VII.G.3 Economic Analysis of Stationary PEMFC Systems

Harry J. Stone (Primary Contact), Darrell Paul, Stephen Millett, Gretchen Hund, Kathya Mahadevan, Kathleen Judd
Battelle Memorial Institute
10300 Alliance Rd., Suite 155
Cincinnati, OH 45242
Phone: (513) 362-2602; Fax: (513) 362-2610; E-mail: stoneh@battelle.org

DOE Technology Development Manager: Kathi Epping
Phone: (202) 586-7425; Fax: (202) 586-9811; E-mail: Kathi.Epping@ee.doe.gov

DOE Project Officer: David Peterson
Phone: (303) 275-4956; Fax: (303) 275-4753; E-mail: David.Peterson@go.doe.gov

Technical Advisor: John Kopasz
Phone: (630) 252-7531; Fax: (630) 972-4405; E-mail: Kopasz@cmt.anl.gov

Contract Number: DE-FC36-03GO13110

Start Date: October 1, 2003
Projected End Date: September 30, 2007

Objectives

Assist DOE in the development of stationary polymer electrolyte membrane fuel cell (PEMFC) systems (1-250 kW range) by providing an independent analysis of technology, market, and economic drivers of PEMFC cost and adoption. Sub-objectives include:

- Determine major cost drivers, analyze engineering and lifecycle costs, and evaluate opportunities for cost reduction from technological breakthroughs.
- Identify and characterize strategic markets.
- Develop technical targets (user requirements) for various market segments and applications.
- Identify critical success factors for commercialization to 2015.
- Evaluate the economic and environmental impacts of PEMFC adoption.
- Educate stakeholders and raise awareness of national programs.

Technical Barriers

This analysis considers the impact of many technical barriers in the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, including:

<u>Distributed Hydrogen from Natural Gas or Renewable Liquid Feedstocks:</u>

- A. Fuel Processor Capital Costs
- B. Fuel Processor Manufacturing
- C. Operations and Maintenance
- D. Feedstock Issues

Fuel Cells (Stationary/Distributed Generation Systems):

- A. Durability
- B. Cost
- C. Electrode Performance
- D. Thermal, Air and Water Management
- F. Fuel Cell Power System Integration
- G. Power Electronics
- H. Hydrogen Purification/Carbon Monoxide Cleanup
- I. Startup Time/Transient Operation

Technical Targets

This analysis models the cost of stationary PEMFC systems and identifies user requirements in various market segments corresponding to DOE technical targets for stationary PEMFC systems. The models also analyze the combined impact of volume and technology breakthroughs (from research and development initiatives) on the cost of PEMFCs. Analysis results (Table 1) show that a 10,000-unit annual production volume alone will not achieve DOE 2010 targets unless substantial technological breakthroughs are realized.

Table 1. DOE 2010 Targets Compared to Battelle Engineering Cost Model (Model assumes cost reduction from learning curve and volume-based cost reduction at an annual production volume of 10,000 units without technology breakthroughs.)

	Units	2010 Target	Projected Cost at 10,000-Unit Annual Production Volume
Cost (Fuel Cell Stack Operating on Hydrogen) Small (3-25 kW)	$/kW	750	1,174
Cost (Integrated Stationary Fuel Cell System Operating on Liquefied Petroleum Gas) Large (50-250 kW)	$/kW	750	1,600

Approach

- Analyze cost drivers, evaluate sensitivity, and model the potential impact of volume and technology breakthroughs on costs of PEMFC systems and the cost of electricity produced by PEMFCs; compare PEMFC costs to competing technologies.
- Evaluate the current cost and performance of PEMFCs and competing technologies.
- Determine market drivers and user requirements through scenario and marketing analyses.
- Use market penetration of PEMFCs in stationary applications and fuel cell performance data to evaluate potential impact on the economy, the environment, and energy security.

Accomplishments

- Completed engineering cost models and sensitivity analysis of cost drivers for a 5-kW direct hydrogen backup power PEMFC (5-kW system) and a 50-kW LPG (propane) reformer/PEMFC (50-kW system) at production volumes of 1,000, 10,000, and 100,000 units; initiated analysis of potential PEMFC cost impacts of developmental technologies.
- Initiated lifecycle cost analysis for the 5-kW and 50-kW systems.
- Completed analysis of U.S. electricity markets to identify stationary application market opportunities for PEMFCs in the 1 to 250-kW range.

- Identified potential early adopter markets and completed development of user requirements (technical targets) for financial, telecommunications, and hotel markets.
- Conducted over 115 stakeholder interviews and surveys; held four industry workshops for exploratory marketing research and one user focus-group to discuss findings and secure additional input to the research.
- Identified principal scenarios and critical drivers for successful stationary PEMFC commercialization using expert focus groups to provide input on descriptors for the Interactive Future Simulations™ Model.

Future Directions

- Complete economic analyses of 50-kW and 200-kW natural gas reformer PEMFC systems.
- Complete technical targets tables for early adopter markets in three additional applications.
- Evaluate the cost and performance of PEMFC against competing alternatives for various applications.
- Consult with stakeholders to validate findings, and to update technology breakthrough opportunities.

Introduction

The focus of this project is to expand our understanding of the economic, technology, and marketplace drivers needed for commercialization of stationary PEMFC systems out to the year 2015. The integrated analysis will benefit DOE and fuel cell stakeholders by identifying the potential impact of research and development decisions for reducing system costs, thereby enabling focus on initiatives likely to advance commercialization of stationary PEMFCs.

Approach

Economic and diffusion (rate of adoption) models are being developed, after literature review and discussion with industry experts, to evaluate (1) the engineering cost of PEMFCs with various levels of production volume and/or technological progress, (2) the lifecycle cost of electricity produced by PEMFCs, and (3) market adoption rates. The sensitivity of the PEMFC cost or lifecycle cost to technology breakthroughs in areas of current research activities is also being evaluated.

Market and technology analysis uses a combination of methods: published data, focus groups, surveys, and interviews. The marketing analysis determines technical targets (user requirements) to enter specific markets. Critical commercialization drivers are determined using proprietary Interactive Future Simulations Software™.

Technology analysis evaluates (1) current cost and performance of PEMFC systems, (2) research and development with potential impact on PEMFC costs, and (3) current cost and performance of existing and emerging competing technologies.

Stakeholders, including developers, component makers, key industry influencers and DOE, provide input to and critical review of assumptions and conclusions.

Results

Complete results from the analysis to date are being assembled in the First Interim Report on the Economics of Stationary Polymer Electrolyte Membrane Fuel Cells.

Economic analyses. The engineering cost model design specifications and assumptions for lifecycle sensitivity analysis of factors impacting the cost of electricity ($/kWh) are shown in Table 2.

Volume impacts on costs of the 50-kW system are shown in Table 3. For the 50-kW systems, the fuel cell is the second leading system cost (24%).

Analysis of the sensitivity of lifecycle cost of electricity to improvements in key factors is shown in Figure 1. The analysis is on a cash basis. Discount rates and tax implications are not considered. The worst case conditions approximate the current state of the technology. Except for the life of the fuel cell, the baseline was set such that the worst case (current

Table 2. Key Assumptions and Specifications of Propane Reformer PEMFC System for Grid-Independent Baseload Applications

Engineering Cost Analysis, Design Assumptions	
Peak power	50 kW
Power density	0.2 W/cm^2
Current density	0.2 A/cm^2
Catalyst	Platinum, 0.6 mg/cm^2
Fuel (hydrogen)	Hydrogen (99.99%) purified reformate
Durability	8,000 hours (0.91 year) continuous operation
Cells/stack	471 cells
Membrane active area/cell	600 cm^2
Amount of membrane needed	282,828 cm^2
Number of bipolar plates	942
Power degradation, % over 1 year (8,760 hours) of operation	2
Inverter efficiency, %	90
Hydrogen purification	Palladium membrane separator
Fuel (to reformer)	Propane (desulfurized)
Lifecycle Cost Sensitivity Analysis, Base Assumptions	
Fuel Cell Cost, $	$136,364
Installation Cost, $	$41,581
Annual O&M Cost	$1,309
Fuel Cost, $/kWh	0.14
Average Annual Usage, hours	8760 (at 50 kW)
Life of Fuel Cell, years	2.5
Propane, $/gal.	1.22
Efficiency, %	44
Tank (1999 gal)	8200

condition) is 10% less favorable than the baseline. Except for the life of the fuel cell, the best case is set at 10% more favorable than baseline. The fuel cell life ranges from an approximate current condition of

Table 3. Production Volume Impacts on 50-kW Propane Reformer/PEMFC Subsystem Costs

	1,000 Units ($)	**10,000 Units ($)**	**100,000 Units ($)**
Fuel Processing	25,971	19,059	14,786
Hydrogen Cleanup	48,838	21,651	11,165
Fuel Cell Subsystem	32,790	20,153	12,011
Power Electronics and Systems Integration	15,510	11,346	9,680
Systems Assembly	12,794	7,804	2,559
Total Cost	135,901	80,013	50,201
Cost/kW	2,718	1,600	1,004

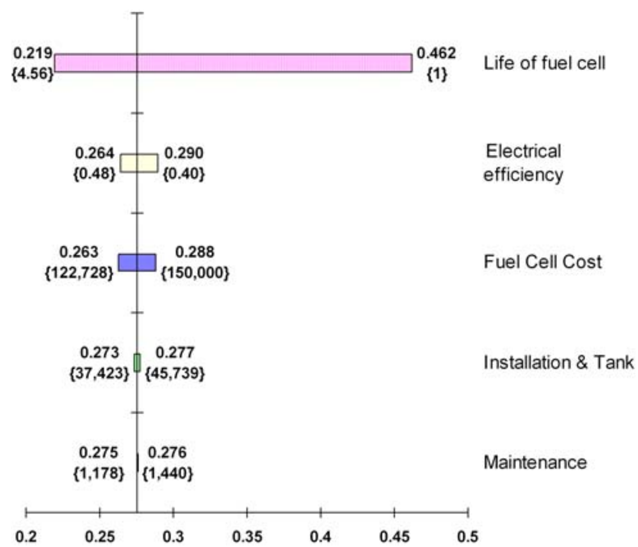

Figure 1. Sensitivity of Lifecycle Cost of Electricity to Changes in Key Factors in the 50-kW Propane Reformer/Palladium Membrane Separator/PEMFC (The x-axis is the average $/kWh of electricity produced calculated from average cash flow over a 40,000 hour (4.56 year) time frame.)

1 year (8,760 hours) for the worst case to a market-required 4.56 years (40,000 hours) for the best case. The baseline case is 2.5 years (21,914 hours).

Penetration of baseload markets requires improvement from the current 1 year to 4.56 year fuel cell life. Achieving this necessary level of durability lowers the cost of electricity by 53%. Ten

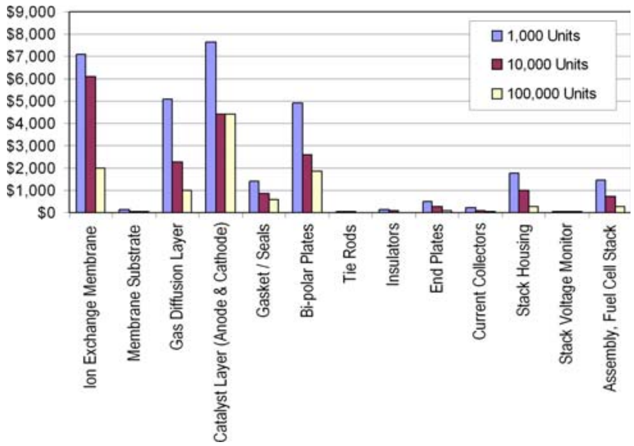

Figure 2. Cost of Fuel Cell Subsystem Components in the 50 kW System

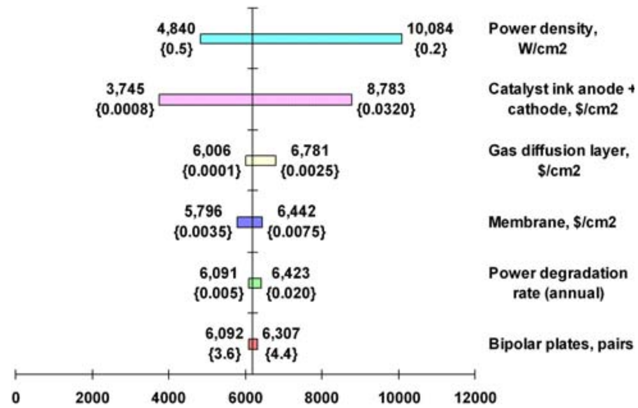

Figure 3. Sensitivity Analysis of Breakthrough Technology Impacts on Stack Costs in the 50-kW Propane Reformer/Palladium Membrane Separator/PEMFC (The x-axis is the cost in $ of a 50-kW stack. The technology breakthrough is assumed to be combined with annual production volumes of 100,000 units.)

percent improvements in the fuel cell cost or efficiency yields only modest improvements in the cost of electricity by comparison.

Engineering cost analysis showed the fuel cell stack represented a significant proportion of the cost of the fuel cell system when produced in high volumes. The impact of technology breakthroughs in stack components on the cost of the stack was analyzed using a sensitivity analysis tool. The "base case" assumes only incremental technological improvements occur. The "best case" in the analysis assumes that significant technology breakthroughs in areas of current research occur.

The relative cost of components in the 50 kW fuel cell subsystem (Figure 2) depends on the annual production volume. Highest cost impacts for the 50-kW baseload system at high volume (Figure 3) are leveraged through technological breakthroughs in catalyst ink cost and power density.

Market Analyses. PEMFCs in the 1 to 250 kW range have the potential to penetrate various early adopter market segments provided they are able to meet the user requirements for various applications in each market segment. Users and potential users of fuel cells for backup and prime power electricity needs in the telecommunications, financial, and hotel industries were surveyed and interviewed to identify user requirements. Tables 4-9 show "the market requirements for adoption of new energy technologies" by application as specified by users and potential users.

Table 4. Telecom Industry: Market Requirements for Adoption of New Energy Technologies in Repeater Stations/Huts

Technical Parameters	"Market Requirements": Backup Applications	"Market Requirements": Prime Power Applications
Size (kW)	20-200	150-250
Capital Cost ($/kW)	600-2000	600-1000
Installation Costs ($)	1000-2000	1000-2000
Operations & Maintenance Costs ($/kWh)	<0.03	<0.03 - 0.05
Lifetime (years)	20	20
Reliability (% time available)	99.9999	99.99
Footprint (L*B*W) (m^3)	Varies by location of site	Varies by location of site
Typical Operation Conditions (ºC)	0-40	0-40
Efficiency (%)	>35	>5
Emissions	At regulatory threshold	At regulatory threshold

Table 5. Telecom Industry: Market Requirements for Adoption of New Energy Technologies in Central Offices

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Prime Power Applications
Size (kW)	50-150	150-250
Capital Cost ($/kW)	1000-2000	1000-2000
Installation Costs ($)	1000-4000	1000-4000
Operations & Maintenance Costs ($/kWh)	<.03	<.03
Lifetime (years)	18	18
Reliability (% time available)	99.99999	99.99999
Footprint (L*B*W) (m^3)	Varies by location of site	Varies by location of site
Typical Operation Conditions (ºC)	15-25	15-25
Efficiency (%)	>35	>35
Emissions	At regulatory threshold	At regulatory threshold

Conclusions

Most early adopter applications of PEMFCs will be for backup power, where proven reliability is the emphasis.

In addition to reliability, for PEMFCs to penetrate high-volume baseload applications, technology improvements must achieve:

- Competitive cost of generated electricity
- Adequate durability
- Performance track record that reduces perceived risks and boosts consumer confidence

Achieving 40,000-hour durability is a necessary condition for most baseload markets and a key driver for lower lifecycle costs of fuel cell systems. Capital cost is the second most important parameter for lowering the lifecycle cost of the systems analyzed to date. Power density and catalyst cost are the major cost drivers for stack costs in fuel cell systems. Fuel cell efficiency is important for reducing the lifecycle costs of the 50-kW baseload system.

Table 6. Telecom industry: Market Requirements for Adoption of New Energy Technologies in Controlled Environmental Vaults

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Prime Power Applications
Size (kW)	20-50	150-250
Capital Cost ($/kW)	600-1000	1000-2000
Installation Costs ($)	2000-3000	1000-4000
Operations & Maintenance Costs ($/kWh)	<.03	<.03-0.05
Lifetime (years)	20	20
Reliability (% time available)	99.99999	99.99
Footprint (L*B*W) (m^3)	Varies by location of site	Varies by location of site
Typical Operation Conditions (ºC)	0-40	0-40
Efficiency (%)	>55	>55
Emissions	At regulatory threshold	At regulatory threshold

Table 7. Telecom Industry: Market Requirements for Adoption of New Energy Technologies in Switching Stations

Technical Parameters	Market Requirements: Backup Applications
Size (kW)	25-50
Capital Cost ($/kW)	600-2000
Installation Costs ($)	1000-4000
Operations & Maintenance Costs ($/kWh)	<.03
Lifetime (years)	15
Reliability (% time available)	99.99
Footprint (L*B*W) (m^3)	Various
Typical Operation Conditions (ºC)	15-25
Efficiency (%)	>35
Emissions	At regulatory threshold

Table 8. Financial Industry: Market Requirements for Adoption of New Energy Technologies in Backup and Grid-Parallel Applications

Technical Parameters	Market Requirements: Backup Applications	Market Requirements: Grid-Parallel Power Applications*
Size (kW)	>50	>250
Capital Cost ($/kW)	<300-3000	300-2000
Installation Costs ($)	3000-4000	3000-4000
Operations & Maintenance Costs ($/kWh)	.07-.12	.05-.12
Lifetime (years)	10-20+	15
Reliability (% time available)	99.999 - 99.99999#	99.99~
Footprint (L*B*W) (m^3)	Varies, can be no larger than competing alternative	Varies, can be no larger than competing alternative
Typical Operation Conditions (ºC)	-15 to 40	-15 to 40
Efficiency (%)	>55	>55
Emissions	Meets regulatory threshold	Well below the regulatory threshold

* Grid parallel applications for peak shaving and baseload application at smaller facilities
+ Lifetime requirements are dependent on use
# High reliability is of strategic importance for adoption of technology in this market sector
~ Reliability needs to be comparable to the grid at the very minimum

Table 9. Hotels: Market Requirements for Adoption of New Energy Technologies in Backup Applications

Technical Parameters	Market Requirements: Backup Power Applications
Size (kW)	150-250
Capital Cost ($/kW)	300-600
Installation Costs ($)	2000-3000
Operations & Maintenance Costs ($/kWh)	<.03-.07
Lifetime (years)	10-15
Reliability (% time available)	99.999% (3 sec-5 min/yr) – 99.99999% (3 sec/yr)
Footprint (L*B*W) (m3)	Varies, can be no larger than competing alternative
Typical Operation Conditions (ºC)	-15 to 40
Efficiency (%)	>65%
Emissions	Well below regulatory threshold

FY 2005 Publications/Presentations

1. Stone, Harry J. Economic analysis of stationary PEMFC systems. DOE Hydrogen Program, 2005 Program Review, Washington, D.C., 2005.
2. Millett, Steve, and Kathya Mahadevan. Commercialization scenarios of polymer electrolyte membrane applications for stationary power generation in the United States by the year 2015. October 2005. Journal of Power Sources.
3. Millett, Steve, and Kathya Mahadevan. Scenario analysis of the commercialization of polymer electrolyte membrane (PEM) fuel cells for stationary applications in the U.S. by the year 2015. 2004 Fuel Cell Seminar, San Antonio, TX, 2004.