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Identification and Characterization of Near-Term Direct Hydrogen PEM Fuel Cell Markets

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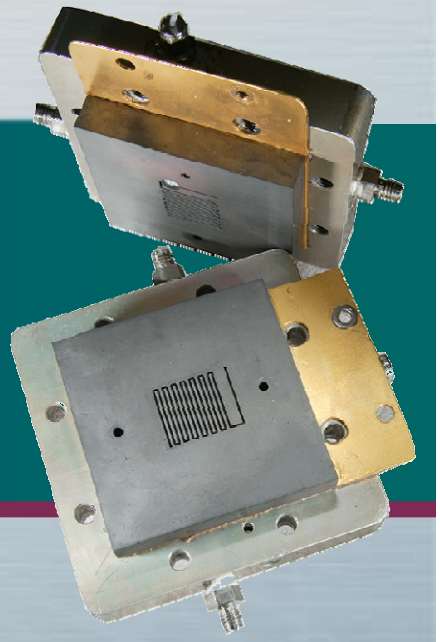
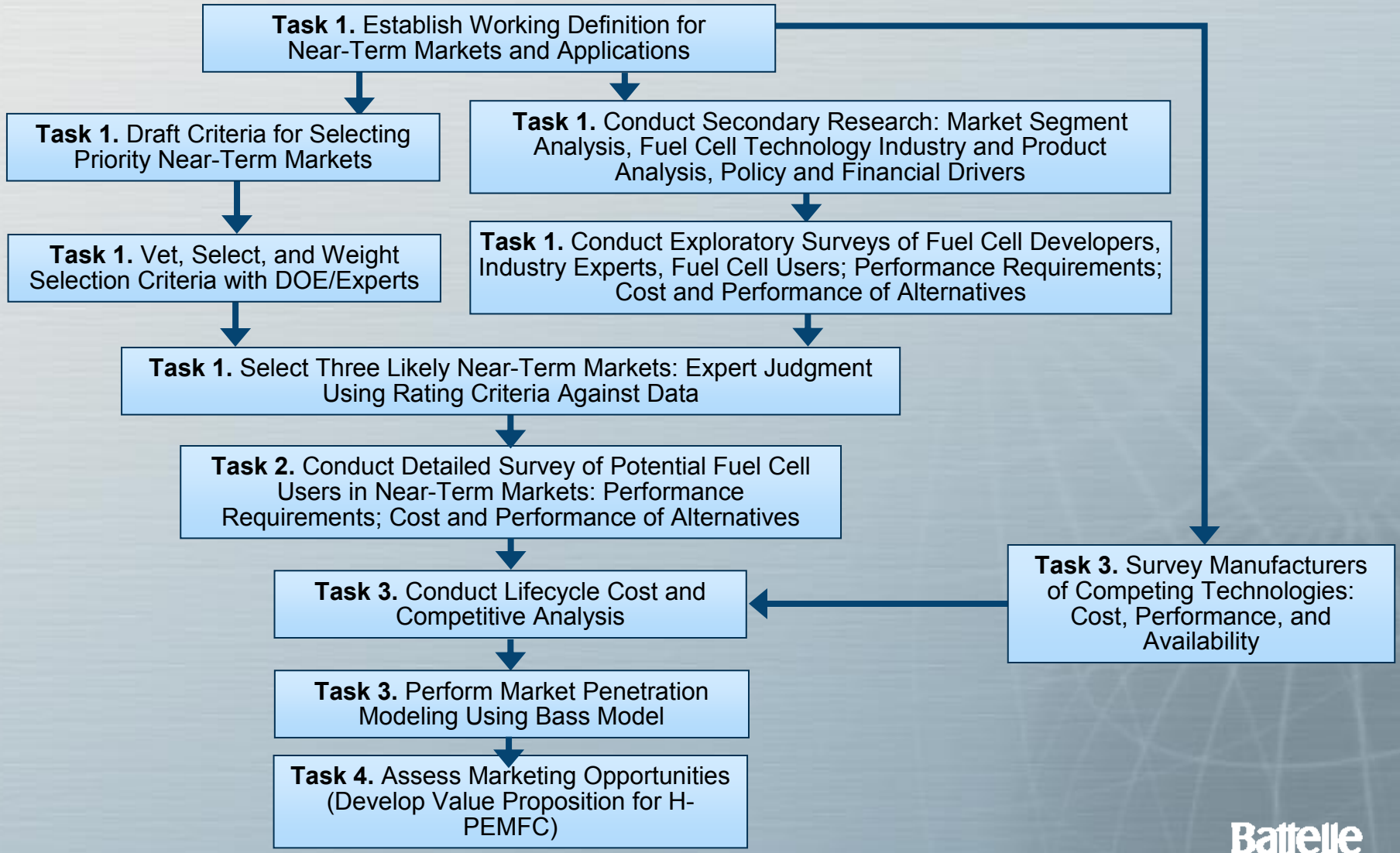
Project Objectives

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

Methodology



Methodology: Selection of Near-Term Markets

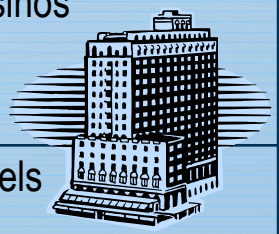
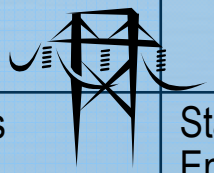
Criteria for Selecting Priority Near-Term Markets

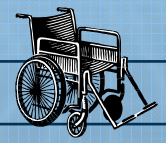
- H-PEMFC offer unique value to market segment not met by competing technologies
- H-PEMFC product characteristics and their potential benefits must fit user requirements (high priority needs)
- Sufficient market size and growth potential of the market segment ensures current and continued fuel cell 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

Market Analysis: 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



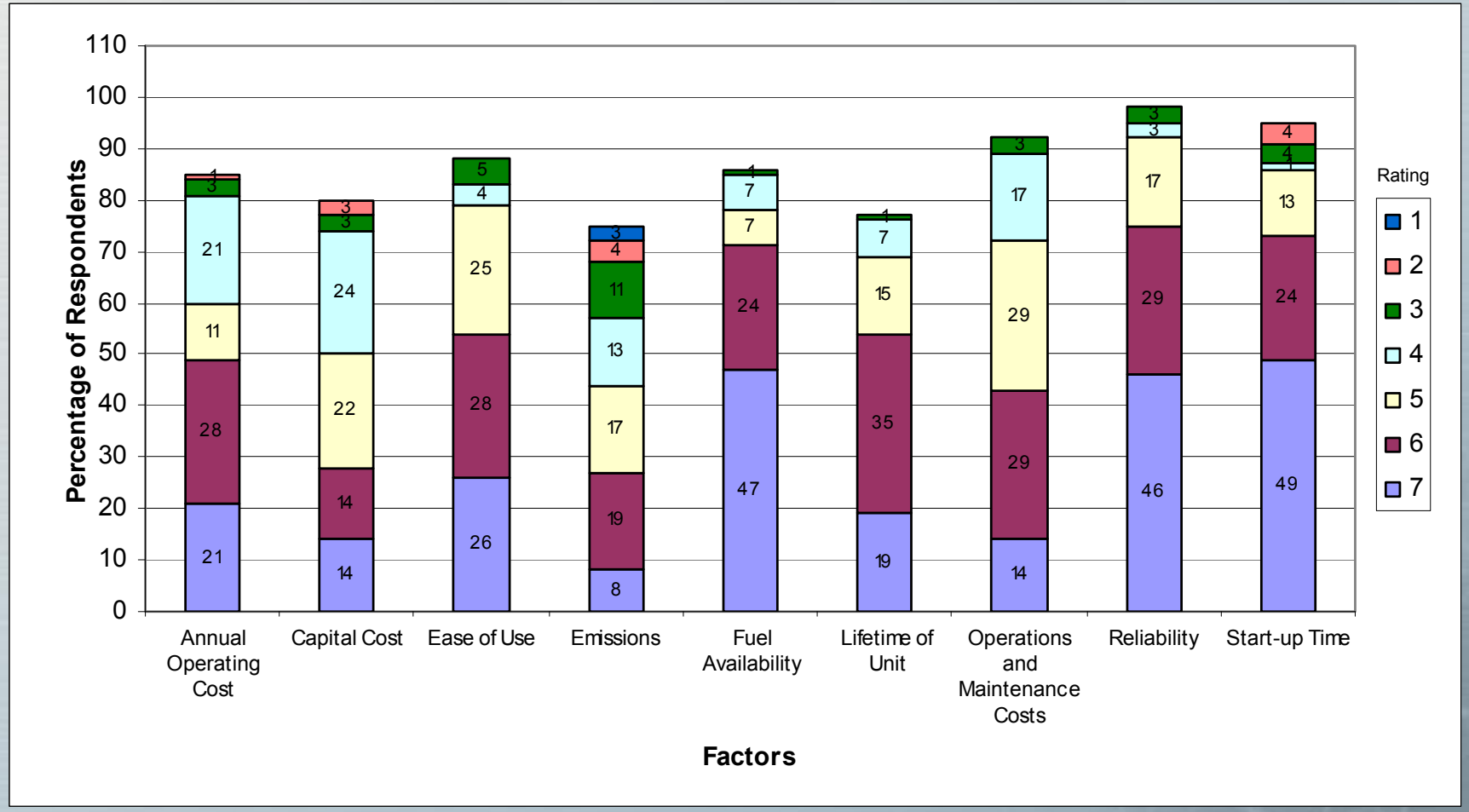



Market Analysis: Sample Respondents

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.

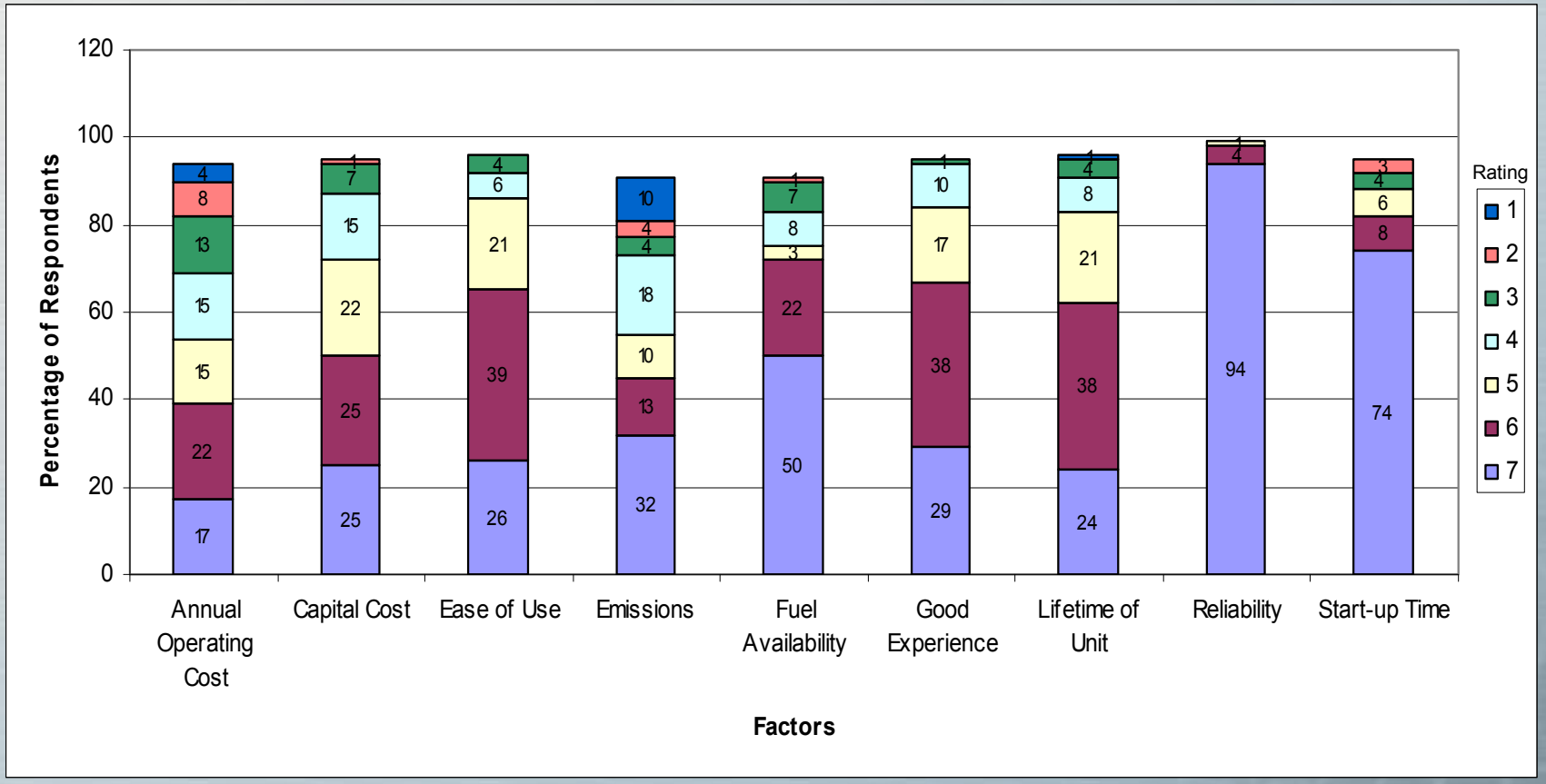
Total Number of Respondents—136 surveys and 87 Interviews
Total Number of Backup Power Users—83
Total Number of Specialty Vehicle Users—29
Total Number of Special Vehicle Manufacturers/Integrators—24

Backup Power Market Analysis: User Satisfaction With Current Backup Power Systems



*Rating of 6 and 7 was classified as very good

Backup Power Market Analysis: Importance of Various Factors in Selecting a Backup Power System



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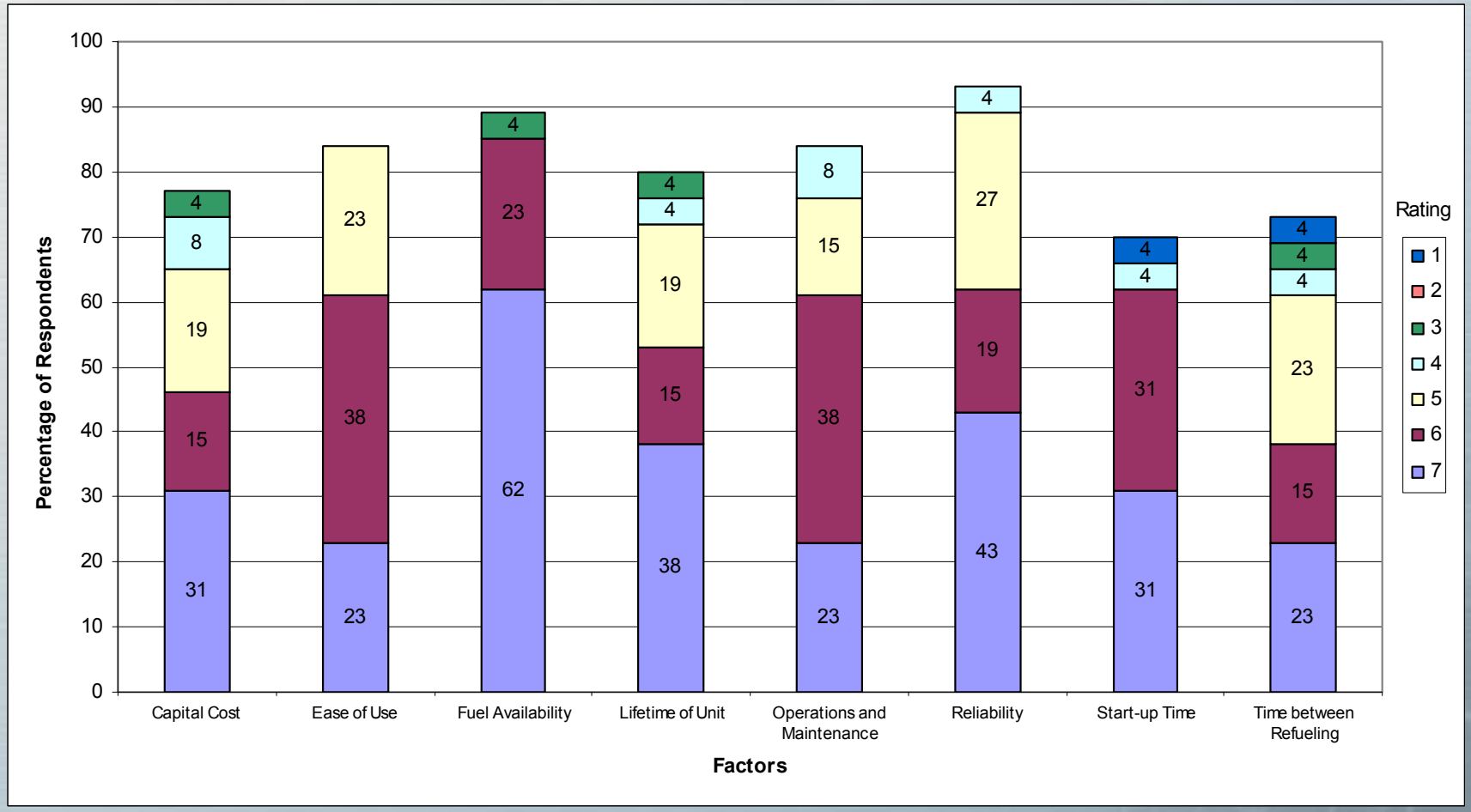
Specialty Vehicle Market Analysis: User Satisfaction With Current Technology



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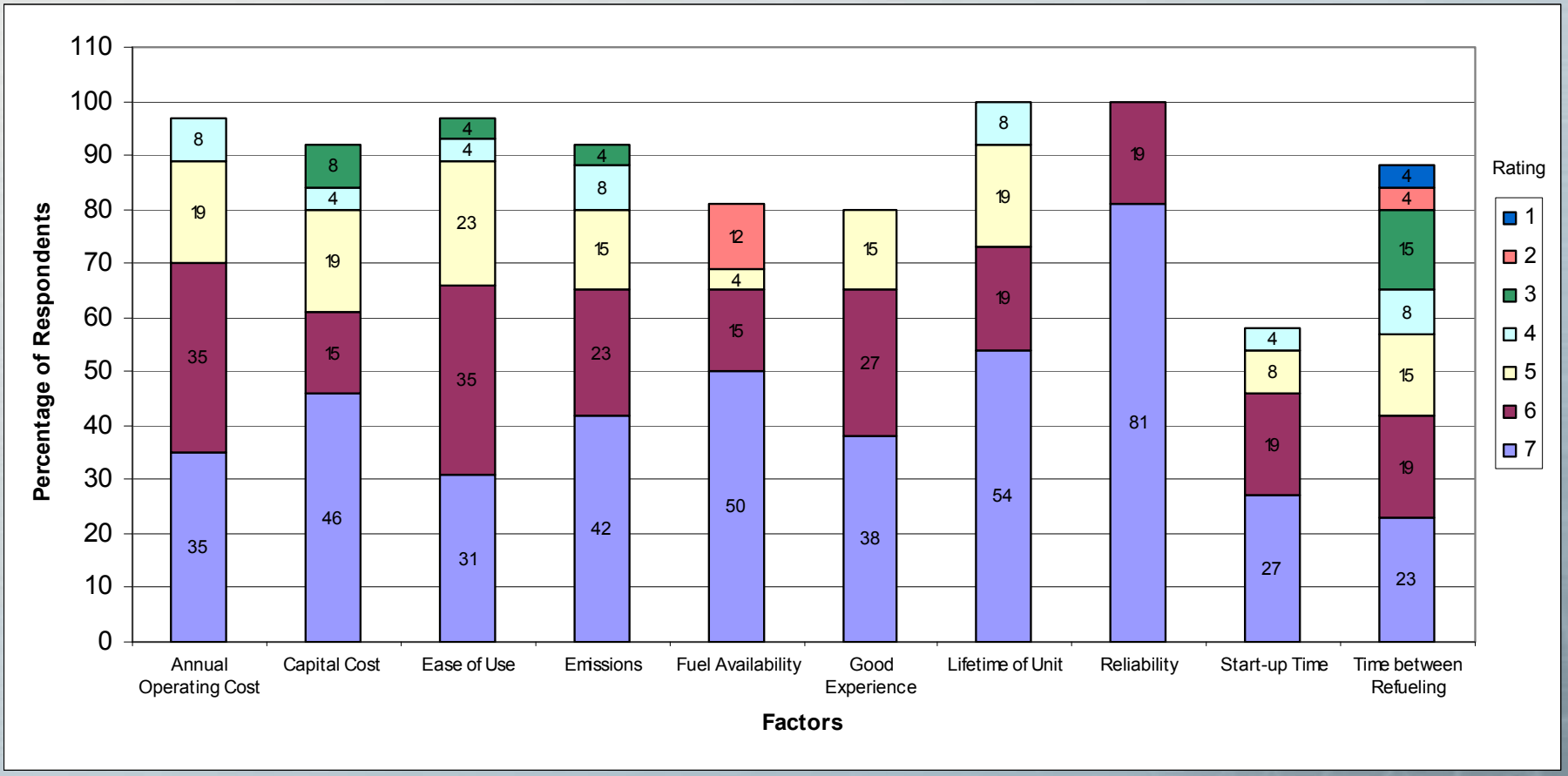
Specialty Vehicle Market Analysis: Importance of Various Factors in Selecting a Specialty Vehicle



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Market Analysis: 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

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

Emergency Response: Market Analysis Summary

Market Description	State and local government agencies using backup to support radio towers for emergency communications
Market Size	~15,000 radio tower sites
Growth Rate	Rate not available. Expected to expand as communications increase and number of states mandating backup for these systems increases
Current Mode of Operation	Battery-only, battery-generator, and generator-only (diesel and LPG)
Factors Considered When Evaluating Power Systems	Reliability and fuel availability are very important to most, followed by lifetime of the unit, startup time, ease of use, good past experience
Factors That Most Influence Decision to Purchase Alternative Power Source	Reliability and capital cost
Satisfaction With Current Technology	Users most satisfied with lifetime and reliability of current systems
Have Alternatives Been Considered?	Most have not considered alternatives to current backup systems. Two currently have fuel cell systems installed; one has a solar panel
Approach to Capital Purchase Decision-Making	Emphasize capital cost, rather than formal return on investment
Importance of Government Incentives in Purchasing	Important decision-making factor; necessary to bring capital cost down

Emergency Response Radio Towers: Lifecycle Cost Analysis Assumptions

Backup Runtime	kW	Fuel Replacement	Battery Replacement	H-PEMFC Comparison	Lifecycle Assumptions
Scenario 1					15-year lifetime No residual value 8% discount rate 1.9% inflation rate With and without $1000 kW incentive
52 hours	5	Annually	3- and 5-year	To battery-generator system (Outdoor Installation)	
Scenario 2					
176 hours	5	Every 5 years	3- and 5-year	To battery-generator system (Outdoor Installation)	
Scenario 3a					
72 hours	3	Annually	5-year	To battery-generator system (Indoor Installation)	
Scenario 3b					
8 hours	2	Annually	5-year	To battery system (Indoor Installation)	
Scenario 3c					
72 hours	3	Annually	5-year	To costs of installing new generator system and replacing existing generator system (Indoor Installation)	

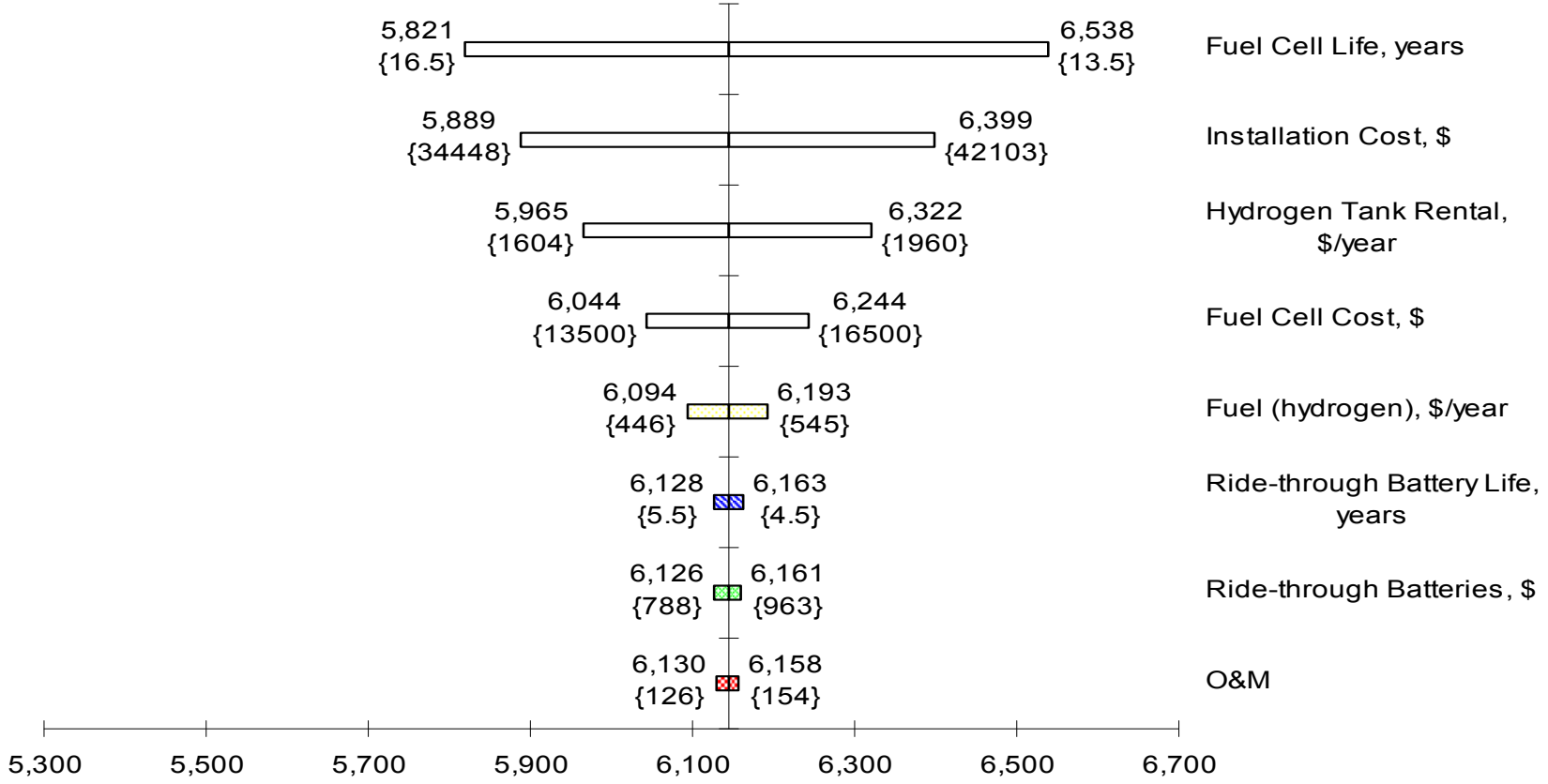
Emergency Response: Lifecycle Cost Analysis

- For shorter required runtimes (i.e., 8 to 72 hours per year), H-PEMFC compete with both battery-generator and battery-only systems
- For runtimes of 176 hours per year, the high cost of H2 storage and use makes H-PEMFC less attractive than the alternatives
- Shorter battery lifetimes increase the lifecycle costs of the battery-generator systems
- Incentives make H-PEMFC more attractive from capital cost perspective as compared to battery-generator system (H-PEMFC ~50% cheaper) and batteries only (H-PEMFC ~ 30% cheaper)

Runtimes	3-Year Battery Replacement			5-Year Battery Replacement							
	Battery-Gen.	H-PEMFC w/out Incentive	H-PEMFC w/ Incentive	Battery-Gen.	H-PEMFC w/out Incentive	H-PEMFC w/ Incentive	Gen. (New Inst.)	Gen. (Replace Existing Inst.)	Battery Only	H-PEMFC w/out Incentive	H-PEMFC w/ Incentive
8-hr									19,037	14,023	12,136
52-hr	69,860	63,521	58,804	61,082	61,326	56,609					
72-hr				47,318	33,901	32,014	28,283	24,886			
176-hr	93,129	102,403	97,686	75,575	100,209	95,491					

Emergency Response: Sensitivity Analysis

Improving fuel cell life, followed by reducing installation cost, has the largest impact on the cost of owning and operating a H-PEMFC



Annual cost of owning and operating a H-PEMFC backup power unit

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Emergency Response: Opportunities for H-PEMFC

- H-PEMFC value over existing technologies
  - Compared with batteries, H-PEMFC offer longer, continuous runtime and are more durable in harsh environments
  - Compared with generators, H-PEMFC have lower maintenance requirements and lower emissions
- Key opportunities for H-PEMFC as backup power to radio tower sites
  - When shorter runtimes are required (1 to 3 days)
  - In harsh environments, which can shorten battery lifetimes
- Financial incentives (as users emphasize capital cost), demonstration projects, and fuel availability are critical for H-PEMFC to compete effectively in this segment

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 ultracapacitors
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 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**

	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 – Varying H-PEMFC Lifetime and Battery Change-Out Time

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

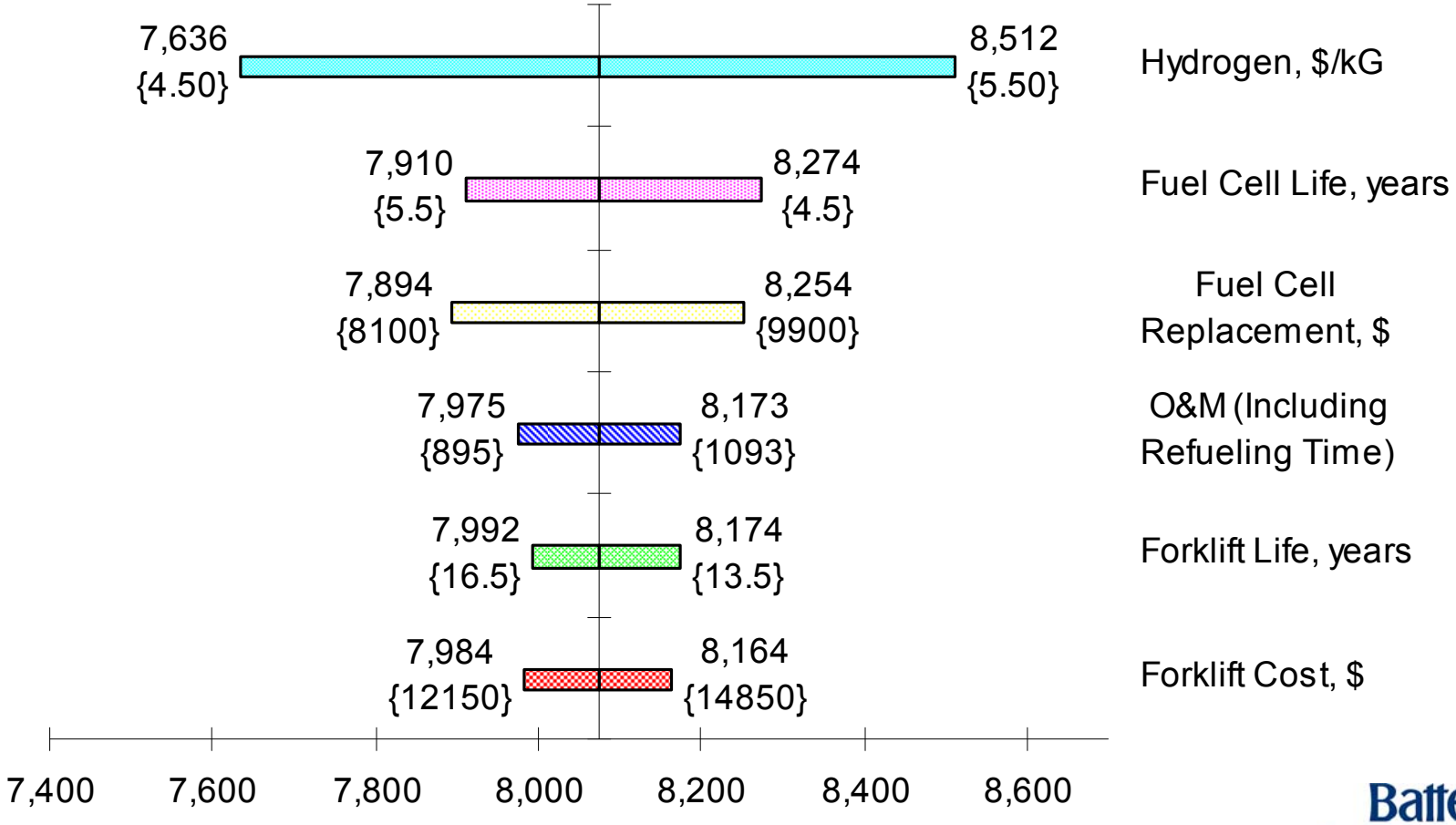
	Battery-Powered Pallet Truck (3 Batteries Per Truck)	Battery-Powered Pallet Truck (2 Batteries Per Truck)	H-PEMFC-Powered Pallet Truck w/out Tax Incentive	H-PEMFC-Powered Pallet Truck w/ Tax Incentive
NPV of Capital Costs ($)	21,572	17,654	48,626	45,796
NPV of O&M Costs (Including the Cost of Fuel) ($)	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

In the base, communication, and subsidy cases, annual sales reach 10,000 units in 9 years, 8 years, and 4 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

*Base case – assumes no government intervention, Communication case assumes government provides communication support, Subsidy case assumes subsidy of $1000 per kW
**Initial market size – 108,606 units
***Initial available market for PEM fuel cell-powered forklifts – 43,442 (40% of market)
****Growth rate 5%

Forklifts: Opportunities for H-PEMFC

- The value of H-PEMFC forklifts compared with alternatives varies significantly by application and is impacted by declining hours of operation and declining labor rates
- H-PEMFC forklifts can provide value over battery-powered forklifts in high-productivity environments (operating 3 shifts per day)
  - Refuel rapidly, eliminating time and cost of replacing batteries
  - Deliver constant voltage as long as fuel is available
  - Eliminate trips to battery changing station, thus increasing productivity
  - Reduce vehicle repairs due to fewer moving parts
  - Eliminate battery storage/changing rooms and associated cost
- For widespread H-PEMFC forklift adoption, reliability, capital costs, and fuel availability must be addressed

Conclusion: Requirements for Successful Market Penetration

- Strategic focus on location of hydrogen and corresponding incentives for hydrogen refueling to ensure an affordable and available source of hydrogen
- Technical focus on durability, reliability, and reducing cost of H-PEMFC
- 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