X.1 Solid Oxide Fuel Cell Diesel Auxiliary Power Unit Demonstration

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Contract Number: DE-EE0000478

Subcontractors:
- Electricore Inc., Valencia CA
- PACCAR, Inc., Bellevue, WA
- TDA Research, Inc., Wheat Ridge, CO

Project Start Date: August 1, 2009
Project End Date: September 30, 2013

Objectives

- Design, develop, and demonstrate a 3-5 kW Solid Oxide Fuel Cell (SOFC) Auxiliary Power Unit (APU) for heavy-duty commercial Class 8 trucks (Figure 1).
- Utilize Delphi's next generation SOFC system as the core power plant and prove the viability of the market opportunity for a 3-5 kW diesel SOFC APU system.
- Test and demonstrate the diesel SOFC APU system in a high visibility fleet customer vehicle application that will support hotel loads and other real world operating conditions.

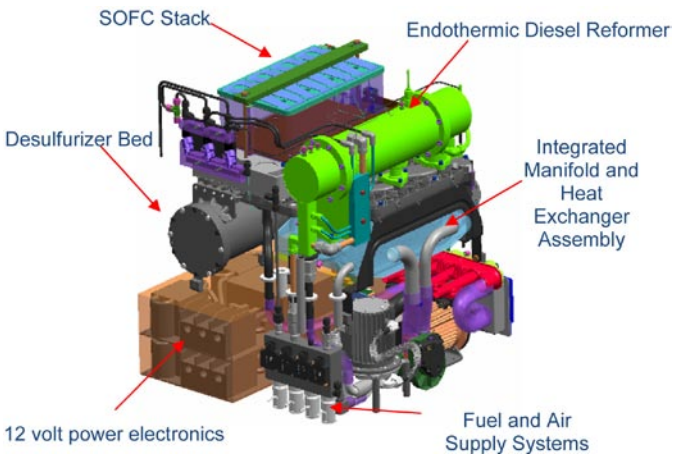

FIGURE 1. Delphi SOFC APU Schematic

Relevance to the American Recovery and Reinvestment Act (ARRA) of 2009 Goals

During this phase of the project, a total of four jobs were created/maintained;

- Delphi: three full-time employees
- PACCAR: one full-time employee

As a result of this project, Delphi's SOFC APU was installed on a highly visible fleet truck. The demonstration provided Delphi, and their partner and fleet customer, with real world experience of the technology in the application. This demonstration should increase the overall awareness of SOFC APUs and help to facilitate commercialization of the product. Additionally, this project supported further development of Delphi's SOFC stack with additional exposure and testing in a different environmental application.

Technical Barriers

As a result of the successful execution of this project, Delphi addressed:

- System vibration robustness
- Overall system packaging
- System weight
- System cost
- System manufacturability
- System durability/reliability

During SOFC APU system testing, Delphi discovered a significant issue with the desulfurizer during repeated thermal cycles. Trials of alternative desulfurizing materials failed to meet requirements. Delphi opted to remove the desulfurizer from the system, providing a lower net power unit as designed with the volume for the desulfurizer bed not utilized. Future development in the area of high temperature desulfurization materials is still needed.

Technical Targets and Milestones

- Install the SOFC APU on a vehicle in service and complete real-world application demonstration.
- Provide 3-5 kW of power during truck idle periods allowing for reduced fuel consumption and harmful emissions.

- Specific power ≥15 w/kg
- Power density ≥10 w/l
- Net system efficiency ≥35%
- ≥2,000 hours of operation

Accomplishments

- Operator Instructions, Safety and Training Manual prepared
- Driver training completed
- APU Field Service Plan developed and included:
  - Frequency of checks by Delphi Engineers
  - Training of technicians on site
- Field data collection plan developed
- Desulfurizer removed due to difficulty with sorbent
- System modified and recalibrated to operate without sorbent
- SOFC APU operation confirmed in the lab
- SOFC APU mounted on Peterbilt Class 8 Truck and driven on demonstration loop (Figure 2)
- SOFC APU demonstration was completed with 1,098 truck miles and 1,125 hours of operation
  - Demonstration unit performance: 22% net efficiency, 8 W/l power density, 7 W/kg specific power

INTRODUCTION

Delphi's SOFC system, installed on heavy-duty commercial trucks providing auxiliary power, addresses the growing concerns about emissions, fuel consumption, and noise. In the United States today, there are more than one million long-haul, heavy-duty commercial trucks with sleeper cabs on the road. When drivers stop for their mandatory rest periods or loading/unloading, they often leave their engines idling in order to heat/cool the sleeping areas and operate other vehicle systems. This idling practice is costly to the driver, the fleet owner, and harmful to the environment. The Environmental Protection Agency's Smart Way Transport Partnership estimates that each year, long duration idling of truck engines consumes approximately 960 million gallons of diesel fuel and emits 11 million tons of carbon dioxide, 180 thousand tons of nitrogen oxides, and 5 thousand tons of particulate matter into the air. In addition to the consumed fuel and emissions, idling trucks create elevated noise levels. The SOFC APU has the potential to decrease idling fuel consumption by up to 85%, reduce exhaust emissions below federal regulation emission standards, and decrease radiated noise levels to less than 60 decibels when compared to the truck's main engine.

FIGURE 2. Delphi SOFC Demonstration Truck

As a result of the on-road demonstration under this project, Delphi will be able to present user profile data to its fleet customer. This data will reinforce the lab-generated data showing that use of an SOFC APU as an anti-idling solution will provide drivers and fleets with reduced fuel consumption as well as reduced emissions and noise. This demonstration should increase the overall awareness of SOFC APUs and provide positive momentum in preparing to commercialize this product.

APPROACH

Under this project, Delphi pursued a three-phase approach to conduct its development. During Phase 1, Delphi worked with its partner, PACCAR, to establish the application's specifications and commercial requirements for the SOFC APU. Phase 2 work focused on design verification and system testing (lab and on-vehicle). Phase 3 included the demonstration of the SOFC APU on a heavy-duty Class 8 vehicle. The data collected during the demonstration phase was analyzed and reported.

All Delphi facilities involved in the project were required to meet Delphi's stringent safety requirements and are in alignment with the Safety Planning Guidance documentation specified by DOE. Additionally, there are no changes to the information contained within the National Environmental Policy Act forms submitted.

RESULTS

During this report period, Delphi:

- Evaluated and gained a better understanding of the effects of sulfur and the impact it has on SOFC APU performance.

- Demonstrated 3.5 kW net power with zero sulfur fuel and 2.0 kW net power with ultra-low sulfur diesel fuel which is regulated to contain <15 ppm sulfur.
- Completed several of the tasks necessary to provide a road-ready SOFC APU and completed a demonstration test.
- Completed SOFC APU system integration into the truck including mounting APU controls in the sleeper and adding data logging systems to the vehicle (Figure 3).
- Completed vehicle demonstration testing with the APU operating in a typical driver usage scenario by providing power for rest stops and overnight cabin comfort/power demands. Figure 4 shows the power output of the APU during a 24-hour period from the demonstration test, which included APU start-up while driving and 17 hours of providing auxiliary power during a typical overnight resting period.

FIGURE 3. "In-Cab" APU Control Interface

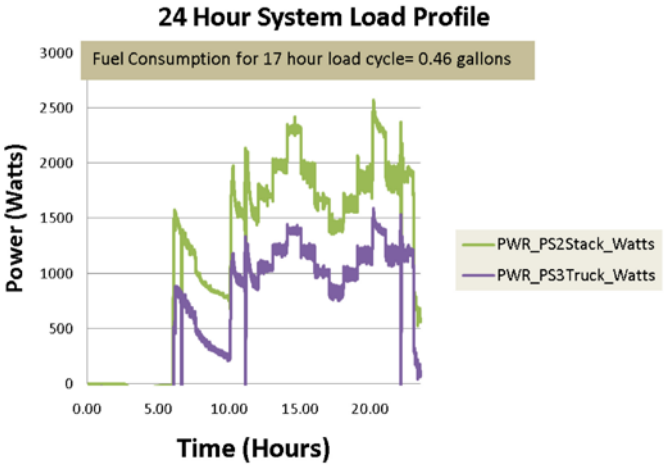

FIGURE 4. Demonstration Data

CONCLUSIONS AND FUTURE DIRECTIONS

Delphi demonstrated the potential of the SOFC APU as an anti-idle solution for truck manufacturers and their fleet owners and completed this project. While feedback for the technology was positive, significant commercial pull driven by anti-idling regulations, is still lacking. Delphi is currently putting the developed APU technology on the shelf, and will continue to develop its SOFC stack for other applications.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. 2012/964806 Published: Combustor for a Fuel Cell System

2. 2013/152533 Pending: Fuel Reformer reactor without intersecting flow paths

3. 2013/363760 Pending: Heat Exchanger Reformer with Thermal Expansion Management

4. 2013/713039 Pending: Fuel Reformer with Thermal Management

5. 2013/527631 Pending: Multi-Fuel Combustor with Swirl Flame Stabilization

6. 2013/711834 Pending: Fuel Reformer Catalyst Arrangement

FY 2013 PUBLICATIONS/PRESENTATIONS

1. May 2013 DOE Hydrogen Program Peer Review Presentation: "Solid Oxide Fuel Cell Diesel Auxiliary Power Unit", Dan Hennessy.