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Market Opportunity Assessment for Direct Hydrogen PEM Fuel Cells in Pre-automotive Markets

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Project I.D. FC 26

Battelle

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DOE Annual Program Review

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Overview

Timeline

- Project start date: November 2003
- Project end date: September 2007
- Percent complete: 64% (Mar 2007)

Barriers

- All distributed generation systems barriers
- All fuel-flexible fuel processor barriers
- All fuel cell component barriers

Budget

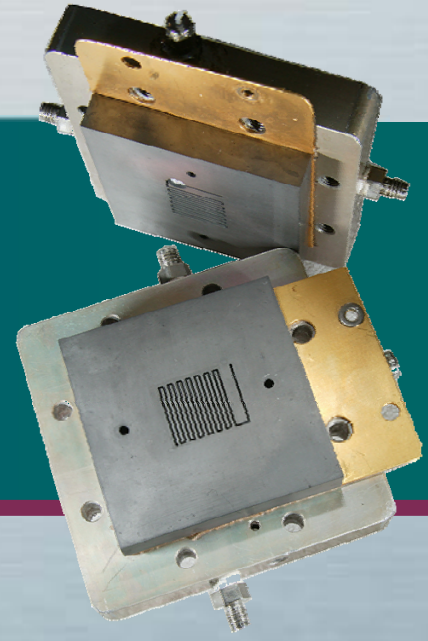
- Total Project Funding: DOE Share $3,163,800 and No Contractor Cost-Share
- Funding received in FY04: $515,851
- Funding received in FY05: $700,000
- Funding received in FY06: $575,000
- Funding expected in FY07: $750,000

Assistance

- H2A, NREL
- More than 30 companies and agencies have participated in facilitated discussions
- More than 220 current or candidate users have participated in surveys, interviews, and focus groups

Project Objectives

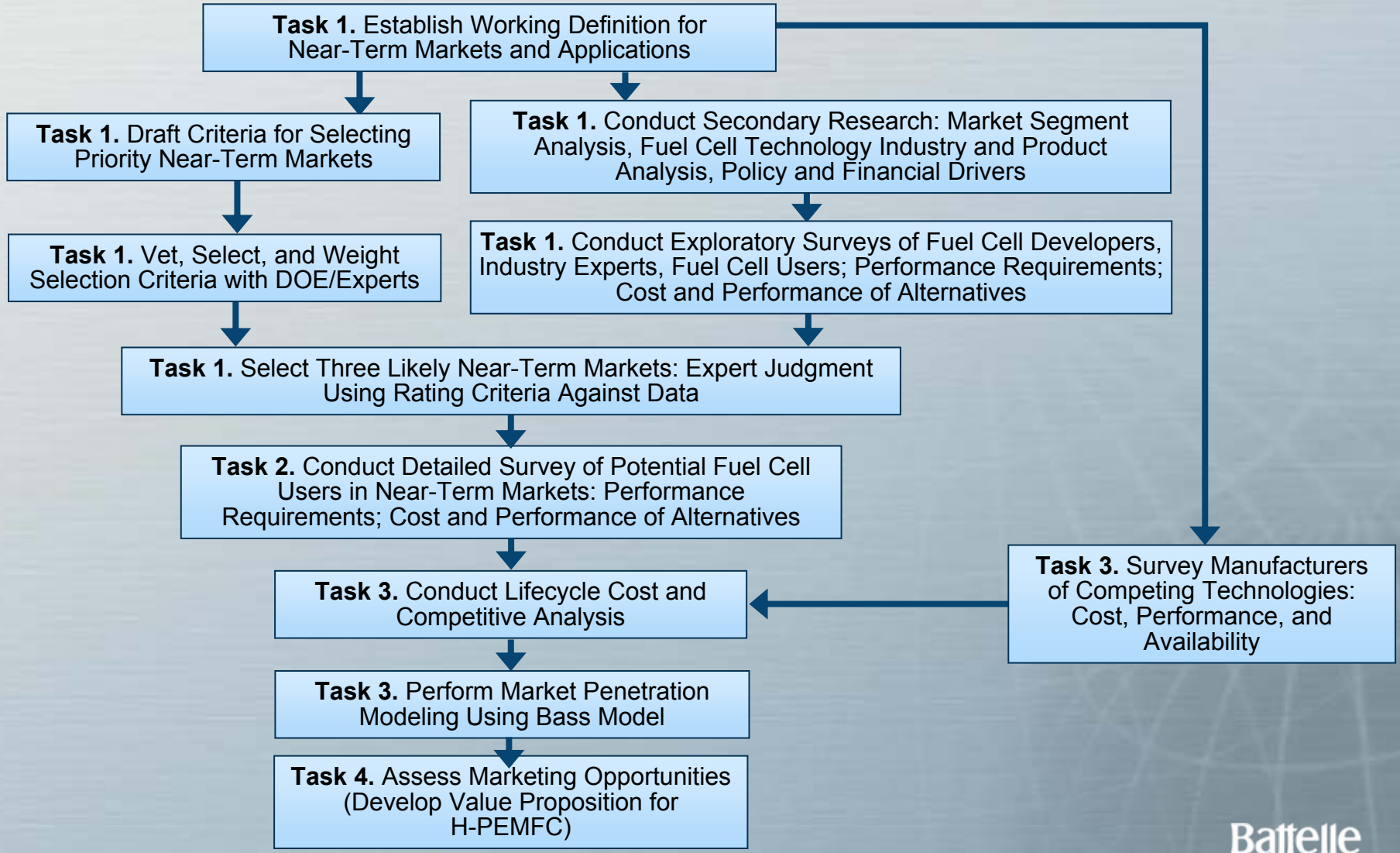
To assist DOE in developing fuel cell systems by analyzing the technical, economic, and market drivers of direct hydrogen PEM fuel cell (H-PEMFC) adoption. 2006 support included the following:



- Market segmentation of 1–250 kW H-PEMFC into near-term (2008) and mid-term (2012) market opportunities
- Lifecycle cost analysis of H-PEMFC and competing alternatives in near-term markets
- Market opportunity assessment of H-PEMFC in near-term markets

Note: Scope of the project is limited to direct hydrogen PEM fuel cells in the 1 kW to 250 kW size range. Scope does not include vehicle applications and DoD applications.

Approach


Task 1. Establish Working Definition for Near-Term Markets and Applications
Task 1. Draft Criteria for Selecting Priority Near-Term Markets
Task 1. Conduct Secondary Research: Market Segment Analysis, Fuel Cell Technology Industry and Product Analysis, Policy and Financial Drivers
Task 1. Vet, Select, and Weight Selection Criteria with DOE/Experts
Task 1. Conduct Exploratory Surveys of Fuel Cell Developers, Industry Experts, Fuel Cell Users; Performance Requirements; Cost and Performance of Alternatives
Task 1. Select Three Likely Near-Term Markets: Expert Judgment Using Rating Criteria Against Data
Task 2. Conduct Detailed Survey of Potential Fuel Cell Users in Near-Term Markets: Performance Requirements; Cost and Performance of Alternatives
Task 3. Conduct Lifecycle Cost and Competitive Analysis
Task 3. Survey Manufacturers of Competing Technologies: Cost, Performance, and Availability
Task 3. Perform Market Penetration Modeling Using Bass Model
Task 4. Assess Marketing Opportunities (Develop Value Proposition for H-PEMFC)

Approach: Definition of Pre-Automotive Applications and Markets

Pre-automotive applications and markets for H-PEMFC are defined as those opportunities that **support the technology and industry development necessary to ensure automotive H-PEMFC commercialization by 2015.**

These markets for H-PEMFC can be those that use components and underlying technologies **similar to automotive H-PEMFC.** These markets are composed of applications that have some operational characteristics similar to automotive H-PEMFC.

These markets for H-PEMFC can also be those **with early adopters for backup power and grid independent/parallel power applications.** Increased demand from these markets could **decrease component cost, maintain investor interest, and help develop a supplier base of H-PEMFC technology.**

Approach: Selection of Near-Term Markets

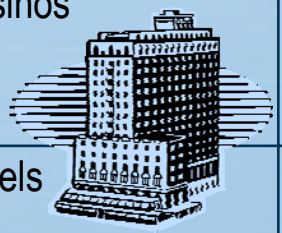
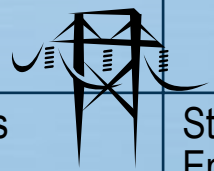
Criteria for Selecting Priority Near-Term Markets

- H-PEMFC offer unique value to market segment not met by competing technologies
- H-PEMFC product characteristics and their potential benefits must fit user requirements (high priority needs)
- Sufficient market size and growth potential of the market segment ensures current and continued fuel cell adoption
- Cost of reaching the market, including product development and marketing, is reasonable
- H-PEMFC products are available for immediate application or can be developed over the short-term

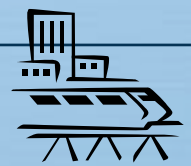
Approach: Segments Analyzed

Backup Power			Specialty Vehicles
Non-Government Markets		Government Markets	
Telecom	Water and Wastewater Treatment	Federal Agencies: NASA NRC DOT DoD DHS NOAA DOE EPA GSA NPS	Forklifts
Finance	Chemical Manufacturing		Automatic Guide Vehicles
Data Centers	Oil and Gas—Refineries		Mining Vehicles
Pharmaceuticals	Chemical Manufacturing		Tow Tractors
Healthcare	Metals Processing and Refining		Golf Carts
Grocery Stores	Computer and Electronic Products		Turf Maintenance Vehicles
Casinos	Transportation Manufacturing		Commercial Sweepers
Hotels	Electric Utility Substations	State and Local Emergency Response Communications	Ice Resurfacers
Amusement Parks	Mining		Wheelchairs
Ski Parks	Airports		Motorized Bicycles/Scooters
Railways	Food Manufacturing		Unmanned Undersea Vehicles and Unmanned Aerial Vehicles







Approach: Sample Respondents

Examples of Backup Power Users Surveyed	Examples of Specialty Vehicle Users Surveyed	Examples of Specialty Vehicle Integrators Surveyed
Metropolitan Washington Airports Authority	American Airlines	Raymond Corp.
Texas Instruments	DALGlobal Services	NACCO Materials Handling Group, Inc.
DTE Energy	Marzetti Company	FMC Technologies, Inc.
US EPA	Dollar General Co.	LEKTRO Inc.
Costco Wholesale	Horizon Air	Transbotics, Inc
Giant Eagle	BHP Billiton - San Juan Coal Co.	Nilfisk-Advance
Children's Hospital	Meijer	Columbia ParCar Corp.
Mittal Steel (Slab Product Plant)	Limited Brands Inc.	The Toro Company (Commercial Division)
Alaska Railroad Corporation	US Airways	Hoveround
Miami-Dade Police Department	Sam's Club	Pride Mobility Products Corp.
Ohio Emergency Management Agency	Home Depot	AeroVironment Inc.

Total Number of User Respondents—136 surveys and 87 Interviews
Total Number of Backup Power Users—83
Total Number of Specialty Vehicle Users—29
Total Number of Special Vehicle Manufacturers/Integrators—24

Technical Accomplishments: Highlights

- Worked with the US Fuel Cell Council to ensure inputs were received from industry through the course of the study *(17 completed surveys were obtained; 3 meetings were conducted)*
- Identified of near-term and mid-term markets where PEM fuel cells offer value over competing alternatives
- Performed comprehensive marketing research through primary and secondary methods to understand user requirements in various markets
- Modified the H2A model to allow cost comparisons between fuel cells and alternative electricity generation
- Applied Bass innovation diffusion models to determine market penetration scenarios
- Developed value propositions for PEM fuel cells in three near-term markets (emergency response market segment, forklift market segment, and airport tug market segment)
- Presented results at various meetings and disseminated information to candidate users

Technical Accomplishments: Near-Term and Mid-Term Markets

Near-term Markets (2008)

H-PEMFC offer unique value proposition (not completely dependent on capital cost)

- Forklifts in Warehousing/ Distribution Centers
- Airport Ground Support Equipment (GSE)
- Telecommunications
- State and Local Agencies of Emergency Response (Radio Towers)
- Government (FAA, NOAA)

Mid-term Markets (beyond 2012)

H-PEMFC can provide value if barriers including capital cost are addressed

- Railways
- Data Centers
- Electric Utilities
- Government
- Water and Wastewater Utilities
- Healthcare
- Water and Wastewater Utilities
- Manufacturing
- Airports
- Grocery Stores
- Hotels
- Automatic Guide Vehicles
- Industrial Tractors
- Commercial Sweepers
- Turf Maintenance Vehicles
- Mining Vehicles
- Golf Carts

Forklifts: Market Analysis Summary

Market Description	Warehousing/distribution centers that use Class 1, 2, and 3 battery-powered forklifts for materials handling. Applications include reach trucks, stand-up and sit-down riders, pallet jacks, and stockpickers.
Market Size	84,771 Class 1, 2, 3 units shipped in 2003 ($3.2 B); battery-powered forklifts represent 58% of total market
Growth Rate	Projected 5% per year to 2013
Current Mode of Operation	Mostly battery-powered; some propane ICE-powered for heavy materials handling
Impact of Downtime	Loss of productivity through decreased movement of materials and decreased labor productivity; increased operation and maintenance costs
Factors Considered When Evaluating Power Systems	Reliability, ease of use, and lifetime of unit are very important to most
Factors That Most Influence Decision to Purchase Alternative Power Source	Reliability and capital cost
Satisfaction With Current Technology	Users generally satisfied with current systems, particularly with fuel availability, ease of use, and lifetime of unit. However, battery charging and maintenance negatively impact productivity, resulting in some dissatisfaction with batteries.
Have Alternatives Been Considered?	Yes, better battery systems, hydrogen fuel cells, and fast charging systems
Approach to Capital Purchase Decision-Making	Return on investment
Importance of Government Incentives in Purchasing	~50% consider incentives

Forklifts: Lifecycle Cost Analysis Assumptions

Scenario 1 Pallet Trucks	Scenario 2 Sit-down Rider Truck
Operate 7 hours per shift 3 shifts per day 7 days a week	Operate 7 hours per shift 3 shifts per day 5 days a week
H-PEMFC use 3 kW stacks with NiMH batteries	H-PEMFC use 8 kW stacks with ultra capacitors
Batteries changed out every shift, taking about 30 minutes; Operator cost $15/hr	Batteries changed out every shift, taking about 15 minutes; Operator cost $15/hr
Hydrogen costs assumed at $5 per kg	
H-PEMFC replaced every 5 years at $3000/kW	
For battery-powered trucks, 2-3 replacement batteries per truck	
H-PEMFC refueled once every shift, refueling time 1 minute	H-PEMFC refueled once every shift, refueling time 3 minutes

Forklifts: Lifecycle Cost Analysis Assumptions (continued)

	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 ($)	8,000	13,500	25,000	35,000
Lifetime (yr)	15	15	15	15
Hours of Operation (hr/yr)	7,644	7644	5,460	5,460
Cost of Accessories ($)	2,406	–	2,406	–
Battery Charger	*1,800*	–	*1,800*	–
Cranes/Hoists	*210*	–	*210*	–
Cost for Battery Room	*396*	–	*396*	–
Routine Maintenance ($/yr)	3,600	720	3,600	720
Electricity/H2 Fuel Cost ($/yr)	1,307	4,380	1,307	5,612
Refueling Time (min/day)	30	3	15	3
Refueling/Recharging Cost ($/yr)	8,213	274	2,925	390
Replacement Costs ($)	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—Ultracapac. every 10 years

Forklifts: Lifecycle Cost Analysis Summary

- **H-PEMFC-powered pallet trucks require significantly less investment than battery-powered pallet trucks under conditions of near-continuous use and with H2 at $5 per kg.**

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

- **Larger H-PEMFC-powered sit-down trucks require more investment than battery-powered sit-down forklift trucks. However, with incentives in operations that use three batteries or more per truck, H-PEMFC could offer value.**

	Battery-Powered Sit-down Truck (3 Batteries Per Truck)	Battery-Powered Sit-down Truck (2 Batteries Per Truck)	H-PEMFC-Powered Sit-down Truck w/out Tax Incentive	H-PEMFC-Powered Sit-down Truck w/Tax Incentive
NPV of Capital Costs ($)	51,977	43,271	63,988	56,440
NPV of O&M Costs (Including the Cost of Fuel) ($)	76,135	76,135	65,344	65,344
NPV of Total Costs of System ($)	128,112	119,405	129,332	121,784

Forklifts: Lifecycle Cost Analysis Summary

- In scenario 1, even if H-PEMFC stack is replaced every 2 years, H-PEMFC-powered forklifts are more attractive than battery-powered alternatives

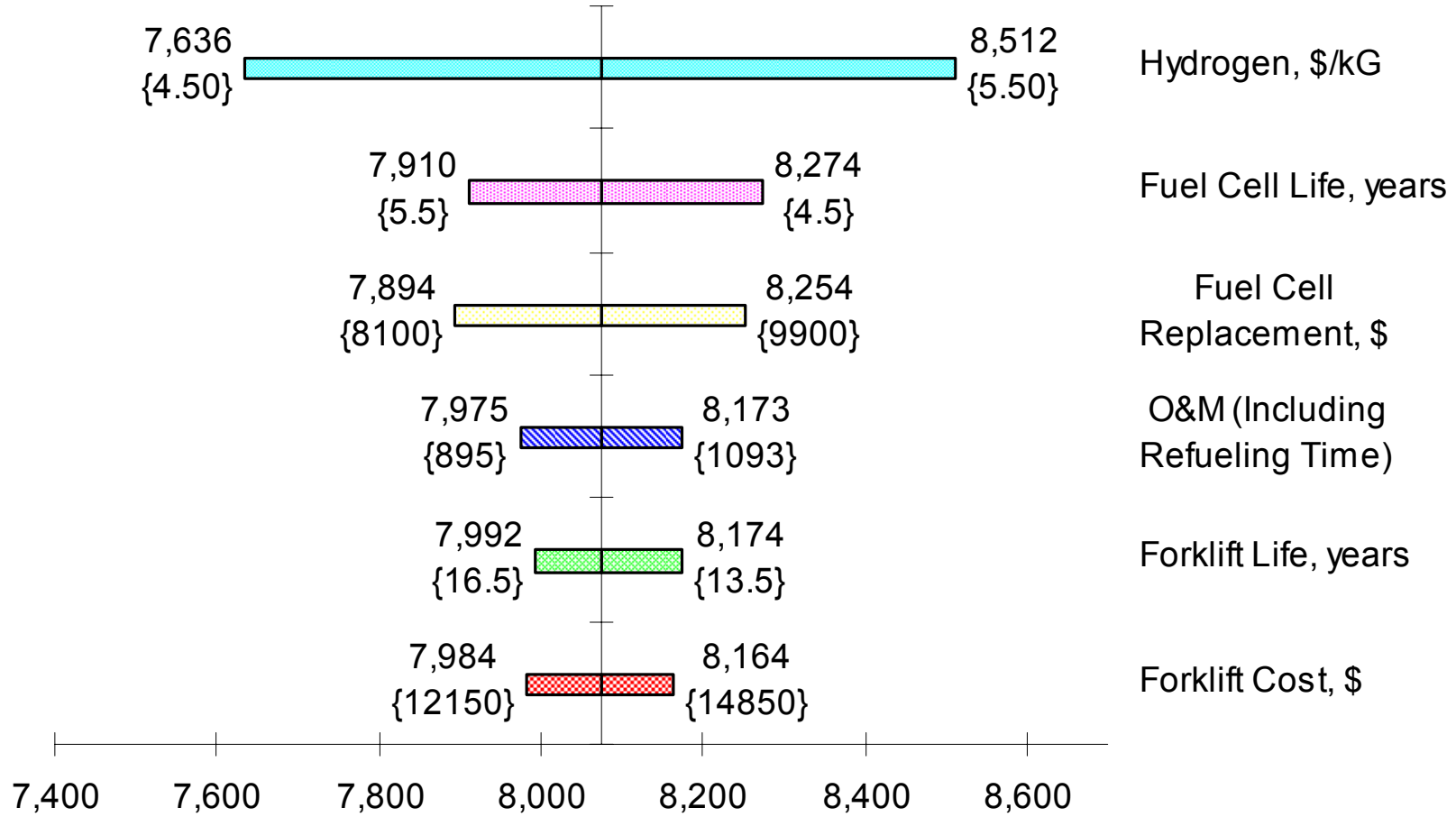
	Battery-Powered Pallet Truck (3 Batteries Per Truck)	Battery-Powered Pallet Truck (2 Batteries Per Truck)	H-PEMFC-Powered Pallet Truck w/out Tax Incentive	H-PEMFC-Powered Pallet Truck w/ Tax Incentive
NPV of Capital Costs ($)	21,572	17,654	48,626	45,796
NPV of O&M Costs (Including the Cost of Fuel) ($)	127,539	127,539	52,241	52,241
NPV of Total Costs of System ($)	149,111	145,193	100,867	98,036

- If battery change-outs take 30 minutes and if H-PEMFC is replaced every 3 years in scenario 2, a H-PEMFC-powered forklift requires more investment than battery-powered alternatives. With incentives H-PEMFC is more attractive in operations that use three or more batteries per truck.

	Battery-Powered Pallet Truck (3 Batteries Per Truck)	Battery-Powered Pallet Truck (2 Batteries Per Truck)	H-PEMFC-Powered Pallet Truck w/out Tax Incentive	H-PEMFC-Powered Pallet Truck w/ Tax Incentive
NPV of Capital Costs ($)	51,977	43,271	94,163	86,615
NPV of O&M Costs (Including the Cost of Fuel) ($)	105,541	104,569	65,344	65,344
NPV of Total Costs of System ($)	157,517	147,839	159,507	151,959

Forklifts: Sensitivity Analysis

Improvements to hydrogen cost, followed by fuel cell life, will have the greatest impact on the annual cost of owning and operating a H-PEMFC–powered pallet truck



Forklifts: Market Penetration Analysis Assumptions

Assumption	Base Scenario	Communication Scenario	Subsidy Scenario
Market Growth Rate (%)	5	5	5
Government Actions	None	Communications	Subsidize purchase at $3000/unit
Values of *p* and *q*	*p* = 0.008 *q* = 0.423	*p* = 0.012 *q* = 0.423	*p* = 0.070 *q* = 0.423
Initial Number of Class 1,2, 3 Battery-Powered Forklifts Purchased Annually	108,606	108,606	108,606
Initial Number of Class 1,2, 3 PEM Fuel Cell-Powered Forklifts Purchased Annually	*m* = 43,442	*m* = 43,442	*m* = 43,442
Average Initial Price of H-PEMFC-Powered Forklifts ($)	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 (%)	40	40	40

m = total potential adopters; *p* = a coefficient of innovation; *q* = a coefficient of imitation

Forklifts: Market Penetration Analysis

In the base, communication, and subsidy cases, annual sales reach 10,000 units in 8 years, 7 years, and 3 years, respectively, after commercial introduction

	3 Years After Commercial Introduction			10 Years After Commercial Introduction		
	Base Case	Communication Case	Subsidy Case	Base Case	Communication Case	Subsidy Case
Annual Sales (units)	1,587	2,367	12,663	22,885	30,392	60,172
Annual Sales ($ millions)	32	47	253	458	608	1,203
Market Share (%)	1	2	10	13	17	34

Forklifts: Value Proposition for H-PEMFC

- H-PEMFC forklifts offer most value in high productivity environments (3 shift operations)
- The value of H-PEMFC forklifts compared with alternatives varies significantly by application and is impacted by declining hours of operation (i.e. number of shifts), declining labor rates, the time required for battery change-outs, and the cost of hydrogen
- H-PEMFC forklifts can provide value over battery-powered forklifts in high-productivity environments
  - Refuel rapidly, eliminating time and cost of replacing batteries
  - Eliminate battery storage/changing rooms and associated cost
  - Eliminate trips to battery changing station, thus increasing productivity
  - Deliver constant voltage as long as fuel is available, increasing productivity
  - Reduce vehicle repairs due to fewer moving parts

Conclusion: Requirements for Successful Market Penetration

- Technical focus on durability, reliability, and reducing cost of H-PEMFC
- Strategic focus on the location of hydrogen and corresponding incentives for hydrogen refueling
- Increased lifetime of H-PEMFC products
- Proven reliability of H-PEMFC products
- Incentives that lower capital costs
- Increased market awareness of benefits of H-PEMFC

Future Work

FY 2007 Scope of Work

- Complete Market Opportunity Assessments for PEM Fuel Cells in Federal Markets (Support of EPAct 2005, Section 783)

- Complete Market Opportunity Assessments for PEM Fuel Cells in Portable markets

Project Summary

Relevance

Identify technical, economic, and market place drivers for successful development of PEM fuel cell systems.

Approach

Perform market opportunity analysis to identify early and critical pre-automotive markets where H-PEMFC are likely to successfully compete to support development and deployment of robust PEM fuel cells products.

Integrate marketing research methods (surveys, focus groups, scenario analysis, innovation diffusion modeling), technology evaluation (surveys, expert focus groups) and economic analysis (engineering cost models, lifecycle cost models) to understand market opportunities and adoption rates

Technical Accomplishments and Progress

Identified near-term markets for PEM fuel cells; Completed market analysis, lifecycle cost analysis, and market penetration modeling for selected backup power and specialty vehicle applications.