing in the research and development of home refueling systems for FCVs. For BEVs, home refueling appears to be essential for basic functionality in addition to other goals and less economically challenging at least for the time being. For PHEVs, home refueling opens up the potential benefits of a dual-fuel vehicle—one fuel available in a large-scale retail network and the other at home and other parking locations (assuming the coincidence of parking and electricity at these places).

A comparison among home refueling systems for

different vehicle types is given in table 1 (appended at the end of the paper) to present the

issues faced by various AFVs and facilitate further exploration of the implications.

Table 1 Home refueling for different alternative fuel vehicles

Vehicle type	Equipment	Fueling Time	Equipment cost (installation excluded, \$2008)	Fuel cost (in 2008 dollar)	Consumer experience	Fuel source
Gasoline Vehicle	A pump and a tank	Several minutes	--	\$0.06/kWh ~0.12 kWh (non-home refueling)	Yes	Delivered gasoline
CNG vehicles	A compressor, natural gas supply, and dispensing equipment	Several minutes ~ several hours (for a full tank for a 300 miles range depending on storage availability)	\$3000 ~ \$4000	\$0.04/kWh ~ \$0.07/kWh (\$1.1/therm ~ \$2.0/therm)	Yes	Existing residential NG
BEVs	An outlet, a charger and grid or stand-alone electricity	Several hours (for a full recharging for a 100 miles range)	0 ~ \$2200 ^a	\$0.05/kWh ~ \$0.15/kWh	Yes	Grid electricity
PHEVs	An outlet, a charger (may be unnecessary for some PHEVs, and grid or stand-alone electricity)	Several hours (for a full recharging for a 60 miles range)	0 ~ \$2200	\$0.05/kWh ~ \$0.15/kWh	Yes	Grid electricity
FCVs	An electrolysis unit or a reforming system, energy supply, and dispensing equipment	Several minutes ~ several hours (for a full tank for a 300 miles range depending on storage availability)	\$10000 ~ \$20000 ^b	\$ 0.11 kWh ~ \$ 0.25 /kWh (\$3.5/kg ~ \$8/kg) ^c	No	Existing residential NG, or Grid electricity

Note: a, b and c, the prices are estimates based on available literature [13, 14, 19].

2.7 Neighborhood refueling

Neighborhood refueling would provide transportation fuel to residents of a particular neighborhood or community. Neighborhood refueling outfits may include a dispensing system or an outlet connected to a dedicated facility with support personnel and power distribution infrastructure [20].

Neighborhood refueling is different from home refueling, in that neighborhood refueling outfits are sized for several homes rather than only one. The capacity may be 10 to 20 times larger than home refueling outfits; and the materials, specifications, economies of scale and efficiencies are different. Neighborhood refueling is also different from conventional public refueling stations. First the capacity is much smaller. Second, neighborhood refueling would be located near or

in the community to offer convenience and security similar to home refueling.

The demand for neighborhood refueling is aggregated demand of 10-20 households; for tri-generation hydrogen refueling systems, the less peaky electricity and hot water demand profiles may improve the economics of the systems. Higher capacity factor and utilization of the systems can be achieved. Neighborhood refueling systems can be operated commercially or as co-ops. One example of neighborhood refueling would be some existing bio-diesel co-ops, where a group of people from a community come together to invest in processing waste vegetable oil into bio-diesel.

Neighborhood refueling systems can be installed outside a residential area, such as workplaces. However, some characteristics of neighborhood refueling should be taken into account when adopting these systems outside a residential area.

- First, are the demand profiles suitable for adopting neighborhood refueling systems in terms of economic benefits?
- Second, does the location of the systems offer convenience and security similar to home refueling. This can be measured by the distance from the location people stay or work to the refueling systems.

Neighborhood refueling is suitable for multi-family residences (e.g., townhouses and condominiums), and may be particularly important for densely populated areas where individual garages, carports or other reserved parking are not available for home refueling. These areas are most often where criteria pollutants and GHG emissions problems are more severe.

3 Consumer Preferences and Response

Consumers' preferences, response and, ultimately, their purchasing decision are essential to the commercialization of home and neighborhood refueling systems. Before making a purchasing decision, consumers evaluate the costs, and the functional, psychological, and social benefits associated with a product or service. If the price of a product or service is above his/her willingness-to-pay (WTP), a consumer will not purchase the product or service [21]. Marketing organizations need to

understand the preference structure of consumers for home and neighborhood refueling systems. Do consumers like refueling at home? What functional and psychological benefits associated with these systems they value most? More importantly, how much is the targeted consumers' WTP for these systems?

Some previous research and government document on home refueling for CNG vehicles and BEVs indicate that consumer response is overall positive. As pointed out in [3], refueling at home is an attractive benefits to a large proportion of drivers (57% in their survey), and several studies "consistently find a large proportion of drivers who dislike fueling at retail gasoline service stations, sometimes to the point of consistently requiring a spouse or other person to refuel the vehicle". Abbanat [8] asked a stated preference question of CNG vehicle drivers to estimate their WTP for a home refueling appliance: the results suggest few were willing to pay over \$5,000 for the appliances. Although these studies offer some clue on consumers' overall opinion of home refueling, very few studies focus on understanding the preference structure of consumers for home and neighborhood refueling systems, and the positive consumer response and lessons learned on home refueling for CNG vehicles and BEVs demonstrate its potential and warrant further research.

4 Important Questions, Challenges and Opportunities

Home and neighborhood refueling technologies for AFVs are currently available, and no major barriers exist to the widespread commercialization of home refueling systems for CNG, PHEV or BEVs. Home refueling technologies for FCVs are in an earlier stage of development. The biggest challenge for FCVs probably is mainly associated with cost and addressing consumers' perceived safety concerns.

Despite the potential for home and neighborhood refueling to play an important role in attracting consumers to use alternative fuels and partially solving the fuel availability issue, many questions essential for the commercialization of these technologies remain unanswered, including [14]:

- 1) What is the technical, environmental, and economic performance of the technologies?

- 2) What are the constraints on the practical viability of the technologies?
 - a. Potential limits on practical viability include local land-use regulations, building codes, and noise standards, the covenants, codes and restrictions (CCRs) of many private communities, and any of a number of other possible limits on home refueling that may not have constrained the role of home refueling for gasoline at the birth of the automobile.
- 3) How much will consumers value the multi-faceted benefits associated with home and neighborhood refueling?
 - a. What is their WTP for the service?
 - b. And how will they pay?
 - c. How will they value inherently non-monetary aspects such as loss of space in or near a parking area, noise and vibration, scheduling maintenance of home refueling devices, losses of mobility caused by outages of home refuelers?
- 4) How and to what extent will policy impact the commercialization of the technologies? These policies include not only the apparent drivers for clean air, greenhouse gas emissions reductions, energy security, and fuel flexibility, but also contemporary efforts to revive a domestic US automobile industry.
- 5) Is home and neighborhood refueling a permanent or transitional strategy? And is it likely to be permanent for some “fuels” and transitional for others?

Home refueling systems with tri-generation offer the possibility of providing home heat and electricity in addition to fuel, and thus better economics. Several companies are investing in hydrogen home refueling systems, and some data have become available on performance and cost. Independent studies to evaluate the technical and economical performance of these home refueling systems are needed to better inform policy makers and the public about their potential. In future work we will provide detailed analyses on the technical and economic performance of home and neighbourhood refueling systems for FCVs.

5 Concluding Remarks

An important analogy from the early development of the gasoline station network is that innovative, small volume, widely available, refueling methods including home and

neighborhood refueling may be necessary during the introductory periods of alternative fuel vehicles (AFVs).

Furthermore, home refueling offers many attractive features other non-station refueling methods and a sparse public station network could not offer including reduced trips to refuel vehicles, convenience, freedom, and security of refueling at home. Some previous research and government document on home refueling for CNG vehicles and BEVs indicate that consumer response is overall positive. A stated preference survey study with a number of CNG vehicle drivers suggests few were willing to pay over \$5,000 for the appliances.

Cost and other concerns such as perceived safety may have significant impact on consumers' purchasing decisions, which may make the marketing strategies fundamentally different between BEVs (and PHEVs) and other AFVs of interest.

Neighborhood refueling is suitable for multi-family residences (e.g., townhouses and condominiums), and may be particularly important for densely populated areas where individual garages, carports or other reserved parking are not available for home refueling. These areas are most often where criteria pollutants and GHG emissions problems are more severe.

Acknowledgments

The authors would like to thank the sponsors of the Sustainable Transportation Energy Pathways (STEPS) program at Institute of Transportation Studies, University of California, Davis.

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