

## II.1.4 Advanced PEM-Based Hydrogen Home Refueling Appliance

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- HHR production capacity sufficient to support 500,000 vehicles would reduce hydrogen costs to between \$3.55 and \$4.25 per kg
- Cost of HHR installation to support 500,000 vehicles is between \$2,425 at present and \$1,336 for future.

### Accomplishments

- Preliminary Design – developed specific system designs that meets the system requirements for product operation and commercial acceptance.
- Design Analysis – three different designs were evaluated based on technical, operational, safety and cost.
- Process Analysis – made an economic analysis detailing the process economics.
- Technology Development Plan – defined technical plans to address specific technical factors important to the successful development of the HHR.



### Objectives

The main objective was to examine the real-world technical, operational and market factors that are associated with implementing the hydrogen home refueler (HHR). The detailed effort was comprised of:

- a feasibility study,
- an analysis identifying the technical, operational, and safety requirements of the appliance,
- a preliminary design,
- estimates of energy use and environmental emissions,
- a detailed analysis of the process economics for the proposed technology, and
- a technology development plan.

### Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section (3.1.14.3) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost

(H) System Efficiency

### Technical Targets

This project addressed the issue by providing an analysis of the feasibility of an alternative, HHR, where consumers can refuel their cars at home for a competitive price of gasoline.

### Introduction

ElectroChem examined in detail the potential for a novel HHR to provide the daily hydrogen needs for fuel cell passenger vehicles. The HHR appliance uses ElectroChem's innovative integrated flow field (IFF) stack design in a highly reliable proton exchange membrane (PEM) based electrolyzer system [1]. The appliance is clean, safe, and cost-effective, and provides a significant infrastructure cost savings during the growth phase of the fuel cell vehicle market.

A system design proposed in the report was examined in detail for safety, cost, performance, and market acceptance. Manufacturing costs were examined under the assumptions of a highly automated mass production capacity of 500,000 units annually, commensurate with vehicle manufacturing. The H2A model was used to examine total operating costs and the effective price of fuel to the consumer.

### Approach

The key design elements of the proposed HHR appliance are:

- The HHR provides 1 kg of H<sub>2</sub> directly to the vehicle storage tank, using lower cost, off-peak electricity, over an 8-hour period. (Sufficient for a 65-mile driving range.) This effectively "tops-off" the vehicle every night.

- No high-pressure H<sub>2</sub> is stored in the appliance and the inherent system design is simplified for maximum safety and minimum cost.
- Appliance installation costs are modest and typical homes already have sufficient electrical capacity to support the unit.
- HHR operation is simple and computer controlled for maximum safety, efficient operation, and can be as easy to use as recharging a cell phone.

**Results**

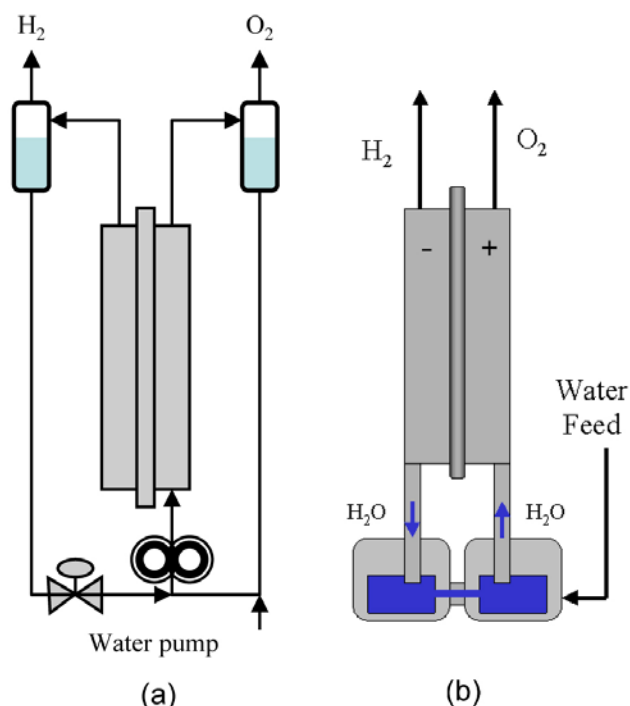
The HHR appliance creates a paradigm shift. Hydrogen is generated at night using off-peak electricity and fed directly to the vehicle tank at 5,000 psi for daily commuting. Forecourt hydrogen refueling stations are then only needed to facilitate long distance travel greater than 300 miles. The cost advantage of hydrogen production of ElectroChem’s HHR over forecourt hydrogen station states in the fact that:

- no manpower is required for operation,
- no real estate is required for installation,
- the simple design has few components, and
- no additional infrastructure is required (electrical power lines, delivery trucks, or natural gas lines).

A system design analysis has found that the safety is readily assured by the adaptation of existing design rules applied to home refueling systems for compressed natural gas, and electric vehicle rechargers [2]. In addition, the HHR is based on ElectroChem’s IFF Electrolyzer (as shown in Figure 1) which passively manages the water content of each cell, guaranteeing reliable performance (enhanced efficiency and superior operational stability) and greatly reducing the number of moving parts. The significant system simplifications also reduce manufactured cost.

Manufacturing costs were examined under the assumptions of a highly automated mass production capacity of 500,000 units annually, commensurate with vehicle manufacturing. The cost estimates partially leveraged the benefits of using materials that are also produced for fuel cell vehicles. Several approaches to cost estimation were used, with each providing similar results, concluding that the HHR can be manufactured for between \$1,000 and \$2,000.

	Forecourt	HHR
Capacity kg/day	1,500	3
number of systems per year	500	1,275,000
Cost/station (Present)	\$6,727,303	\$2,425
Cost/station (Future)	\$5,169,290	\$1,336
Total Installed Cost (Present)	\$3.36 Billion	\$3.09 Billion
Total Installed Cost (Future)	\$2.58 Billion	\$1.70 Billion



**FIGURE 1.** A conventional PEM electrolyzer (a) is schematically compared with the ElectroChem PEM IFF design (b). In the IFF design, water recirculation pumps are eliminated and phase separation occurs internal to the cell.

Because the number of HHR units manufactured is very large (one per vehicle) the manufactured costs are quite low. (The HHR unit is nearly as low a cost on a per kg hydrogen basis as the much larger forecourt station.) This is because, the HHR unit makes up its cost disadvantage by not requiring the excess station costs. It is seen that the total installed cost of the two approaches are nearly the same.

Our primary finding is that HHR production capacity sufficient to support 500,000 vehicles would reduce hydrogen costs to between \$3.55 and \$4.25 per kg, a cost and energy equivalent that is competitive with gasoline. One gallon of gasoline has nearly the energy equivalent of 1 kg of hydrogen. However, it is also noted that hydrogen vehicles are expected to be twice as efficient on a cost per mile basis. Therefore, it costs half as much to drive a mile with hydrogen.

The forecourt approach to hydrogen refueling was critiqued in detail, particularly during the period of fuel cell vehicle market growth. The problem in the forecourt approach is that large quantities of high-pressure hydrogen must be stored on-site to enable fast vehicle refueling [3]. It is concluded that the serious underutilization of capacity during market growth makes the use of forecourt based fuel very expensive, no matter what technology is used to produce the hydrogen. It is estimated that the perceived need for subsidies to

support infrastructure development can be reduced by a factor of four, if the HHR system is successfully deployed.

The environmental impact of the PEM-based HHR system is minimal because of its inherent use of safe materials, few moving parts, and no toxic emissions. The mass deployment of the HHR refueling system will also reduce carbon emissions. The material components are highly recyclable and the owner will be financially incentivized to recycle by the modest content of precious metal (approx. \$100 per unit).

### Conclusions and Future Directions

The HHR appliance is a key enabler of fuel cell vehicles. The HHR is seen as a means to rapidly expand the fuel cell vehicle market to all locations simultaneously, without geographic limitations, and with minimal infrastructure cost. Two specific technology development recommendations are made to enable the HHR to achieve its potential of low system cost and high reliability. 1) IFF electrolyzer development to achieve its system cost and reliability potential, and 2) electrolyzer membrane development to reduce hydrogen gas crossover to enable 5,000 psi IFF electrolyzer operation. Additional effort should be placed on low-cost, reliable hydrogen compressor designs, as a fallback to the chance that reduced crossover membrane development only partially meets its goals.

### FY 2010 Publications/Presentations

1. 2010 DOE Hydrogen Program Review Meeting, Poster section, Washington, D.C., June 7, 2010.

### References

1. Michael Pien Ph.D., Steven A. Lis, Ph.D. and Marvin Warshay, Ph.D., "Feasibility of Electrolyzer Based Home Refueling System for Advanced Plug-in Hybrid Vehicle Applications", EPRI, Palo Alto, CA: 2008 EP-P25770/C12457. 2008.
2. David L. Greene, Paul N. Leiby, Brian James, Julie Perez, Margo Melendez, Anelia Milbrandt, Stefan Unnasch, Daniel Rutherford, Matthew Hooks, Ed. Shawna McQueen, *Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements*, March 2008, Oak Ridge National Laboratory, U.S. Department of Energy, contract DE-AC05-00OR22725.
3. Steven Cohen, Stephen Porter, Oscar Chow, David Henderson, "Hydrogen Generation From Electrolysis", Final Report for DOE Award DE-FC36-04GO13030, 2008.