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Feasibility of Electrolyzer Based Home Refueling System for Advanced Plug-in Hydrogen Vehicle Applications

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EXECUTIVE SUMMARY

In this EPRI supported technology innovation project, ElectroChem has demonstrated operation of a unique cell design that allows great simplifications, yet high performance, for PEM electrolyzer technology suitable for automotive Home Hydrogen Refueling. The feasibility of a home-based hydrogen electrolyzer refueling system for charging advanced plug-in hybrid vehicles has been investigated. A bottoms-up analysis of the total manufacturing, installation, maintenance, and power costs shows that a small appliance based on this technology can efficiently refuel individual hydrogen vehicles using off-peak power @ $0.035/kW-hr for as little as $2.81/kg of H_2. Further funding and development is required to research, develop, test, and produce these units for mass market sales.

Introduction and Background

World wide, significant R&D investments continue in key areas toward realizing a Hydrogen Economy as a new energy carrier. Growing concerns over carbon dioxide (CO_2) emissions and dependence on imported fossil fuels are the biggest drivers for investments in the hydrogen energy carrier option.

In 2003, President Bush announced The Hydrogen Initiative, and its intention to reduce the nation's dependence on foreign oil through the production of hydrogen fuel targeted primarily at vehicle use.[1] While many automobile companies are working towards developing and manufacturing hydrogen fueled cars, they are very concerned about how the hydrogen infrastructure will become available in order to serve the deployment of the vehicles in the marketplace.[2] The primary obstacle to implementation is the perceived infrastructure investment cost associated with building and operating hydrogen refueling stations during the early market penetration years of hydrogen vehicles. Biofuels, PHEV's and all-electric vehicles are seen by automotive and oil companies as intermediate options which do not have the magnitude of the infrastructure issue that hydrogen has. However, many industry experts anticipate that further evolution of these vehicles will continue and will include the use of renewable or alternative fuels, such as hydrogen to enhance range and to reduce costs. The transition to pure hydrogen is seen as the primary goal.

One approach to help meet this infrastructure challenge is to offer refueling via a Home Hydrogen Refueling (HHR) appliance – if such an appliance could be technically and economically viable. In HHR, the owner refuels his vehicle by plugging it into the appliance located at his home each evening. Hydrogen is generated at night using off-peak electricity and fed directly to the vehicle tank for daily commuting. Large refueling stations are then only needed to facilitate long distance travel; greater than 300 miles.

Such an appliance would be a key enabler of more efficient vehicles and would create a paradigm shift. Distributed hydrogen production using off-peak electricity for Home Hydrogen Refueling could be an ideal opportunity for utility companies to advance this infrastructure and enter the market by offering a reduced cost solution. This approach makes maximum use of the current grid capacity at times when demand is lowest.

Historically, the feasibility of HHR systems has been prohibitive due to cost, performance, and dis-economies of scale issues. In comparing fuel costs, a gallon of gasoline has the approximate energy content of a kilogram of hydrogen. To be economically attractive, the per-kilogram cost of hydrogen needs to match current gasoline prices. If such costs can be met, HHR would be both a near term and long term solution.

EPRI identified a novel electrolyzer concept being developed for NASA by ElectroChem, which could potentially find use as a vehicle refueling system. The underlying innovation uses, an Integrated Flow Field (IFF) technology, which has demonstrated highly efficient, reliable, and passive fuel cell performance.[3,4]

EPRI's Technology Innovation area sponsored research in 2007 to further assess the technical and economic feasibility of this technology for applications in a Home Hydrogen Refueling Appliance.

Project Objectives:

The objectives of this project were to:

- Demonstrate Proof-of-Concept by successfully operating its unique PEM IFF Electrolyzer/Hydrogen Generator.
- Develop a specific electrolyzer system design and assess the technical and economic feasibility for a home automotive refueling (HHR appliance) sized to support the operation of a single passenger car.
- Develop an R&D action plan for the next steps.

Results and Findings:

Experimental: The advanced IFF Electrolyzer/Hydrogen Generator cell outperformed a conventional electrolyzer cell, in efficiency of hydrogen production as well as stability of operation. Long-term stable and efficient cell operation did not require water circulation or phase separators, proving viability under passive operating conditions. Passive operation is enabled by the unique IFF design that transports and separates water and gases inside each cell through its fundamental properties.

Analysis: Passive operation permits major system simplifications, size reductions, and cost savings. A technical analysis showed that a high reliability, small-sized HHR unit, with few moving parts, and no high pressure storage, could produce sufficient high purity hydrogen for the vehicle refueling associated with a typical daily commute.

A target appliance design was developed to meet the daily commuting needs of the average US driver of a fuel cell vehicle such as the Honda FCX Clarity.[5] Complete electrical to hydrogen conversion efficiency was 65%. The unit was sized to provide 1 kg of H_2 in an 8 hour period, although typical usage would only be 0.5 kg (50% utilization). Long life materials were selected, allowing researchers to predict a 10 year product life. Compression is accomplished electrochemically.

Manufacturing volumes of up to 100,000 units annually were examined, a number sufficient for a market entry vehicle. The bottoms up cost analysis included materials costs and scaling factors appropriate to several levels of volume manufacturing similar to those found in the automotive industry. Labor costs included complete factory facilities and overhead costs. Total capital cost and installation was amortized as a 10 year mortgage with 8% interest.

The HHR's operating parameters are as follows:

Parameter	Value	Units
Hydrogen Production Capacity	1	kg/day
Period of Operation	8	hrs
Operating Voltage	240	Volts (AC)
Power Use During Operation	6.3	kW
Physical Size	2 x 2 x 2	feet
Daily Commute	35	Miles
Mileage Efficiency of Vehicle	65.7	Miles per kg
Annual Mileage	12,000	Miles
Capacity Utilization	50%	
Product Life	10	Years

A schematic of the HHR appliance is illustrated in Figure ES- 1. In this schematic all the major components are sized appropriately.

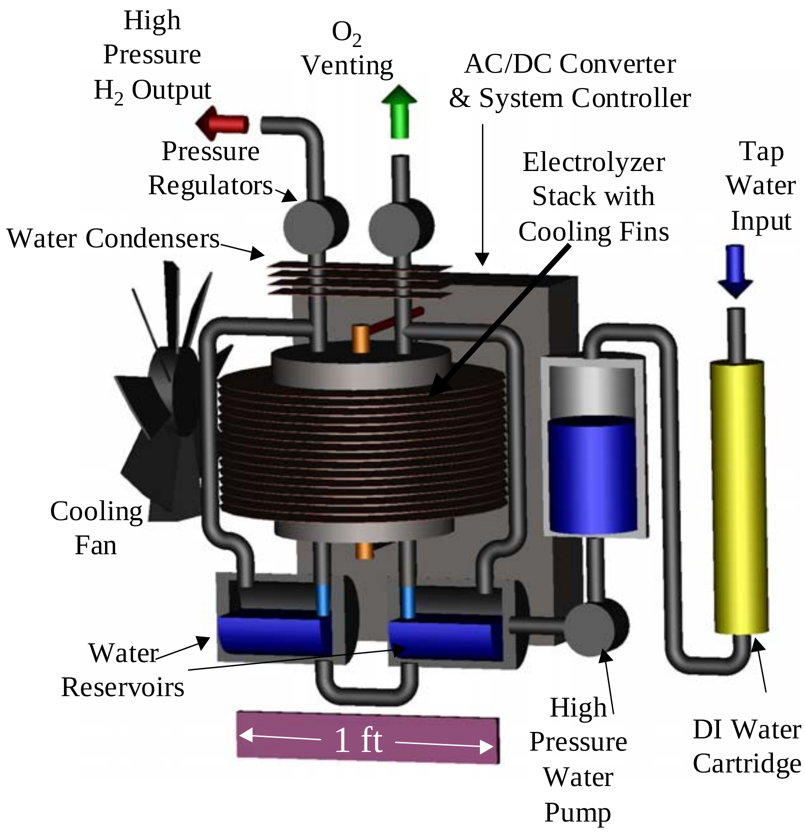

Figure ES- 1. Schematic of the Home Hydrogen Refueling Appliance.

A summary of operating costs for a typical use scenario are as follows for units produced at manufacturing volumes of 100,000 per year.

Installed Appliance Cost	**$2221**
Annual Mortgage Cost	**$331**
Annual Maintenance	**$50**
Power Cost	**$0.035/kW-hr**
Power Cost of H_2	**$1.76/kg**
Annual Power Cost @ 50% Utilization	**$322**
Total Annual Fuel Cost @ 50% Utilization	**$703**
H_2 cost @ 50% Utilization	**$3.85/kg**
H_2 cost @ 100% Utilization	**$2.81/kg**

Relative appliance capital costs components for the HHR are illustrated in Figure ES- 2. It is seen that the cost of special materials such as precious metals and Nafion™ Membrane play only a minor role. Therefore price fluctuations in these components will have minimal impact. Cost sensitivities and the effective fuel cost for driving is shown in Figure ES- 3 and Figure ES- 4.

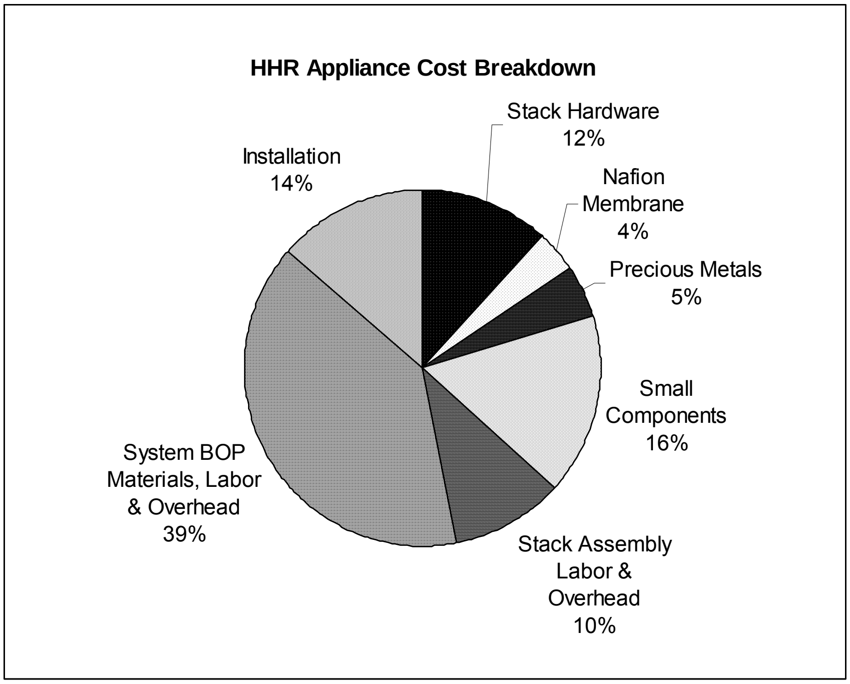

Figure ES- 2. Cost components of the installed HHR Appliance.

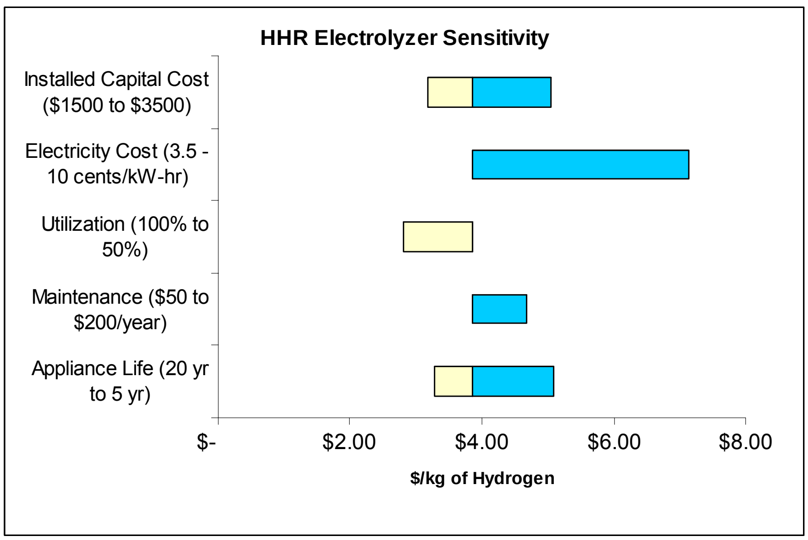

Figure ES- 3. The effective cost of hydrogen fuel is sensitive to several factors, but remains in the vicinity of current gasoline prices.

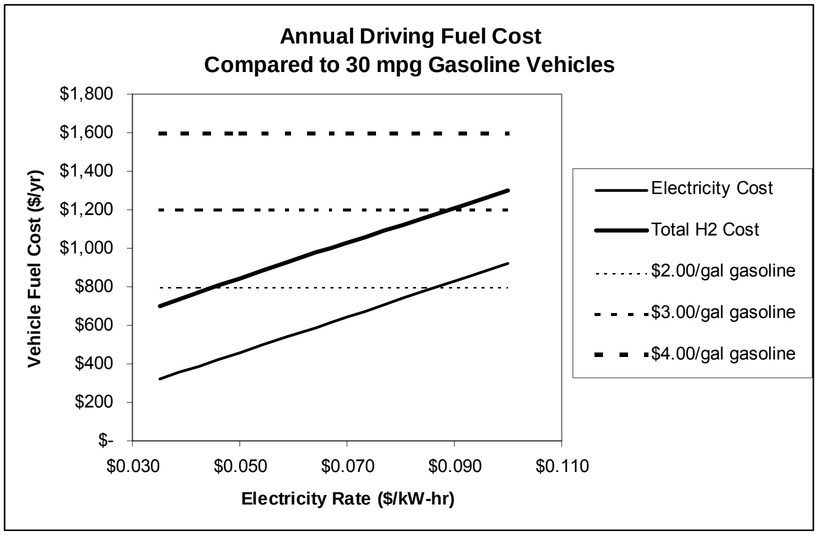

Figure ES- 4. The true cost comparison for the typical vehicle owner is his annual fuel costs, which the HHR makes significantly lower under most pricing scenarios. Annual costs for typical 12,000 miles/yr are compared with a gasoline vehicle having a mileage of 30 mpg.

Advantages of a Home Hydrogen Refueler. Conventional electrolyzer based hydrogen refueling stations ("Forecourt") are generally much larger (150 to 1000 kg/day) systems with estimated production costs for hydrogen of $14/kg. These facilities assume the need for station manpower, real estate, hydrogen storage facilities, added electrical capacity, and rapid refueling equipment. The HHR has none of these cost elements. The HHR is operated by the owner and an on-board computer. The small appliance size allows the unit to be located at the home so no extra land need be purchased. No hydrogen storage is needed beyond the vehicle tank itself. The power requirement of the HHR (6 kW) fits within the electrical capacity of the typical home, so added electrical capacity is not required. Vehicle refueling is over a period of hours, not minutes. The HHR also takes advantage of volume manufacturing efficiencies, with cost and QA control, where 100,000 appliances per year could jump start the market entry at a low investment cost.

On the other hand, the permit and safety requirements for a Hydrogen Refueler located in homes will be different than for the Central Refueling Stations. Some requirements will be more stringent while some will be less stringent.

Recommendations

The system simplifications allowed by this innovation enable the design of a small, efficient and low cost HHR appliance, targeting hydrogen vehicle refueling at home with off-peak electricity.

The baseline technology is in the early stage of development and needs to be scaled-up.

Research and development funds to produce a prototype HHR system are required.

The major elements of the follow-on development work would be:

- Communicate the findings from this work to industry strategic partners;
- Development of Integrated Flow Field multi-cell stack hydrogen generator subsystem;
- Carry out performance and durability tests of the stack.
- Design, development, and construction of a full HHR Appliance Prototype; and
- Testing and evaluation of the appliance.

The estimated development costs are $2 million over a two year period to advance the current technology to a 1 kg/day fully integrated system.

At the completion of the development, there would be an opportunity for utilities to capitalize on this vision to create not only a hydrogen infrastructure for transportation but to participate in the full potential for a hydrogen economy worldwide.

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