V.I.3 Solid Oxide Fuel Cell Development for Auxiliary Power in Heavy Duty Vehicle Applications

Steven Shaffer
Delphi Corporation
5500 W. Henrietta Rd., Mail Code 146-HEN-575
West Henrietta, NY 14586
Phone: (585) 359-6615; Fax: (585) 359-6061
E-mail: steven.shaffer@delphi.com

DOE Technology Development Manager:
Terry L. Payne
Phone: (202) 586-9585; Fax: (202) 586-9811
E-mail: Terry.Payne@ee.doe.gov

DOE Project Officer: David Peterson
Phone: (303) 275-4956; Fax: (303) 275-4788
E-mail: David.Peterson@go.doe.gov

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

Contract Number: DE-FC36-04GO14319

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

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 Hydrogen, Fuel Cells and Infrastructure Technologies Program (HFCIT) Multi-Year Research, Development and Demonstration (RD&D) Plan:

(A) Durability
(B) Cost
(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 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 HFCIT Multi-Year RD&D Plan:

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

Characteristic	Units	2010/2015 Targets[1]	Delphi 2008 SOFC APU Status[2]
Specific Power	W/kg	100/100	40
Power Density	W/L	100/100	52
Efficiency @ Rated Power [a]	%LHV	35/40	38
Cost [b]	$/kW	400/400	665
Cycle Capability (from cold start) over operating lifetime	number of cycles	150/250	50
Durability	hours	20,000/35,000	4,660
Start-up Time	min	15-30/15-30	90

[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

- Successfully integrated a full-scale hot-reformate desulfurizer, diesel endothermic reformer, and SOFC stacks.
- Demonstrated 50 thermal cycles on the SPU 1 Natural Gas System.
- Completed integration and test of a diesel-fueled SPU 1 system (SPU-1E) to support heavy-duty commercial vehicle applications.

- Successfully tested the 12 V power electronics interface for heavy-duty commercial vehicle applications including SOFC system, 12 V direct current/direct current (DC/DC) converter, lead-acid battery, software and controls.
- Initiated internal development on a more robust igniter to survive the aggressive thermal environment.
- Fabricated a three piece Inconel casting for our Integrated Component Manifold.

✧ ✧ ✧ ✧ ✧

Introduction

Delphi Automotive Systems, LLC (Delphi) has teamed with heavy-duty truck original equipment manufacturers (OEMs) PACCAR Incorporated (PACCAR), and Volvo Trucks North America (VTNA) to define system level requirements and develop a 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 a 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 truck manufacturers including VTNA and PACCAR to develop specific technical goals 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.

Results

In the past year Delphi has focused on updating the OEM system requirements (following an 18 month project shut down in 2006-2007) and initialization activities for subsystem building and testing. Specifically, work has focused on the SOFC APU hardware design and build; subsystem test fixture hardware build; and subsystem testing and development iterations. Highlights include:

1. Developing initial strategies for APU-truck integration including mounting a demonstration unit on a Class 8 truck frame.
2. Further development of a Class 8 truck demonstrator unit based on the SPU-1E powerplant – Figure 1.
3. Continued hardware design and subsystem testing of the next generation SOFC system.
4. Preliminary exhaust comparisons between the Delphi SOFC system and comparable diesel genset APUs.

Several other technical focus areas, including eliminating carbon deposition during system warm up, partial oxidation and endothermic reformer design, and balance of plant upgrades continued per the project schedule.

SOFC APU Hardware Design and Build

Delphi continues progress on both the SPU-1E and next generation SOFC APU designs. The SPU-1E system design was completed and included a truck output and input power converter, alternating current (AC) input power converter, power interface controller, truck mounting frame and enclosure with vibration isolators, electronics housing with vibration isolators, reduced gas supply assembly and controller, user

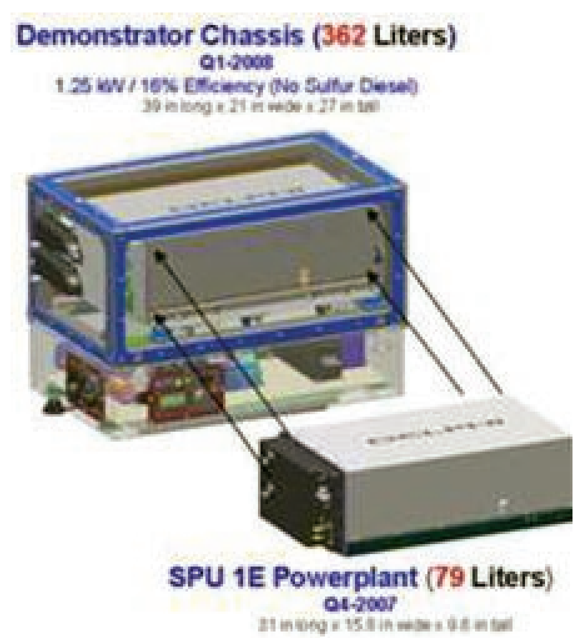

FIGURE 1. SPU-1E Powerplant Mounted Inside the Truck Demonstrator Chassis

interface panel, remote user interface head, and wireless remote personal computer monitoring system.

Additionally, Delphi has made significant progress on the hardware enhancements for the next generation diesel SOFC APU. These enhancements have focused on increasing the power level to 3.0 kW net with improved cooling environment around the stacks; reducing the pressure drop of components to minimize parasitic loads; improving efficiency by using an "endothermic" reformer and high recycle flow; and increasing insulation thickness and thermal component compartmentalization to reduce heat loss.

Power Electronics and System Controls

Development in 2008 continued on the power electronics tray for integration on the SPU-1E demonstration unit. The integrated electrical interface hardware allows for supply of input power to the SOFC system via 12 V DC vehicle electrical power or from a 120 V AC power source. Figure 2 shows the electronics tray integrated with the SPU-1E powerplant.

Vehicle Interface and Diagnostics Vehicle Interface Hardware

Preliminary work on vehicle integration has begun. Delphi is using the SPU-1E system as an integration demonstrator unit to gain a better understanding of truck integration issues. While the system is not the intended commercial production unit, it does contain both a diesel-powered SOFC powerplant and power electronics module.

Subsystem Test Fixture Hardware Build

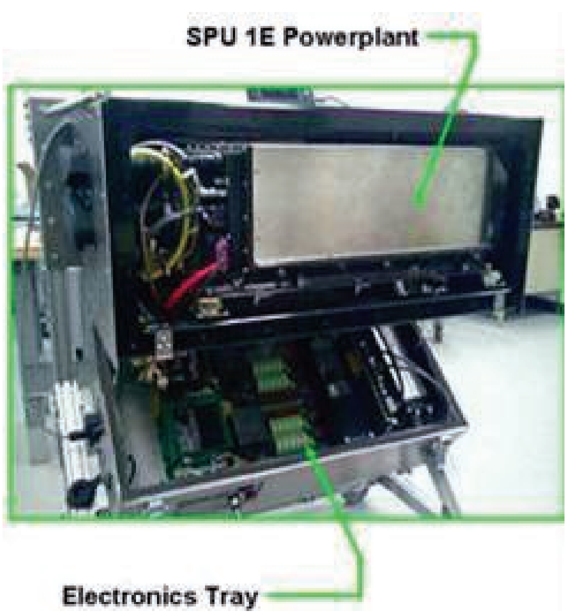

FIGURE 2. Electronics Tray Integrated with the SPU-1E Powerplant

Delphi is currently building multiple test fixtures to be able to conduct component and subsystem level testing. These test fixtures simulate other subsystems, system inputs (i.e. diesel from the truck fuel tanks), and the environment (i.e. system heat).

Subsystem Testing and Development Iterations

Testing has progressed on several subsystems through 2008. One area of major effort is carbon deposition associated with running the system on diesel fuel. It is believed this phenomena is related to the oxygen:carbon ratio in the reformate stream. Tests have shown that post-reformer air injection reduces carbon deposition. Additional testing is being performed to validate these findings.

Conclusions and Future Directions

Delphi's SOFC development is recognized as being among the best performing, compact, cost-effective and durable SOFC system and stacks available today. In the 2007/2008 calendar year, Delphi has done the following:

- Achieved a major breakthrough in durability by demonstrating 50 thermal cycles of an SOFC system.
- Developed and demonstrated an integrated diesel reformer system both in the lab and on a vehicle.
- Strong interactive advanced characterization and modeling complemented the system demonstrations.
- Successfully integrated a full-scale hot-reformate desulfurizer, diesel endothermic reformer, and SOFC stacks while running the simulated heavy duty truck hotel loads.
- Two presentations were delivered.

For the remainder of project, Delphi will fulfill reporting obligations, and prepare manuscripts for publication and conference presentations. Delphi will also develop, build and test the next generation SOFC diesel APU system and subsystems for later bench top testing.

The future direction is to continue developing the next generation SOFC system for commercial volume production introduction.

FY 2008 Publications/Presentations

1. January 2008: DOE Pre-Solicitation Workshop; Washington, D.C.; Presentation: "SOFC Technology R&D Needs"; Presented by: Steven Shaffer, Delphi Corporation.

2. June 2008: DOE Hydrogen Program Peer Review; Golden, CO.; Presentation: "Solid Oxide Fuel Cell Development for Auxiliary Power in Heavy Duty Vehicle Applications"; Presented by: Steven Shaffer, Delphi Corporation.