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The Business of Innovation

Stationery and Emerging Market Fuel Cell System Cost Analysis

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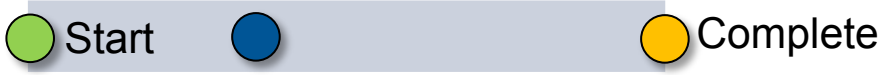
May 17, 2012

FC097

Overview

Timeline



Nov 2011

25% period 1 scope completed

Jul 2016

Budget (DOE Project Funding)

$300K Funded to Date

$541K FY12

$2 M

PARTNERS

Extensive solicitation of fuel cell industry stakeholders for design review is proposed

Initial partners:

- Hydrogenics
- NexTech
- Fuel Cell and Hydrogen Energy Association

Leverage past and new industry partners as project continues

Barriers Addressed

Cost reduction of fuel cell components and materials	Manufacturing capability	Customer acceptance

Program Objective/Focus

OBJECTIVE

To assist DOE in developing fuel cell systems for stationary and emerging markets by developing independent models and cost estimates

- Primary (including CHP) power, backup power, APU, and material handling
- 80°C PEM, 180°C PEM, SOFC technologies
- 100, 1K, 10K, and 50K* annual production rates
- 1, 5, 10, 25, 100, 250 kW fuel cell system powers

* 50K production rate for primary power systems only

FY12 FOCUS

Material Handling Equipment (MHE) applications

Identified 10kW and 25kW PEM for specific consideration in FY12

Auxiliary Power Unit (APU) applications

Identified 1kW and 5kW SOFC and HTPEM for specific consideration in FY12

Technical Barriers Addressed

Technical Barriers	Project Goals
Cost reduction of fuel cell components and materials	1. Identify major contributors to fuel cell system cost 2. Quantify potential cost reduction based upon technological improvements
Manufacturing capability	3. Identify major contributors to fuel cell system manufacturing cost 4. Identify areas for manufacturing R&D to improve quality and/or throughput 5. Provide basis for consideration of transition from
Customer acceptance	6. Develop accurate cost projections that can be used to evaluate total cost of ownership and facilitate early market adoption

Manufacturing Cost Analysis Approach

We are here

Market Assessment

- Characterization of potential markets
- Identification of operational and performance requirements
- Evaluation of fuel cell technologies relative to requirements
- Selection of specific systems for cost modeling

System Design

- Conduct literature search
- Develop system design
- Gather industry input
- Size components
- Gather stakeholder input
- Refine design
- Develop BOM
- Define manufacturing processes
- Estimate equipment requirements

Cost Modeling

- Gather vendor quotes
- Define material costs
- Estimate capital expenditures
- Determine outsourced component costs
- Estimate system assembly
- Develop preliminary costs
- Gather stakeholder input
- Refine models and update costs

Sensitivity & Lifecycle Cost Analysis

- Sensitivity analysis of individual cost contributors
- Monte Carlo analysis for trade-off of cost contributors
- Lifecycle cost analysis to estimate total cost of ownership

Material Handling Equipment (MHE) Market Assessment

- Considered a broad range of material handling applications and equipment
  - Best near-term opportunity for fuel cell systems is mobile equipment operating within a fixed range
    - Forklifts of all classes, personnel & burden carriers, automated ground vehicles
- Quantified performance metrics of existing equipment for those markets
- Evaluated suitability of fuel cell power modules for each application by process of elimination
  - Primary metrics: System size, usage data, end-user requirements

MHE – Fuel Cell System Selection

Summary of Systems Selected for Analysis

Technology		PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC
Fuel Cell System Size		1 kW			5 kW			10 kW			25 kW			100 kW			250 kW		
MHE Application	Class 1																		
	Class 2																		
	Class 3																		
	Class 4*																		
	Class 5*																		
	Class 6																		
	Class 7																		
	AGV																		

Analyzed in FY12

To be analyzed in FY13

System size not within normal application range

Application to be reconsidered in future years

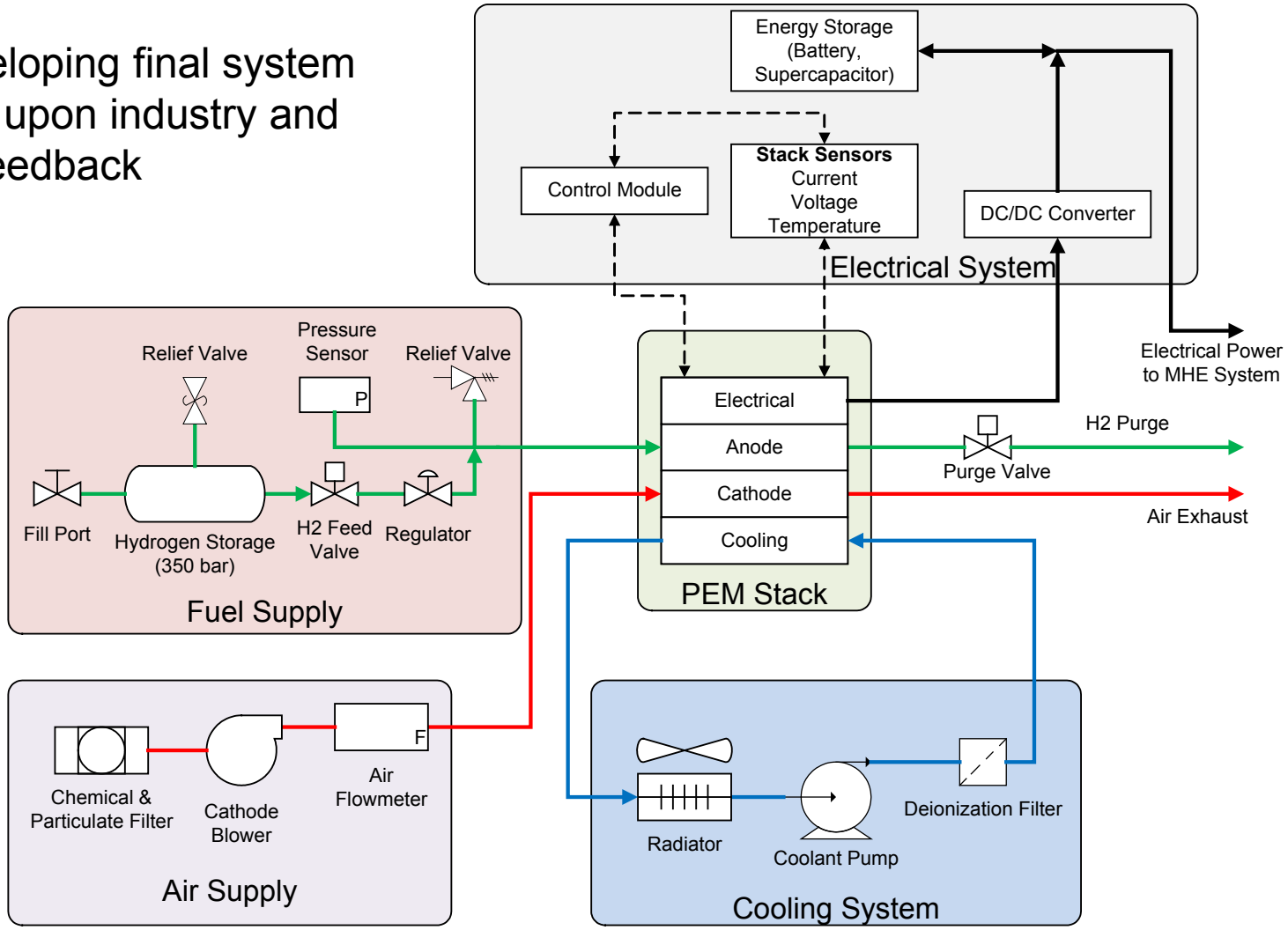
*** By definition Class 4 and 5 equipment are fueled by internal combustion engine**

MHE – Market Assessment Results

- Fuel cell systems of 1, 5, 10, and 25kW net are applicable to multiple MHE applications
- PEM systems will be the first considered
  - Most mature technology
  - Multiple options for centralized plant hydrogen fueling
  - Well suited for rapid start-up and transients
- SOFC and HTPEM
  - Not considered in FY12
  - Offer fuel flexibility, facilitating market penetration
  - Not an ideal fit based upon deployed fuel cell MHE usage data
  - Re-evaluate their potential in future years based on market evolution, technological progress, and project results, including cost analysis of APU systems

MHE – Preliminary System Schematic 10 and 25kW PEM

Basis for developing final system design based upon industry and stakeholder feedback



Material Handling System Preliminary System Specification 10 and 25 kW PEM

Parameter	10 kW System	25 kW System
Net power output	10 kW	25 kW
Peak hybrid system power	15–20 kW (150–200% nominal)	37–50 kW (150–200% nominal)
Regulated output voltage	48 VDC	
Parasitic losses	10%	
Operating temperature	70°C, liquid cooled	
Design life	10,000 hrs	
Full-load cell voltage	0.65 V	
Full-load current density	1 A/cm^2	
Active area	450 cm^2	
Number of cells	38	94
Bipolar plates	Coated metal	
Humidification	None	

Preliminary system specification will be refined to final specification based upon industry and stakeholder feedback

Auxiliary Power Unit (APU) Market Assessment

- Considered a broad range of APU applications
- Identified market drivers
- Quantified performance requirements
- Evaluated suitability of fuel cell power modules for each application by process of elimination
  - Primary metrics: System size, market requirements, technological readiness, market drivers

APU – Fuel Cell System Selection

Starting from the entire scope of systems (size, technology), focus selection on systems best suited for near-term APU applications

	Technology	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC	PEM	HTPEM	SOFC
	System Size	1 kW			5 kW			10 kW			25 kW			100 kW			250 kW		
APU Application	RV																		
	Commercial Truck																		
	Maritime																		
	Commercial Aviation																		

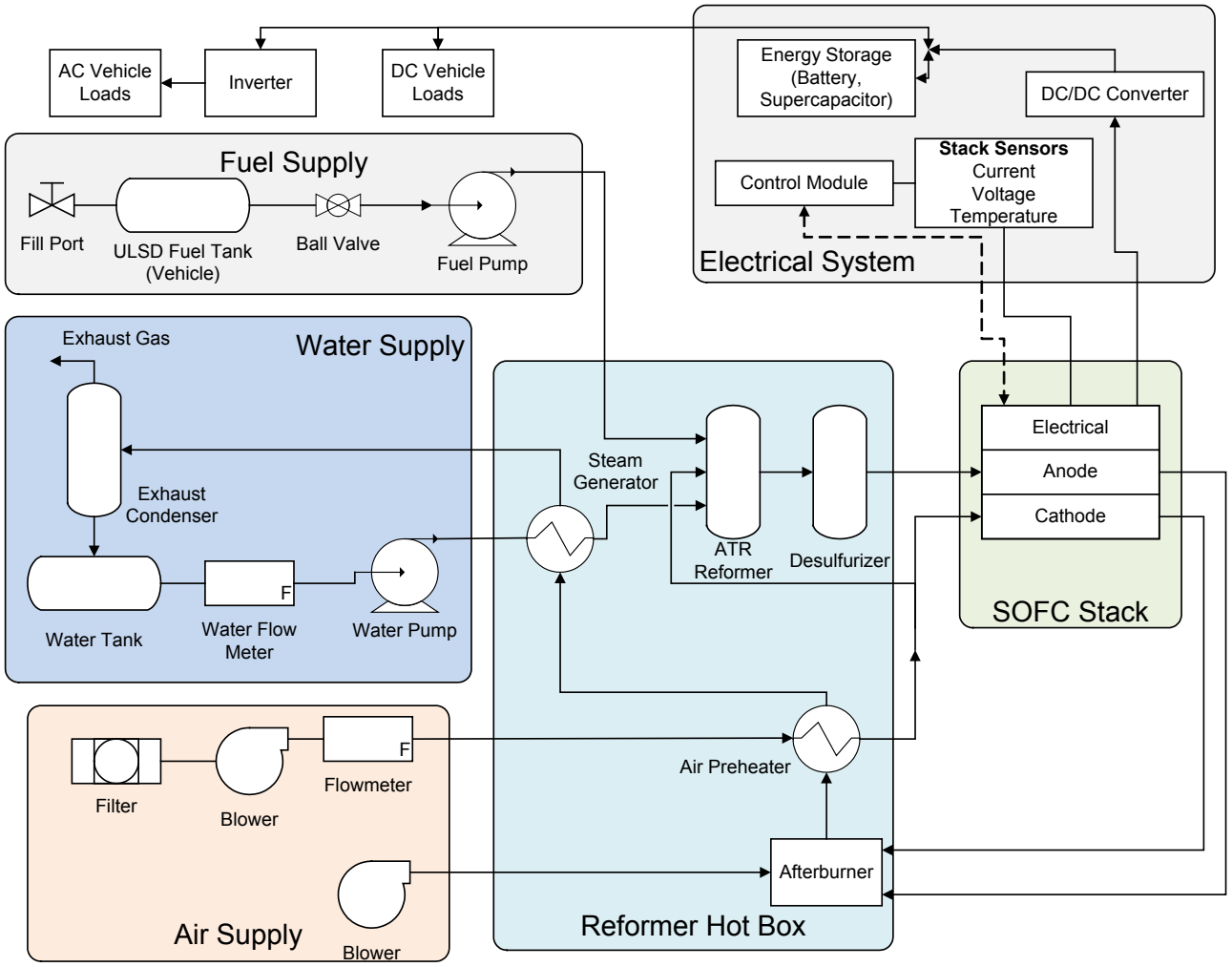
- Analyzed in FY12
- Commercial market and drivers unclear
- System size not within normal application range
- Application to be reconsidered in future years
- Application to be reconsidered in future years, outside APU product range, but potential market as primary power for small aircraft including UAV

APU – Market Assessment Results

- Recreational vehicle
  - Barriers are limited regulatory market drivers and seasonal usage
- Commercial truck
  - 1kW and 5kW systems selected for analysis in FY12
  - Considering both SOFC and HTPEM systems
  - Regulatory market drivers
  - Technology development at suitable state of development
- Maritime
  - Market interest in systems of all sizes (recreational and commercial)
  - No clear, large, specific commercial markets or drivers for fuel cells
- Aviation
  - Considerable market interest
  - Ideal applications for fuel cell technology
  - Considerable gap between current technology and requirements with respect to power density and specific power

APU – Preliminary System Schematic 1 and 5 kW Autothermal Reformer (ATR)/SOFC

- Basis for developing final system design based upon industry and stakeholder feedback
- General system design in progress, including reforming, desulfurization, and system integration considerations



APU System Preliminary System Specification 1 and 5kW SOFC

Parameter	Value	Value
Net power output	1 kW	5 kW
Regulated output voltage	12 VDC	
Parasitic losses	20%	
Operating temperature	750°C	
Design life	10,000 hr	
Degradation rate	<2% / 1,000 hr	
Full-load cell voltage	0.8 V	
Full-load current density	0.4 A/cm^2	
Active area	500 cm^2	
Number of cells	8	38
Construction	Planar, anode supported	
Primary fuel	Ultra low sulfur diesel	
Reformer performance	<0.1 ppm sulfur, <1% hydrocarbons	

Preliminary system specification will be refined to final specification based upon industry and stakeholder feedback

Collaborations

- Industry input and feedback throughout project
  - Suitability of system design
  - Manufacturing approaches
  - Validity of results
- Involve multiple manufacturers at all levels
  - System integrators and stack manufacturers
    - Ballard, Cummins, Delphi, Hydrogenics, NexTech, Nuvera, Plug Power, Versa Power
  - Stack component manufacturers
    - 3M, Ballard, Bulk Molding Company, DuPont, Gore, GrafTech
  - Blowout preventer (BOP) component manufacturers
    - Emerson, NexTech, Parker, VAIREX

Proposed Future Work

FY12	FY13	FY14, FY15, FY16
• Complete design of HTPEM APU system • Complete full cost assessment of 10kW and 25kW PEM systems for MHE applications • Complete full cost assessment of 1kW and 5kW SOFC and HTPEM systems for APU applications	• Complete assessment of 1kW and 5kW PEM systems for MHE applications • Reconsider entire program scope with DOE to identify next focus of program activities • Stationary power (including CHP) • Backup power • Additional MHE or APU applications based on FY12 results	• Complete additional new analyses • Revisit and update previous analyses based upon technological advancements

Summary

- Progress
  - Defined the application
    - Identified market requirements
    - Identified appropriate fuel cell technologies and system sizes to meet requirements
  - Completed preliminary system design
    - 10kW and 25kW PEM for MHE, 1kW and 5kW SOFC for APU
    - Detailed performance specifications and system requirements
    - Completed basic system design
- Immediate next steps
  - Complete detailed design with feedback from industry
  - Identify manufacturing approaches and equipment costs

Backup Slides

Collaborations

Example collaboration network from previous backup power cost analysis