V.P.3 Market Opportunity Assessment of Direct Hydrogen PEM Fuel Cells in Pre-Automotive Markets

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Objectives

The overarching objectives of the project are to assist the DOE in developing fuel cell systems by analyzing the technical, economic, and market drivers of direct hydrogen polymer electrolyte membrane fuel cell (H-PEMFC) adoption. Project objectives are to:

- Complete market segmentation of H-PEMFC applications in the <1-250 kW size range including portable, backup power, and specialty vehicle applications into near-term (2008) and mid-term (2012) market opportunities.
- Develop an understanding of technology and market factors, including user requirements that will drive the adoption of H-PEMFCs in these markets and applications to 2015.
- Determine the cost and quality of H-PEMFC products that will be commercially available by 2008.
- Perform lifecycle cost analysis of H-PEMFCs and competing alternatives in near-term markets.
- Estimate market adoption rates for H-PEMFCs in near-term markets.
- Develop value propositions and complete market opportunity assessments for H-PEMFC in near-term markets.

Technical Barriers

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

(A) Durability

(B) Cost

Technical Targets

This project is gathering early adopter user-requirement data from near-term (2008) markets; gathering information on current H-PEMFC cost and performance for comparison to those user requirements; and, based on current H-PEMFC adequacy to meet user requirements, projecting lifecycle costs, market penetration, and the corresponding annual production volume likely to be achieved in transition markets. It is anticipated that the analysis provided by this project will assist the DOE in developing and/or modifying technical targets for various H-PEMFC applications.

Accomplishments

- Completed analysis of the market opportunity for H-PEMFCs in the 1-250 kW size range in three near-term markets. Published a report titled *Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets* [1].
  - Identified near-term and mid-term markets where H-PEMFCs offer value over competing alternatives.
  - Performed comprehensive marketing research through primary and secondary methods to understand user requirements in various markets. Received input from approximately 265 stakeholders including 223 candidate users of H-PEMFCs.
  - Modified the H2A model to allow cost comparisons between H-PEMFC and alternative methods of electricity generation.
  - Applied Bass innovation diffusion models to determine market penetration scenarios.

- Developed value propositions and market opportunity assessments for H-PEMFCs in three near-term markets (emergency response, forklift, and airport tug).
- Worked with the U.S. Fuel Cell Council to ensure inputs were received from industry through the course of the study. Seventeen completed surveys were obtained; three meetings were conducted.
- Presented results at various meetings and disseminated information to candidate users.

- Completed identification and segmentation of portable fuel cell markets and Federal fuel cell markets for H-PEMFC in the <1-250 kW size range.
- Initiated additional surveys of candidate users, integrators, and manufacturers.

Introduction

The DOE is working on the development of H-PEMFC vehicles and realizes that the pathway to commercialization of vehicles will likely include the introduction of H-PEMFCs in near-term markets with fewer technical challenges than automobiles. The DOE also recognizes that fuel cell companies and component developers need to increase fuel cell sales in the coming years in order to support the continued research and development (R&D) required for technological advancements in automotive applications, to develop a supplier network, and to sustain the interest of investors in their companies. In order to facilitate growth of the H-PEMFC industry and support the development of robust products, the DOE is focused on identifying near-term market opportunities for H-PEMFCs in pre-automotive applications. Battelle is providing an assessment of the market opportunities for H-PEMFCs and an analysis of the technical, economic, and market drivers for H-PEMFC adoption in near-term markets. Near-term markets are those segments in which H-PEMFCs can be demonstrated successfully by 2008 in the United States. Analysis of the early markets will provide insights into the requirements for product development, application, and end-user acceptability. Battelle's assessment includes H-PEMFCs in the 1-250 kW size range in specialty vehicle, portable power, and backup power applications.

Approach

To guide the study, Battelle is utilizing a framework integrating market, economic, and technology analysis. Figure 1 shows the methodology used to guide the analysis of the near-term market segments. A marketing research plan was developed to identify the specific

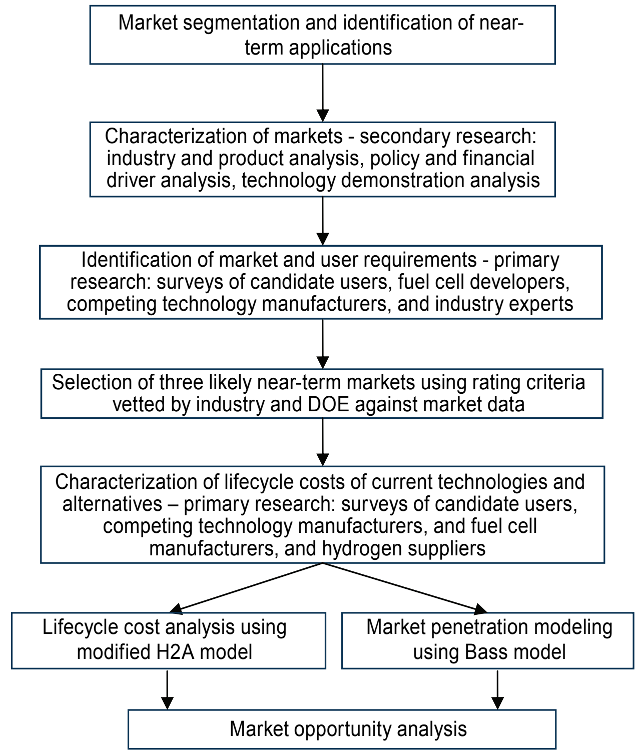

FIGURE 1. Marketing Research Methodology

research questions, data acquisition, and data quality guidelines. Data are gathered through a combination of secondary and primary research, with continuous input from industry and government stakeholders to validate and refine the assumptions and findings. Secondary research includes review of published reports, peer reviewed journal articles, magazine articles, and market research reports to identify market requirements. Primary research includes surveys and interviews with users, manufacturers, integrators, and industry experts to gather user requirements. Selection of interviewees and survey respondents is based on a judgment sample for each market segment. To allow lifecycle cost comparison of H-PEMFC and competing technology solutions, a modified H2A model is utilized. Current H-PEMFC lifecycle costs and lifecycle costs of competing energy generation or storage technologies determined through surveys are used in the lifecycle cost analysis. Lifecycle costs are calculated on a net present value (NPV) basis over a 15-year analysis period. A discount rate of 8% and an inflation rate of 1.9% are applied. H-PEMFC lifecycle costs are calculated with and without incentives of $1,000 per kW. In addition, single-factor sensitivity analysis is performed to show the variability in average annual cost (cash basis) of owning and operating H-PEMFC as individual factors are varied while all other factors are held constant. To estimate market penetration rates, the Bass innovation diffusion model, a three-parameter model for calculating the number of new adopters at a given time, *t*, and cumulative adoptions, *X,* is utilized [2]. The parameters include the total number of potential adopters, *m*; a coefficient of innovation, *p*; and a coefficient of imitation, *q*. The parameter *m* is an estimate of the number of potential adopters at a given point in time. The parameter *p* reflects innovators that make their initial purchase without influence from the number of others who have purchased. The basic formula of the Bass model [3] is:

$$x(t) = p + q[X(t\text{-}1)/m][m - X(t\text{-}1)]$$

Results

During the first half of FY 2007, analysis and reporting on the market opportunity for H-PEMFCs in three near-term markets including backup power applications in state and local agencies of emergency response, forklifts in high-throughput distribution centers, and airport ground support equipment were completed. For each market segment, market requirements for successful H-PEMFC introduction, lifecycle costs of H-PEMFCs and competing alternatives, potential for market penetration of H-PEMFC in three different scenarios, and the value proposition and market opportunity for H-PEMFCs were analyzed. In the second half of FY 2007, marketing research to support the analysis of the market opportunity for H-PEMFCs in Federal and portable markets was initiated and is currently underway. Presented here are the summary results of the market opportunity assessment for H-PEMFC-powered forklifts in high-throughput distribution centers only. Complete results for backup power applications in state and local agencies of emergency response, forklifts in high-throughput distribution centers, and airport ground support equipment are provided in the report titled *Identification and Characterization of Near-Term Direct Hydrogen Proton Exchange Membrane Fuel Cell Markets* [1].

Forklifts at High-Throughput Distribution Centers

Market Requirements. Users of battery-powered forklifts are concerned about increasing productivity of operations by reducing the number of battery change-outs and increasing the lifetime of batteries. Factors considered most important by users when evaluating forklift power systems are reliability, ease of use, and lifetime of unit. Primary factors that influence the users' decision to purchase a forklift powered by an alternative power source (e.g., H-PEMFC) are reliability and capital cost. Users appear to be interested in alternatives and primarily consider return on investment when making purchasing decisions in this market segment.

Lifecycle Cost Analysis. Distribution and warehousing operations currently use battery-powered forklifts to perform the majority of their indoor material handling. Users identified a significant interest in alternatives to batteries in forklifts in order to increase productivity, especially in high-throughput operations. To determine if H-PEMFCs are a viable alternative, the lifecycle costs of H-PEMFC-powered forklifts are compared against battery-powered alternatives for two types of forklifts (pallet truck and sit-down rider truck) commonly used in distribution centers under various operating conditions (Table 1).

From a lifecycle cost perspective, H-PEMFC-powered pallet trucks require significantly less investment (calculated as NPV of costs) than battery-powered pallet trucks under conditions of near continuous use and battery change-out times of 30 minutes (Table 2). The larger H-PEMFC-powered sit-down trucks require slightly more investment than battery-powered sit-down forklift trucks in three shift operations with battery change-out times of 15 minutes (Table 3). Assuming incentives, the NPV of the H-PEMFC-powered forklift is comparable to the battery-powered sit-down truck with three replacement batteries. The NPV of the H-PEMFC-powered forklifts is impacted by declining hours of operation (i.e., number of shifts), declining life of batteries, declining labor rates, the time required for battery change-outs, and the cost of hydrogen. While H-PEMFC-powered forklift trucks require more initial capital investment than battery-powered forklift trucks, they require less investment in operation and maintenance over the lifetime.

Single-factor sensitivity analysis was performed to show the variability in average annual cost (cash basis) as individual factors varied by +/-10% while all other factors were held constant for the H-PEMFC-powered pallet truck. As shown in Figure 2, hydrogen cost has the greatest impact on annual cost of owning and operating a H-PEMFC-powered pallet truck, followed by fuel cell life and H-PEMFC replacement costs. Thus, improvements in hydrogen cost, fuel cell life, and H-PEMFC replacement costs, will have the greatest impact on the annual operating cost of the H-PEMFC-powered pallet truck.

Market Penetration Analysis

The market penetration analysis assumes the following: cost-effective hydrogen fuel is available at the time of introduction; H-PEMFC-powered forklifts are introduced as commercial products; and introduction can be scaled to meet demand. Table 4 shows the assumptions that were used for the three market adoption scenarios. The base scenario assumes no government intervention, communication scenario assumes government communication, and subsidized scenario assumes government subsidy for purchases at $1,000 per kW along with government communication. In all three scenarios, it is assumed that H-PEMFC-powered forklifts offer value as compared to battery-powered forklifts including lower lifecycle costs, ability to operate continuously, and ease of use. The models show the first year annual sales reach 10,000 units is

TABLE 1. Lifecycle Cost Assumptions for Net Present Value Analysis of H-PEMFC- and Battery-Powered Forklifts

	Scenario 1		Scenario 2	
	Battery-Powered Pallet Truck	**H-PEMFC-Powered Pallet Truck**	**Battery-Powered Sit-Down Truck**	**H-PEMFC-Powered Sit-Down Truck**
Cost ($)	8,000	13,500	25,000	35,000
Lifetime (yrs)	15	15	15	15
Hours of Operation (hrs/yr)	7,644[1]	7,644[1]	5,460[2]	5,460[2]
Cost of Accessories ($)	2,406[3]	-	2,406[3]	-
Battery Charger	1,800	-	1,800	-
Cranes/Hoists	210	-	210	-
Cost for Battery Room	396	-	396	-
Routine Maintenance Costs ($/yr)	3,600[4]	720[5]	3,600[4]	720[5]
Electricity/Hydrogen Fuel Costs ($/yr)	1,307[6]	4,380[7]	1,307[6]	5,590[8]
Time for Refueling (min/day)	30	3	15	3
Cost of Refueling/Recharging ($/yr)	8,213[9]	274[10]	5,850[9]	390[11]
Replacement Costs ($)	1,800 – Batteries every 5 years	9,000 – Fuel cell module every 5 years	4,000 – Batteries every 5 years	24,000 – Fuel cell module every 5 years 2,600 – Ultracapacitors every 10 years

[1] Forklift operates 7 hours per shift, 3 shifts per day, and 7 days a week.
[2] Forklift operates 7 hours per shift, 3 shifts per day, and 5 days a week.
[3] Schneider. A. 2004. Vistavia Warehousing, Inc. Global Perspectives on Accounting Education. Volume 1, 25-30.
[4] Routine maintenance is 5 hours per month at $60/hr. Data obtained from Battelle market research surveys.
[5] Routine maintenance is 2 hours per quarter at $90/hr. Data obtained from Battelle market research surveys.
[6] Cost of electricity charging is based on 2.85 kW per hour at 0.06 cents per kWh. Data obtained from L.D. Bailey and Associates. 2004. Electric vs. LP Gas Cost Comparison.
[7] Tank size is 0.8 kg. Runtime from single tank is approximately 8 hours. It is assumed that the tank is filled three times a day. Industry communication, September 2006.
[8] Tank size is 3.7 kg. Runtime from single tank is approximately 18 hours. Industry communication, September 2006.
[9] Battery swapping takes approximately 30 minutes. Operator charge is $15/hr. Battery is changed out once per shift.
[10] Fuel cell takes 1 minute to refuel. The fuel cell is refueled once every shift. Industry communication, September 2006.
[11] Battery swapping takes approximately 15 minutes. Operator charge is $15/hr. Battery is changed out once per shift.
[12] Fuel cell takes 3 minutes to refuel. It is refueled 2 times per day. Industry communication, September 2006.

TABLE 2. Net Present Value of the Lifecycle Costs ($) to Own and Operate a H-PEMFC- (With and Without $1,000/kW Incentive) and a Battery-Powered Pallet Truck

	3-Battery Pallet Truck	**2-Battery Pallet Truck**	**H-PEMFC Pallet Truck w/out Incentive**	**H-PEMFC Pallet Truck with Incentive**
NPV of Capital Costs ($)	21,572	17,654	23,835	21,004
NPV of O&M Costs (Including Fuel) ($)	127,539	127,539	52,241	52,241
NPV of Total Costs of System ($)	149,111	145,193	76,075	73,245

TABLE 3. Net Present Value of the Lifecycle Costs ($) to Own and Operate a H-PEMFC- (With and Without $1,000/kW Incentive) and a Battery-Powered Sit-Down Truck

	3-Battery Sit-Down Truck	**2-Battery Sit-Down Truck**	**H-PEMFC Sit-Down Truck w/out Incentive**	**H-PEMFC Sit-Down Truck with Incentive**
NPV of Capital Costs ($)	44,429	39,497	63,988	56,440
NPV of O&M Costs (Including Fuel) ($)	76,135	76,135	65,131	65,131
NPV of Total Costs of System ($)	120,563	115,631	129,118	121,570

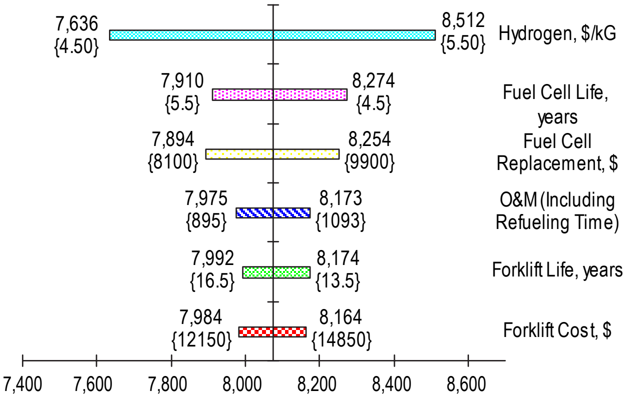

FIGURE 2. Sensitivity Analysis of the Average Annual Cost ($) of Owning and Operating a H-PEMFC-Powered Pallet Truck

eight years after commercial introduction for the base scenario. Under the communications scenario, this amount is reached one year sooner (seven years after commercial introduction). In the subsidized scenario however, 10,000 units are sold much earlier, three years after commercial introduction. Table 5 shows summary of sales and market shares for these three scenarios, at 5, 10, 15, and 20 years after commercial introduction.

Market Opportunity Assessment

H-PEMFC-powered forklifts appear to represent a promising early opportunity for fuel cells in materials handling applications. Market research suggests that there are opportunities for alternative technologies to battery-powered forklifts in high-productivity environments. While lead-acid batteries are a known technology and are fairly reliable, there are concerns with their operation and maintenance, voltage drops as batteries discharge, and downtime during battery change-outs. User requirements for runtime, refueling time, start-up time, operation and maintenance cost, and ease of use fit well with the capabilities offered by H-PEMFC-powered forklifts. Unique benefits of H-PEMFC-powered forklifts make them attractive for innovators as they lead to improvements in productivity.

TABLE 4. Assumptions for H-PEMFC-Powered Forklift Adoption in Distribution Centers and Warehouses

Assumption	Base Scenario	Communication Scenario	Subsidy Scenario
Market Growth Rate	5%	5%	5%
Government Actions	None	Communications	Subsidize purchase @ $3,000/unit
Values of p and q	$p = 0.008$ $q = 0.423$	$p = 0.012$ $q = 0.423$	$p = 0.070$ $q = 0.423$
Initial Number of Class 1, 2, and 3 Battery-Powered Forklifts Purchased	108,606	108,606	108,606
Initial Number of Class 1, 2, and 3 PEM Fuel Cell Powered Forklifts Purchased (m)	40% of total forklift market; $m = 43{,}442$	40% of total forklift market; $m = 43{,}442$	40% of total forklift market; $m = 43{,}442$
Average Initial Price of PEM Fuel Cell-Powered Forklifts	$20,000	$20,000	$20,000
Rate of Price Reduction	Stable; no price reduction	Stable; no price reduction	Stable; no price reduction
Final Share of Battery-Powered Forklift Market	100%	100%	100%

TABLE 5. Summary of Sales and Market Share for Alternative Market Adoption Scenarios for H-PEMFC-Powered Forklifts

	5 Years After Commercial Introduction			10 Years After Commercial Introduction			15 Years After Commercial Introduction			20 Years After Commercial Introduction		
	Base Scenario	Communication Scenario	Subsidy Scenario	Base Scenario	Communication Scenario	Subsidy Scenario	Base Scenario	Communication Scenario	Subsidy Scenario	Base Scenario	Communication Scenario	Subsidy Scenario
Annual Sales (Units)	4,085	6,009	26,830	22,885	30,392	60,172	63,715	70,260	81,020	99,056	100,596	103,737
Annual Sales ($ millions)	82	120	537	458	608	1,203	1,274	1,405	1,620	1,981	2,012	2,075
Market Share (%)	3	4	19	13	17	34	28	31	36	34	35	36

Specifically, H-PEMFC-powered forklifts can be rapidly refueled, eliminating the time and cost of replacing batteries; deliver constant voltage as long as hydrogen fuel is available, eliminating downtime; eliminate trips to the battery changing station, improving productivity; lower energy costs by eliminating battery chargers; eliminate battery storage and changing rooms, increasing warehouse space; and have zero emissions with only water and heat as wastes. Most users consider capital costs and lifecycle costs when evaluating an alternative technology. While H-PEMFC-powered forklifts require more capital investment than incumbent alternatives, they provide significant savings in operation and maintenance. H-PEMFC-powered forklifts offer value in high-throughput applications with continuous operations and where cost of downtime is a concern.

Conclusions and Future Directions

H-PEMFCs currently offer value over competing alternatives in several near-term markets. To penetrate near-term markets, it will be critical to ensure an affordable and available source of hydrogen is available near the target markets. A strategic focus should be on the location of hydrogen and on corresponding incentives for hydrogen refueling. Alternatives to H-PEMFCs exist that adequately meet critical market needs, although fuel cells do provide some incremental benefits over alternatives. To support H-PEMFC adoption, incentives that lower initial capital costs likely will be necessary in the short term. A continued focus on durability, reliability, and reducing the cost of H-PEMFCs to develop more durable and reliable products will also be critical for market adoption. Finally, awareness is a critical first step in purchasing. It will be important to communicate to potential users the benefits of H-PEMFCs over existing technologies, particularly the real-world, industry-specific experiences gained through fuel cell demonstrations.

The future focus of this project will be to complete the market opportunity assessments for H-PEMFCs in near-term Federal and portable markets and will include: (1) identification of market requirements, (2) completion of competitive analysis including lifecycle cost and performance of H-PEMFC and alternatives, (3) market penetration analysis, and (4) value proposition and market opportunity analysis.

FY 2007 Publications/Presentations

1. K. Mahadevan, K. Judd, H. Stone, J. Zewatsky, A. Thomas, H. Mahy, and D. Paul. 2007. Identification and characterization of near-term direct hydrogen proton exchange membrane fuel cell markets. Contract No. DE-FC36GO13110. Available at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pemfc_econ_2006_report_final_0407.pdf.

2. K. Mahadevan, H. Stone, K. Judd, and D. Paul. 2007. Market Opportunity Assessment for Direct Hydrogen PEM Fuel Cells in Pre-Automotive Markets. 2007 Annual Program Review Proceedings. The US DOE Hydrogen, Fuel Cells & Infrastructure Technologies 2007 Annual Program Review Meeting, Crystal City, VA, May 15-18, 2007.

3. K. Mahadevan, H. Stone, K. Judd, and D. Paul. 2007. Economic Analysis of Direct Hydrogen PEM Fuel Cells in Three Near-Term Markets. Hydrogen & Fuel Cells 2007: International Conference and Trade Show, Vancouver, BC, April 30, 2007.

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5. K. Mahadevan, H. Stone, K. Judd, and D. Paul. 2007. Identification and Characterization of Three Near-Term Direct Hydrogen PEM Fuel Cell Markets. ECS Transactions, Volume 5, Issue 1, pp. 843-856.

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1. K. Mahadevan, K. Judd, H. Stone, J. Zewatsky, A. Thomas, H. Mahy, and D. Paul. 2007. Identification and characterization of near-term direct hydrogen proton exchange membrane fuel cell markets. Contract No. DE-FC36GO13110. Available at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pemfc_econ_2006_report_final_0407.pdf.

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