V.I.2 Solid Oxide Fuel Cell Development for Auxiliary Power in Heavy Duty Vehicle Applications

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Subcontractors:

- Electricore, Inc., Valencia, CA
- Volvo Trucks North America (VTNA), Greensboro, NC
- PACCAR, Inc., Mt. Vernon, WA

Project Start Date: September 1, 2004
Project End Date: April 30, 2010

Objectives

To demonstrate a solid oxide fuel cell (SOFC) auxiliary power unit (APU) capable of operating on low sulfur diesel fuel, in a laboratory environment, for the commercial trucking industry.

- Design and develop a SOFC APU that will increase fuel and overall system efficiency of Class 8 long haul trucks.
- System and subsystem shock and vibration limits will be studied and recommendations made in the final report, which will address methods of isolation of the APU system to these parameters.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells – Portable Power/APUs/Off-Road Applications section of the Fuel Cell Technologies (FCT) Program Multi-Year Research, Development and Demonstration (RD&D) Plan:

(A) Durability
(B) Cost
(C) Performance
(G) Start-up and Shut-down Time and Energy/Transient Operation

Technical Targets

This project is directed at the development and demonstration of a SOFC APU for heavy-duty truck (Class 8) applications to reduce idling of the main engine. If successful, the project will address the following DOE technical targets as outlined in the FCT Multi-Year RD&D Plan (see Table 1). Upon completion of the project the attached technical targets verses actuals table was developed and presented to the DOE on June 22, 2010 (see Table 2).

TABLE 1. Auxiliary Power Units (3-5 kW rated, 5-10 kW peak) Targets

Characteristic	Units	2010 / 2015 Targets[1]	Delphi 2008 SOFC APU Status[2]
Specific Power	W/kg	100 / 100	15
Power Density	W/L	100 / 100	12
Efficiency @ Rated Power [a]	%LHV	35 / 40	35
Cost [b]	$/kW	400 / 400	665
Cycle Capability (from cold start) over operating lifetime	number of cycles	150 / 250	125
Durability	hours	20,000 / 35,000	4,660
Start-up Time	min	15-30 / 15-30	120

[a] Electrical efficiency only – does not include any efficiency aspects of the heating or cooling likely being provided.
[b] Cost based on high-volume manufacturing quantities (100,000 units per year).
[1] From Table 3.4.8 (page 3.4-19) of the DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program - Multi Year Research, Development and Demonstration Plan.
[2] Based on reported data to DOE Solid State Energy Conversion Alliance Phase I deliverables for a Natural Gas Based SOFC System.
LHV - lower heating value

Accomplishments

- Design and development of the next generation enhanced DPS3000D APU.
- Full-scale component modeling and build.
- Use of next generation stack design.

TABLE 2. Auxiliary Power Units (3-5 kW rated, 5-10 kW peak) Actual

Technical Targets : 1-10 kW SOFC Auxiliary Power Units (1)						
	Units	2010 Targets (2)	2010 Actuals	(Production)	2015	2020
Specific Power	W/kg	120	7	17	22	25
Power Density	W/L	120	4	10	15	20
Efficiency @ Rated Power (3)	%	35	25	30	35	35
Cost	$/kW	400	(4) See below	(4) See below	(4) See below	(4) See below
Cycle Capability (from cold start) over operating lifetime	Number of cycles	500	(5) See below	416	416	416
Operating Life	hours	5,000	2500	30,000	30,000	30,000
Start-up time	minutes	15-30	180	90	60	60

1 Operating on Standard Ultra-Low Sulfur Diesel
2 Initial targets for program as defined in 2003 SOPO
3. Regulated DC Net/Lower heating value of fuel
4. Heavy duty truck market is highly price sensitive.
5 < 50 System Cycles but >200 stack Cycles

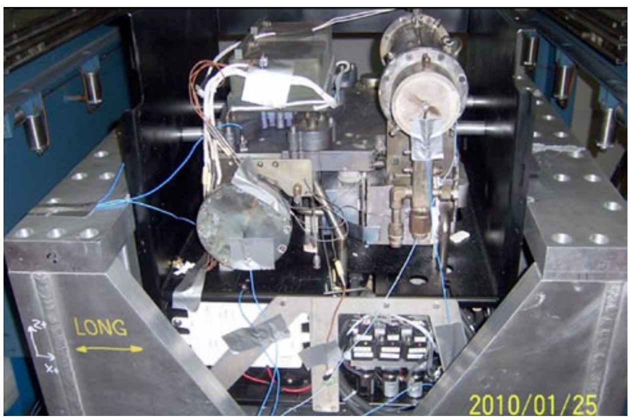

FIGURE 1. DPS3000A System on Shaker Table

- Completion of specialized test stands for testing the DPS 3000D.
- Initial testing of the APU system and subsystems in accordance with test plan.
- Initial vibration and durability testing (see Figure 1).
- Fifteen-hour continuous test and demonstration of a diesel-fueled SOFC APU mounted on a Class 8 Peterbuilt Model 386 truck with loads.

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Introduction

Delphi Corporation (Delphi) has teamed with heavy-duty truck original equipment manufacturers PACCAR Incorporated (PACCAR), and Volvo Trucks North America (VTNA) to define system level requirements and develop an SOFC-based APU. The Delphi team has enlisted Electricore, Inc. to serve as administrative manager for the project.

The project defines system level requirements, and subsequently designs and implements an optimized system architecture using an SOFC APU to demonstrate and validate that the APU will meet system level goals. The primary focus is on APUs in the range of 3-5 kW peak for truck idling reduction. Fuels utilized will be low-sulfur diesel fuel.

Approach

Delphi has been developing SOFC systems since 1999. After demonstrating its first generation SOFC power system in 2001, Delphi has partnered with Volvo Trucks and PACCAR Inc., to develop and demonstrate an SOFC-based APU for heavy truck applications.

Delphi utilized a staged approach to develop a modular SOFC system for low-sulfur diesel fuel and Class 8 truck applications. First, Delphi gathered APU requirements from heavy-duty truck manufacturers including VTNA and PACCAR to develop specific technical requirements for the APU. Following this, Delphi continued the development and testing of major subsystems and individual components as building blocks for the APU. The major subsystems and individual components were then integrated into a "close-coupled" architecture for integrated bench testing. Delphi took additional steps to refine the overall APU and each of its components. Specialized test stands were designed and developed to test the APU enhancements and system functionality.

Status

In the past year Delphi focused on refining and enhancing the overall APU system design and performing detailed system and subsystem testing. Specifically, work was focused on the SOFC APU hardware design and build; subsystem test fixture hardware build; and subsystem testing and development iterations.

The work this period included Tasks 2.6, 2.8, 2.10, 2.11, 3.1, 3.2, and 3.3. These tasks focus on the SOFC APU hardware design and build; subsystem testing and development iterations; system module testing and development; and bench testing of the APU. The testing was completed on time and under budget.

Tests were completed on the enclosure flow under different configurations. The original design had only one inlet, while a revised design had two inlets in various configurations. Comparative testing indicated significant flow improvement by going to the two inlet design. Figure 2 shows the flow velocity at various process air blower (PAB) rates. The dark blue line (bottom) is the flow rate for the one inlet design while the other rates are for the two inlet design under different configurations.

The development of APU hardware and test stands to validate subsystems was initiated and completed in 2010. Delphi engineers noted improvements that can be made to the stand in order to attain the most accurate data from the tests. The system vibration test stand (Figure 1) was successfully designed and fabricated with capability of the following:

- 24/7 unmanned operation
- Hot system running with diesel fuel
- Rapid thermal cycle testing
- Continues load testing
- Three-axis vibration

Positive results were gathered from the vibration testing indicating the robustness of the design for on-road application of the SOFC as an APU.

Additional full APU system development and testing was conducting including:

- Thermal cycling tests of the complete system
- Hardware development
- Software development
- Load cycling of only thermal stacks
- Usage of anode tail gas simulation to generate recycle

During this phase Delphi performed 22 full thermal cycles on ultra-low sulfur diesel (ULSD), and 160 total hours of operation. Delphi successfully demonstrated complete system “Turn-Key” starts, warm-ups, and repeated cool-downs.

Delphi also successfully performed full simulated load cycles using the DPS3000D set 3 with EC stacks, pulled power during cycle testing, monitored stack cell

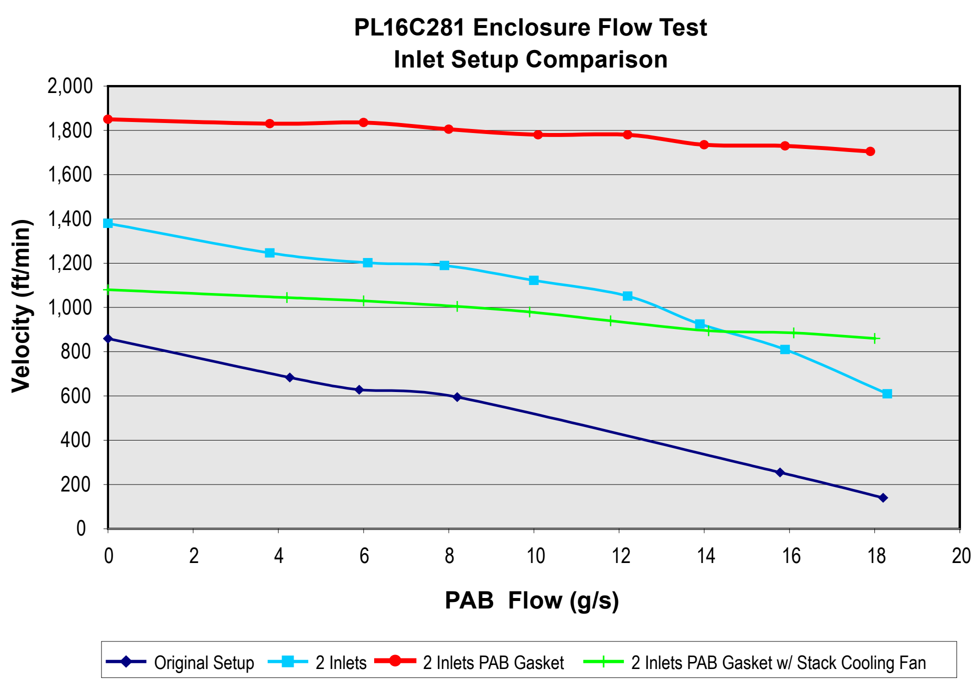

FIGURE 2. Enclosure Flow Test

voltages, performed five ULSD starts and two additional full thermal cycles. Furthermore an initial natural frequency sweep was performed. The SOFC system was also tested for noise generation and electromagnetic compatibility at Delphi Packard Division.

Delphi has finished the final review for the completion of reports and documentation required for the final oral/visual presentation. The final presentation was completed June 22nd, 2010. The presentation was presented to DOE staff and members of the Delphi development team.

The project was completed on time and to budget.

Special Recognitions & Awards/Patents Issued

US Patent Office Grant Numbers: 7562588 and 7648784:

1. 7562588 (**7/21/2009**) - Method and apparatus for controlling mass flow rat of recycle anode tail gas in a Solid Oxide Fuel Cell system.

2. 7648784 (**1/19/2010**) - Method and apparatus for controlling a Fuel Cell system having a variable number of parallel connected modules.

FY 2010 Publications/Presentations

1. November 2009: 2009 Fuel Cell Seminar; Palm Springs, CA; Presentation: "Solid Oxide Fuel Cell Development for Transportation and Stationary Applications: Latest Update on Stack and System Performance", Presented by: Steven Shaffer, Delphi Corporation.

2. June 2010: DOE Hydrogen Program Peer Review; Arlington (Crystal City), VA.; Presentation: "Solid Oxide Fuel Cell Development for Auxiliary Power in Heavy Duty Vehicle Applications"; Presented by: Dan Hennessey, Delphi Corporation.