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Understanding the design and economics of distributed tri-generation systems for home and neighborhood refueling—Part II: Neighborhood system case studies

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ABSTRACT

The lack of a hydrogen infrastructure remains a major barrier for fuel cell vehicle (FCV) adoption. The high cost of an extensive hydrogen station network and the low utilization in the near term discourage private investment. Past experience of fuel infrastructure development for motor vehicles, indicates that innovative, distributed, small-volume hydrogen refueling methods may be required to refuel FCVs in the near term. Among small-volume refueling methods, home and neighborhood tri-generation systems stand out because the technology is available and has potential to alleviate consumer's fuel availability concerns. Additionally, it has features attractive to consumers such as convenience and security to refuel at home or in their neighborhood.

In this paper, we study neighborhood tri-generation systems in multi-unit dwellings such as apartment complexes. We apply analytical tools including an interdisciplinary framework and an engineering/economic model to a representative multi-family residence in the Northern California area. The simulation results indicate that a neighborhood tri-generation system improves the economics of providing the three energy products for the households compared with the two alternatives studied. The small capacity of the systems and the valuable co-products help address the low utilization problem of hydrogen infrastructure.

1. Introduction

Hydrogen fuel cell vehicles (FCVs) are slated for introduction in North America, Europe and Asia over the next few years. Hydrogen refueling infrastructure is a key issue for the rollout of these early fleets. Despite the rapid progress in FCV technology [1,2], lack of refueling infrastructure worldwide is still daunting to automobile companies. Several recent studies have proposed strategies for building early networks of public hydrogen refueling stations [3–5]. Although the proposed strategic station placement can improve consumer accessibility to fuel, the high cost of building an extensive hydrogen station network and the foreseeable low utilization in the near term are still issues, which discourage private investment. Based on past experience of fuel infrastructure development for motor vehicles including gasoline and compressed natural gas (CNG) vehicles, innovative, distributed, and small-volume hydrogen refueling methods may be required to refuel FCVs at least in the near term [6,7]. For instance, CNG is currently available at approximately 1300 refueling stations in 46 states in the US, which is less than 1% of the 170,000 gasoline stations that exist nationally [8]. Drivers of CNG vehicles have complained of access, billing, and location problems related to refueling their vehicles [9]. Lack of refueling infrastructure is an important reason that the number of CNG vehicles on the road grows only slowly, given the fact that the cost and performance of a CNG vehicle is comparable to gasoline vehicles (e.g., based on the official website of American Honda Motor Co., Inc., the 2011 Honda Civic CNG car is only about $1500 more expensive than the 2011 Civic Hybrid, $25,500 vs. $24,000, and has a fast refueling time and a range of 220 miles. CNG car also has less fuel cost). Some CNG car owners have adopted home refueling systems to refuel their cars for convenience [9–11].

Among small-volume refueling methods for FCVs, home and neighborhood tri-generation systems stand out because the technologies are available and have potential to alleviate the consumer's fuel availability concern. They also have other features attractive to consumers such as convenience and security to refuel at home or in their neighborhood. A typical tri-generation system produces electricity and heat for buildings as well as hydrogen for vehicles by converting a hydrocarbon such as natural gas (NG) or biomethane [12]. There are many ongoing demonstrations of tri-generation systems and fuel cell combined heat and power (CHP) systems [13]. In earlier work, we analyzed home tri-generation systems for single family residences [13].

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The results show that tri-generation for home refueling has the potential to be included in hydrogen infrastructure plans or portfolio infrastructure solutions in California and other states or countries. It is competitive with other early options for fueling hydrogen cars, although it is difficult to compete with the conventional system (grid electricity plus NG heat and gasoline), unless capital costs are reduced, gasoline price increases, or other factors such as relative prices for electricity and NG come into play.

In this paper, we study neighborhood refueling tri-generation systems, which serve 10–20 households in multi-unit dwellings such as apartment complexes and town houses. Neighborhood tri-generation systems can be installed at a community of single family houses as well, serving multiple households, as long as it is economical to install and operate these systems based on demand profiles and other inputs. Because the capacity of a neighborhood system is larger than a single-family home system, we expect that economies of scale would improve the economic performance of neighborhood systems compared with home systems.

We apply analytical tools including an interdisciplinary framework and an engineering/economic model (the HTS model) [13] to a representative multi-family residence in the Northern California Sacramento area. We model the yearly operation of a tri-generation system, explore the optimal design of the system, estimate the cost of electricity, heat, and hydrogen, and the system CO_2 emissions, and compare the results to alternatives. We conduct sensitivity analysis to evaluate the potential impacts of uncertainties in energy prices, capital cost reduction, government incentives and environmental cost. In addition, we explore the policy implications of the modeling results for multi-family tri-generation systems.

2. Description of neighborhood refueling and tri-generation systems

Neighborhood refueling systems are located near or in a community to offer convenience and security similar to home refueling. Neighborhood refueling systems are suitable for multi-family residences (e.g., apartment buildings and townhouses); they can serve a community of single family houses as well, as long as it is economical to install and operate these systems. Neighborhood refueling may be particularly important for densely populated areas, such as some cities in the east and west coast, Europe, and Asia, where individual garages, carports or other reserved parking are not available for home refueling.

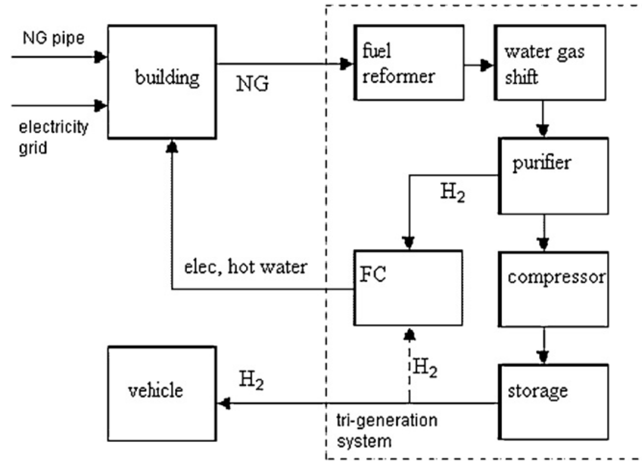

Fig. 1. The schematic of a typical tri-generation system.
Source: [13].

We consider neighborhood refueling systems sized for 10–20 households (averaging hydrogen output capacity of 10–20 kg d^{-1}), which are larger than individual home systems, but smaller than public hydrogen refueling stations that typically offer at least 100 kg d^{-1} of hydrogen. Compared to single family home tri-generation systems, the larger size of neighborhood systems has the potential to improve efficiency and lower costs through economies of scale.

A typical tri-generation system is shown in Fig. 1. A fuel reformer converts NG to a mixture of hydrogen and other gases including CO and CO_2. A water-gas shift processor converts most of the CO to hydrogen and CO_2. A purifier separates hydrogen from other gases. Pure hydrogen can be used by a PEMFC sub-system to generate electricity and heat, and can be compressed and used to refuel vehicles. More details can be found in [13].

3. Methods and data

3.1. Analytical tools

To model tri-generation systems, we developed the HTS model on the basis of the interdisciplinary framework illustrated in Fig. 2.

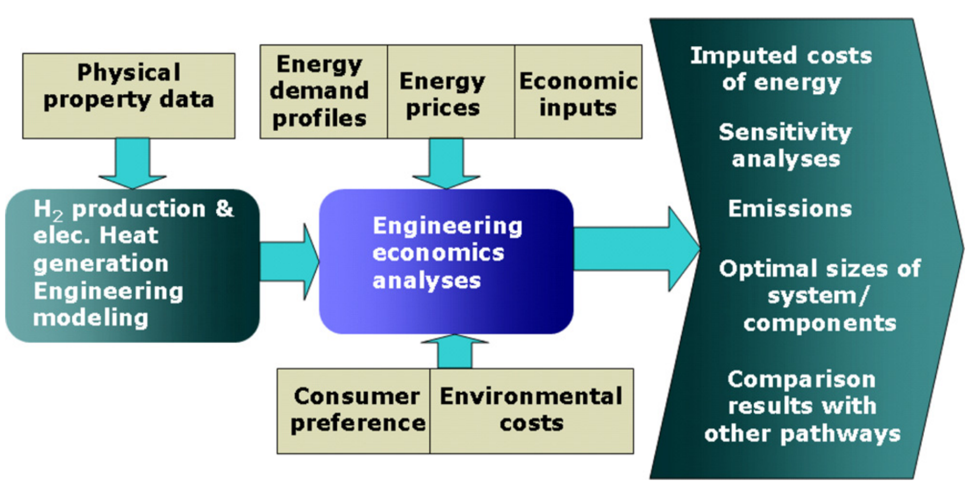

Fig. 2. Interdisciplinary framework for analyzing tri-generation systems.
Source: [13].