

# V.J.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

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 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 <sup>1</sup> | Delphi 2009 SOFC APU Status <sup>2</sup> |
|--|------------------|--------------------------------|--|
| Specific Power   | W/kg             | 100/100                        | 15                                       |
| Power Density  | W/L              | 100/100                        | 12                                       |
| Efficiency @ Rated Power <sup>a</sup>                      | %LHV             | 35/40                          | 35                                       |
| Cost <sup>b</sup>  | \$/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                                      |

<sup>a</sup> Electrical efficiency only – does not include any efficiency aspects of the heating or cooling likely being provided.

<sup>b</sup> Cost based on high-volume manufacturing quantities (100,000 units per year).

<sup>1</sup> 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.

<sup>2</sup> 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

## 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 Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program

## Accomplishments

- Completed the design and layout of the enhanced superior performing DPS3000D Diesel SOFC APU to include: next generation stack design with an increased active area, enhanced thermal energy management controls, endothermic reformer integration, multi-function heat exchanger, integrated reformate desulfurizer, fully integrated

- turnkey system, simplified integrated component manifold, and serviceability enhancements.
- Successful fuel reformer development of a recycle-based endothermic diesel reformer.
- Enhanced geometry packaging and modified the APU profile for mounting on heavy-duty truck chassis.
- Completed development of the DPS3000D test chassis, with integration of endothermic reformer and gaseous desulfurizer, and testing using 2007 specification diesel fuel.
- Modified natural gas platform to operate on diesel fuel for the truck demo chassis test.
- Completed a 15-hour continuous test and demonstration of a diesel-fueled SOFC APU mounted on a Class 8 Peterbuilt Model 386 truck.
- Completed development and initial testing of the development and test stands for the DPS3000D.
- Successfully performed accelerated vibration and durability testing of stack equal to 100,000 vehicle miles.
- Initiated full-scale modeling and fabrication of the APU components and hardware.
- Completed an accelerated truck load testing in the test chamber for the new process blower.



## 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. 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.

## Results

In the past year Delphi has focused on refining and enhancing the overall APU system design and performing detailed system and subsystem 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:

- Design and development of the next generation enhanced DPS3000D APU.
- Full-scale component modeling and build.
- Next generation stack design and development.
- 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.
- 15-hour continuous test and demonstration of a diesel-fueled SOFC APU mounted on a Class 8 Peterbuilt Model 386 truck.

## SOFC APU Hardware Design and Build

Delphi has made significant progress in 2009 on the hardware enhancements for the next generation diesel SOFC APU, the DPS3000D (see Figure 1). 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. Full-scale modeling and fabrication of subsystem components has also progressed in 2009. Figure 2 shows the full-scale modeling and components that have been built.

## Power Electronics and System Controls

Development continued on the power electronics tray for integration on the DPS3000D. The power electronics were validated by testing conducted by

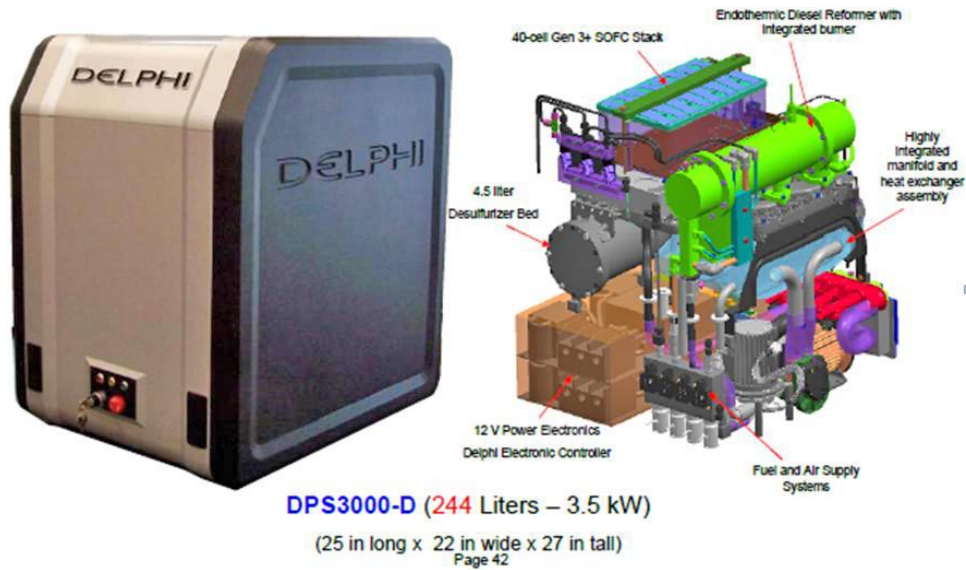


FIGURE 1. Diesel SOFC APU Conceptual Design

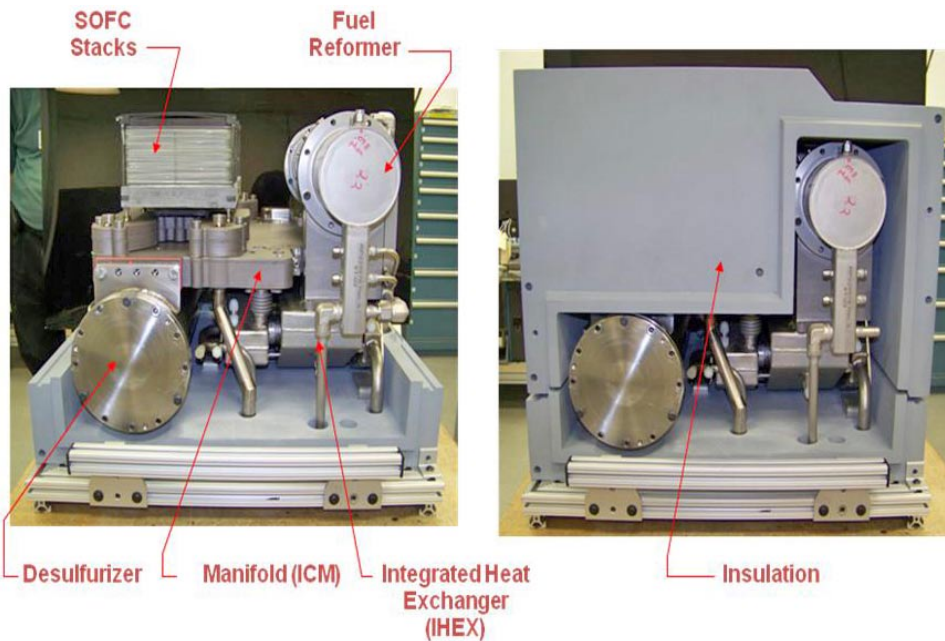


FIGURE 2. Full-Scale Modeling and Manufactured Components

Virginia Tech. Significant progress on the system controls, including a beta version of an optimized control code. The software was deployed on a natural gas SOFC system for initial testing.

**Vehicle Interface and Diagnostics Vehicle Interface Hardware**

Delphi obtained mounting information from multiple heavy-duty commercial truck OEMs in order to analyze how the APU will mount to the truck chassis.

It was necessary to consider a variety of different truck faring designs and styles to insure that operation on the trucks is possible. Effort was made on geometry packaging and modifying the APU profile in order to clear the fairings

**Subsystem Test Fixture Hardware Build**

Delphi has completed building multiple test fixtures to be able to conduct component and subsystem level testing. These test fixtures simulate other subsystems,



**FIGURE 3.** Rapid Thermal Cycle Test Stand

system inputs (i.e. diesel from the truck fuel tanks), and the environment (i.e. system heat). Figure 3 shows the rapid thermal cycle test stand.

### Subsystem Testing and Development Iterations

Testing of the DPS3000D subsystems has progressed through 2009. Highlights include initial testing of the hot zone build module and initial testing of the new process air blower and recycle pump manufactured by R&D Dynamics to Delphi specifications utilizing state-of-the-art air bearing technology.

### 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 2008/2009 calendar year, Delphi has done the following:

- Achieved a major breakthrough in durability by demonstrating accelerated vibration and durability testing of SOFC stack equivalent to 100,000 vehicle miles.
- Developed and demonstrated system and subsystem testing utilizing custom design and built specialized test stands.
- Completed full-scale modeling and build of subsystems.

For the remainder of project, Delphi will complete the development, build and testing of the DPS3000D SOFC Diesel APU system and subsystems. The future direction is to continue developing the next generation SOFC system for commercial volume production introduction.

### FY 2009 Publications/Presentations

1. April 2009: DoE Critical Milestone #3 Review; Rochester, NY.; Presentation: "Solid Oxide Fuel Cell Development for Auxiliary Power in Heavy Duty Vehicle Applications, Milestone Update"; Presented by: Gary Blake, Delphi Corporation.
2. May 2009: 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: Steven Shaffer, Delphi Corporation.