II.I.7 Hydrogen by Wire — Home Fueling System

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Objectives

- Define critical requirements for proton exchange membrane (PEM) electrolysis home fueling system.
- Define hydrogen production capacity for a recharge time relevant to the end-user.
- Estimate the electrical service requirements and physical size.
- Estimate the capital and operating costs.
- Describe the relevant codes and standards and their impact on cost.
- Describe key elements of product safety related to energy content and electrical hazard.
- Describe the types of operation and maintenance required, and estimate costs.

Technical Barriers

This project addresses the following technical barriers from the Production section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency

Technical Targets

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Production via Distributed Water Electrolysis

Characteristics	Units	2012 Target	2010 Status
Hydrogen Cost	$/gge	3.70	5.99*
Electrolyzer Capital Cost	$/gge	0.70	2.62*
Electrolyzer Energy Efficiency	% (LHV)	69	55**

*Based on H2A model modified for residential (non-commercial) application
**Includes generation and compression to 350 bar
gge = gasoline gallon equivalent; LHV = lower heating value

Accomplishments

- Estimated required hydrogen production capacity for a range of vehicle fuel efficiency values and vehicle usage profiles.
- Estimated physical size and electricity usage.
- Developed home fueling system bill-of-materials.
- Calculated $/kg cost for a range of fuel efficiency and vehicle usage profiles using the H2A model. Demonstrated significant progress toward DOE hydrogen cost targets established for much larger scale hydrogen production systems.
- Tabulated list of relevant codes and standards.
- Estimated cost impact of municipality specific codes and standards environment.
- Defined maintenance strategy.

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Introduction

The goal of this study was to develop requirements for a home-based hydrogen fueling system, design conceptual systems, compare the impacts of changing key parameters, and evaluate the feasibility of those concepts in meeting the requirements of the home fueling application. Factors considered in developing requirements included driving scenarios, electrical service requirements, recharge times, compression and storage, and codes and standards. Concepts were evaluated on the basis of capital cost, efficiency, safety, and installation and maintenance.

Approach

The approach was to gather primary data, develop a handful of scenarios representative of typical driving habits, and derive the requirements for the home fueling system based on the fundamental information. The driving scenarios were based on primary survey data of commuting distances of average Americans including the National Household Travel Survey [1] produced by the U.S. Department of Transportation Federal Highway Administration and the Omnibus Household Survey [2] from the Bureau of Transportation Statistics. The electrical service requirements were evaluated within the context of power available in a typical residence, and compared to other devices currently found in homes. The recharge times were based on the amount of time a vehicle would be parked at home. Proton Energy Systems' industrial electrolyzer equipment and high-pressure systems were used as sources of information to form the base bill-of-materials for the packaging studies and cost estimates. In addition, Proton's experience servicing its fleet of fielded commercial electrolyzer products was used to inform the maintenance and service plans. In each of the areas investigated, an approach based on available data and manufacturing experience with commercial electrolyzers was used to ensure the analysis and projections were strongly grounded in practical end-use and the realities of manufacturing.

Results

The hydrogen production capacity was estimated for a range of vehicle fuel efficiency values and driving habits, including serving one, two, or three vehicles within one household. With a single 90 mile per kilogram (mi/kg) vehicle, as little as 0.4 kg of hydrogen are required on average each day (Figure 1). With three 55 mi/kg vehicles and higher driving mileage, as much as 1.8 kg of hydrogen might be required on a given day.

The effects of using an electrolyzer that generates hydrogen and directly fills the vehicles only when the vehicles are home was compared with the option of including a small amount of stationary ground storage. While the inclusion of stationary ground storage does allow the hydrogen production equipment to be smaller, as it can be operating continuously, the cost of the ground storage system outweighs the cost reduction of the electrolysis equipment. Therefore, the electrolysis direct fill configuration has the advantage over a system that includes stationary hydrogen storage.

The compression efficiency of mechanical compressors and the electrochemical compression capability of a PEM electrolysis cell were compared. Electrochemical compression from ambient to 5,000 psi and higher is more efficient than mechanical compression from the same starting pressure. A further optimization showed that there may be a marginal efficiency gain by using a combination of electrochemical compression and mechanical compression where the electrochemical portion ensures that there is only one stage of mechanical compression. The efficiency gains for the combined case may be as much as 10% over pure electrochemical compression. However, including mechanical compression in a home fueling system has several drawbacks. First, the upfront purchase cost is higher with a mechanical compressor. In addition, the life cycle maintenance costs, as well as installation costs, and noise regulations in residential neighborhoods all discourage configurations that include mechanical compression. Electrolysis-only configurations were considered for the balance of the study.

A packaging study was conducted to estimate the physical size of a PEM electrolysis hydrogen home fueling appliance. The result of the detailed packaging exercise yielded a rough sizing of the unit, not including any storage or compression, of approximately 30 to 40 inches wide by 24 to 36 inches deep by 60 to 72 inches tall, smaller than a typical refrigerator (Figure 2).

The cost analysis examined the impact of different driving scenarios, different vehicle fuel economies, the incorporation of either storage or mechanical

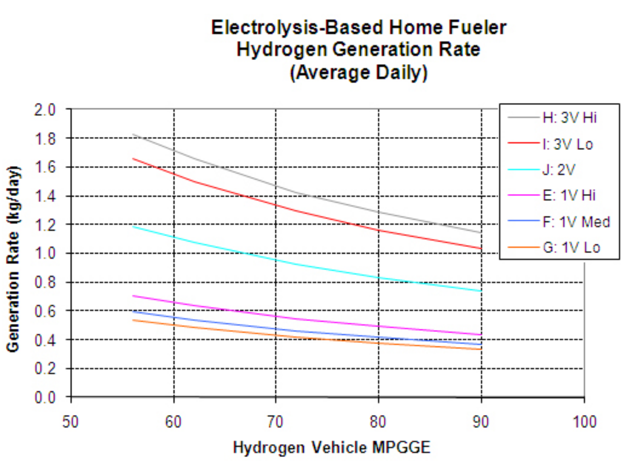

FIGURE 1. Calculated Hydrogen Generation Requirement (average for vehicle driving scenarios and fuel economy)

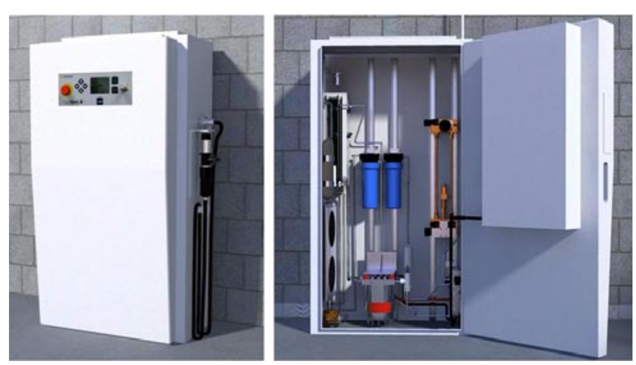

FIGURE 2. A packaging estimate yielded a clean, compact design based on components used in current commercial equipment.

compression, different cell stack configurations, and long-term cost reductions. Moreover, the sensitivity of the cost of hydrogen to several key factors was studied. Interestingly, for the home fueling application, the usage (as it impacts capacity factor) and the capital cost have a much greater impact on the cost of hydrogen compared to larger hydrogen production plants (Figure 3). The cost of hydrogen for a medium volume, cost reduced product is estimated to be about $5.99/kg. The relative cost reduction from an initial prototype to volume production is estimated to be greater than 50% (Figure 4).

There is a cost impact associated with the current municipality specific codes and standards environment. Based on Proton's experience with fueling stations as either the prime equipment installer, or the electrolysis supplier, the costs of coordinating with the authority having jurisdiction can be measured from 4 to 50 hours per installation. This type of installation cost would be

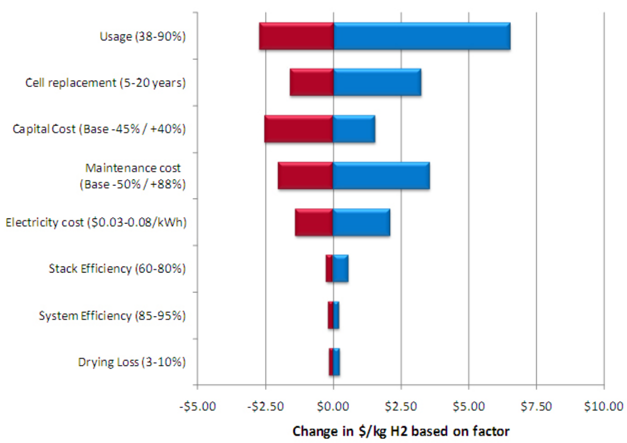

FIGURE 3. Sensitivity analysis of the cost of hydrogen to a number of factors, with usage and capital cost being more significant than in the neighborhood-scale station.

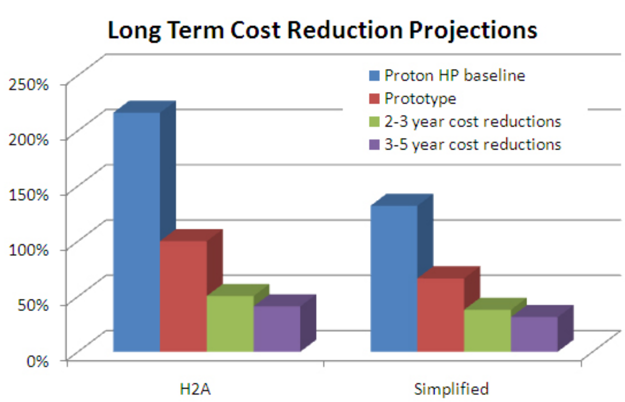

FIGURE 4. Estimate of cost reductions after product introduction (normalized to "Prototype").

severely restricting in expanding the reach of a home fueling product to the residential market. The solution is to coordinate national and international standards (such as International Organization for Standardization 22734-2), to assist states and municipalities in adopting the most up-to-date standards, and to educate the local authorities on what key features they should be looking for in a typical installation of this new type of equipment.

For equipment properly designed and properly installed to the latest standards, a PEM electrolysis-based home fueling station exhibits uniquely appropriate characteristics. For example, the maximum on-board hydrogen inventory at full-pressure production is less than 0.05 kg. The amount of energy contained in that amount of hydrogen is less than 1% of what is contained in a couple of lawn mower gasoline filler tanks and less than 0.1% of that contained in two typical gasoline power vehicles. Thus, a PEM electrolysis-based fueling system minimizes the local presence of fuel by converting water directly to fuel only as it is needed.

Conclusions and Future Directions

The case for including the hydrogen home fueling concept in the overall mix of fueling infrastructure is strong. The home fueler can grow in production volume and geographic distribution with individual vehicles as they are placed in the market with more flexibility than centralized fueling stations. Existing utility infrastructure (water, electricity) can be utilized within their existing capacities to cover the distribution aspect of the fueling infrastructure.

- The hydrogen production capacity required for the practical range of home fueling needs is within the capability of existing PEM electrolysis devices.
- The ability to generate hydrogen at 5,000 psi differential pressure–that is, with oxygen at near-ambient pressure–is another significant advantage of PEM electrolysis technology, eliminating the capital cost, footprint constraints, noise, and long-term maintenance costs associated with mechanical compression equipment.
- The footprint of a PEM electrolysis-based home fueling system can fit comfortably within a typical residential garage.
- Cost reduction efforts in line with Proton's current roadmap can help to bring the hydrogen cost from home fueling down to levels competitive with the targets for neighborhood stations.
- PEM electrolysis-based home fueling equipment has intrinsic characteristics that enhance the opportunities for safe home use, in particular by maintaining a low on-board hydrogen inventory even while operating at full production and pressure.

- Proton recommends that the U.S. Department of Energy support near-term prototype fabrication and test of integrated, residential-scale, home fueling equipment based on PEM electrolysis technology.
- Proton recommends the support of technology development to extend the differential pressure capability of PEM electrolysis equipment and the support of cost reduction efforts to speed the transition of this technology to initial product release.

FY 2010 Publications/Presentations

1. Anderson, E., Szymanski, S. and Dalton, L., "High Differential Pressure PEM-Based Hydrogen Generation for Backup Power and Home Fueling Applications," Paper No. 4650, NHA Hydrogen Conference & Expo, Long Beach, CA, May 4, 2010.

References

1. U.S. Department of Transportation, Federal Highway Administration, National Household Travel Survey, 2001.

2. U.S. Department of Transportation, Bureau of Transportation Statistics, Omnibus Household Survey.