III.3 Solid State Energy Conversion Alliance Delphi SOFC

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- Electricore, Inc., Valencia, CA
- United Technologies Research Center, East Hartford, CT

Objectives

- Develop a 3-5 kW solid oxide fuel cell (SOFC) power system for a range of fuels and applications (see Figure 1).
- Develop and demonstrate technology transfer efforts on a 3-5 kW stationary distributed power generation system that incorporates reforming of methane and then natural gas.
- Develop a 3-5 kW auxiliary power unit (APU) for heavy-duty trucks and military power applications.
- Develop system modeling, stack design and cell evaluation for a high-efficiency coal-based solid oxide fuel cell gas turbine hybrid system.

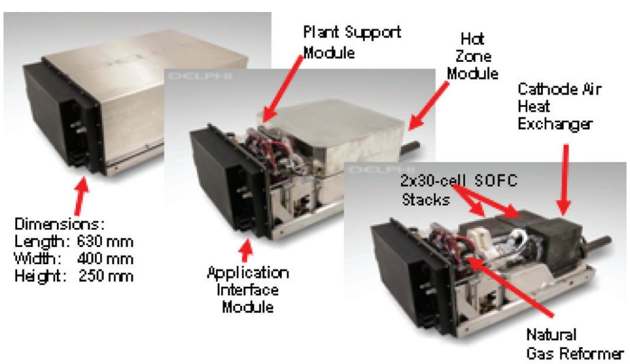

FIGURE 1. Generation 3 SOFC System

Accomplishments

Systems

- A Delphi SOFC system durability test was conducted using utility-supplied natural gas and a TDA Research Inc. sorbent desulfurizer. This system logged over 2,400 hours of testing with a stack degradation rate of less than 1% per 500 hours.
- A Delphi SOFC system was run to full power, and it produced 2.2 kW net and 36% efficiency on methane with full internal reforming. This system was then run for 470 hours at high load (50 amps, 1,800 W net) with 75% internal reforming. The measured degradation on the stacks was 1.1% per 500 hours.

Stack

- Generation 3.2 cassettes were successfully fabricated. Based on the experience gained by producing Generation 3.1 cassettes, the new design was developed to reduce stresses within the cassette, allowing for a more robust cassette.
- An improved cassette-to-cassette seal was developed. Current seals allow only 5 thermal cycles per stack. A new seal was developed that demonstrated 16 thermal cycles in the stack lab without leaks or degradation in power.
- A low-cost coating solution (coupon level test) for interconnects was demonstrated. A new coating was developed which has low resistivity, blocks Cr effectively and, most importantly, can be processed by high-volume manufacturing processes. This will allow for a cost-effective solution for coatings for interconnects.
- An effort is underway to design, develop and fabricate large-footprint cells to enable the eventual design of a MW-class coal-based solid oxide fuel cell gas turbine hybrid system.

Reformer/Catalyst

- An endothermic reformer design was modified for use with US07 diesel fuel and evaluated with recycle-based reforming. The benefit of this type of reforming is the recovery of unspent fuel energy in the anode tail gas.
- A liquid fuel vaporizer was developed to vaporize US07 diesel fuel and demonstrated durability to 500 hours. This is a key development for designing a diesel fuel delivery and catalyst system.

- Natural gas pre-reforming has been demonstrated with ~100% conversion of higher hydrocarbons and no selectivity to ethylene formation, yielding a high-methane-content product suitable for use in internal reforming.
- An improved surface- and gas-phase chemical reaction rate model has enabled chemical kinetics modeling to accurately predict experimental observations of partial oxidation reactions.

Balance-of-Plant

- The cast integrated component manifold (ICM) tooling fabrication and casting process development was completed with the supplier, and three upper and lower ICM manifolds were successfully completed. This will enable high-volume, low-cost manufacturing.
- A test was developed and implemented for studying Cr vaporization in balance-of-plant components. This will enable Delphi to determine the level of chromium being released from completed assemblies and thereby understand the system degradation mechanism.

Introduction

Delphi has been developing SOFC systems since 1999. After demonstrating its first-generation SOFC power system in 2001, Delphi teamed with Battelle under the Solid State Energy Conversion Alliance (SECA) program to improve the basic cell and stack technology, while Delphi developed the system integration, system packaging and assembly, heat exchanger, fuel reformer, and power conditioning and control electronics, along with other component technologies. Compared to its first-generation system in 2001, the Delphi-led team has reduced system volume and mass by 75 percent. By January 2005, the Delphi team was able to demonstrate test cells with power density greater than that required to meet the SECA 2011 goals.

In addition to its compactness, another key advantage of the SOFC is its high system fuel efficiency, particularly when its high-temperature co-product heat can be used in combination with its electrical output. For example, SOFCs can be teamed with gas turbines driven by the SOFC's co-product heat to potentially generate power at 55 percent to 80 percent thermal efficiency (depending on scale and fuel used). This is significantly more efficient than today's typical coal-fueled power plant, which has a thermal efficiency of 35 percent to 40 percent. By co-generating power on-site at industrial facilities, commercial businesses, or even residences, the SOFC's high-grade co-product heat will enable up to 90 percent efficiency in distributed, combined heat and electrical power generation. Similarly, heavy-duty trucks will be able to utilize SOFC auxiliary power systems for both heat and electrical power when parked to save 85 percent of the fuel that they consume when idling the main engine, and likewise reduce idling emissions.

While size and efficiency advantages are important for many potential applications, the SOFC's most significant advantage overall is its very broad applicability due to its inherent fuel-flexibility. With relatively small changes, SOFC systems can potentially operate on a full range of conventional and alternative fuels. This includes natural gas and conventional petroleum-based fuels like low-sulfur gasoline, diesel and propane; high-sulfur military fuels like JP-8 and jet fuel; low-CO_2 renewable fuels from biomass like ethanol, methanol and bio-diesel; synthetic fuels from coal and natural gas; and non-hydrocarbon fuels such as hydrogen and ammonia.

Approach

Delphi utilized a staged approach to develop a modular SOFC system for a range of fuels and applications.

- Develop and test major subsystems and individual components as building blocks for applications in targeted markets.
- Integrate major subsystems and individual components into a "close-coupled" architecture for integrated bench testing.
- Integrate major subsystems and individual components into a stationary power unit for the stationary market.
- Integrate major subsystems and individual components into an APU for the transportation market.
- Leverage previous work for modeling of a MW-scale hybrid power system and development of a hybrid stack module that can operate on simulated coal gas.

Results

SECA Phase II is a continuation of the core hardware development activities begun in Phase I. The systems efforts in Phase II are more application-driven as Delphi moves this technology closer to pilot and production releases. The Phase II project will support and address two market opportunities. The stationary market and the transportation market have unique demands, and development tasks must address specific values that are economic drivers of the design and application.

Delphi has continued to build and test 30-cell Gen 3.1 stack modules. Key lessons have been learned from the performance of these modules and their post-test autopsy analysis. The Gen 3.2 design is complete, and prototype parts are being validated. Fundamental development has focused on low-cost coatings for interconnects, robust seals, sulfur-tolerant anodes and understanding the failure mechanisms within the cell and stack during thermal cycling and long-term continuous durability tests. Process development and improvements include development of more robust and cost-effective formulations and processes for cell manufacturing, and optimization of cassette fabrication and stack assembly processes to improve first-time quality of stacks.

Focused work on diesel (US07) endothermic reforming was conducted this period. The benefit of anode tail recycle as a reactant to diminish inlet coking was demonstrated. A comprehensive comparison of non contact vaporizer versus contact vaporizer was conducted. The endothermic tubular reactor continues to be evaluated. Initial enthalpy balances and heat exchange analysis revealed areas for improvement in heat management. These deficiencies are being addressed via a brazed core design and a more substantial re-design for the next-generation endothermic reactor. A natural gas cracking reactor has been developed to crack or reform C2s to make possible the benefits of internal reforming of natural gas.

A new six-valve process air module assembly was designed, fabricated and assembled along with new modular control valve blocks. Cast Inconel ICMs were received from the supplier, and process development for brazing the castings has been initiated. Recycle pump robustness has been improved by re-orienting the pump, changing pump bearings, and modifying a recycle cooler. Prototype natural gas desulfurizers were specified, purchased, and placed on test. This completed one of the Phase II milestones: running a system on line natural gas. A designed experiment/robust engineering test of sorbents for a hot reformate desulfurizer continued and resulted in sorbent selection for a non-regenerating desulfurizer.

A system study was initiated to investigate SOFC system configurations utilizing gasified coal and to evaluate a modified Delphi SOFC cell. The primary objective of the system study is to formulate highly efficient SOFC-based hybrid system configurations and establish an optimized conceptual design of the SOFC stack and stack-module. The objective of the cell evaluation effort is to determine the compatibility between Delphi's cell and a modified stack design, identifying gaps between the current Delphi cell technology and the stack requirements for a MW-scale hybrid power system.

Conclusions

- Delphi's Phase II SECA project is focused on two markets, stationary and transportation, with additional emphasis on developing the system and stack requirements for a coal-gas-based MW-scale hybrid power system.
- Product and process improvements were initiated for the current Gen 3 stack design with the initial requirements and development for the next-generation stack design.
- A tubular diesel endothermic reformer was initiated and developed. In addition, a natural gas cracking reactor was developed.
- A cast Inconel integrated component manifold was developed and fabricated. A natural gas desulfurizer was specified, purchased, and validated in an SOFC stationary power unit system. Engineering began on a hot reformate desulfurizer.

Future Directions

- Demonstrate SOFC system on varying loads using the natural gas-fueled APU during Q4 2007.
- Demonstrate the next-generation stack during Q4 2007.
- Design and release the next-generation SOFC system during Q1 2008.
- Complete initial test on next-generation SOFC system during Q3 2008.

FY 2007 Publications/Presentations

1. September 2006: SECA Core Technology Workshop and Peer Review, Philadelphia, PA: Presentation by Steven Shaffer, Delphi Corporation, "Development Update on Delphi's Solid Oxide Fuel Cell System".

2. November 2006: 2006 Fuel Cell Seminar in Honolulu, HI: Presentation by Steven Shaffer, Delphi Corporation, "Update on Delphi's Development of a SOFC Power System".

Special Recognitions & Awards/Patents Issued

1. US Patent Office Grant Numbers: 7094486, 7144644, 7147953, 7179558, 7201984, 7217300.