V.I.9 Biogas-Fueled Solid Oxide Fuel Cell Stack*

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*Congressionally directed project

Objectives

The objective of this project is to develop and demonstrate a 400 Watt solid oxide fuel cell (SOFC) stack and evaluate its performance on hydrogen and biogas:

- Cost-effective SOFC manufacturing.
- Electric power generation from different biogas compositions.
- 400 Watt stack design and build.
- Demonstrate 400 W of power output on hydrogen and biogas.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability
(B) Cost
(C) Performance

Technical Targets

This project focuses on maximizing the production efficiency, while at the same time increasing the reliability and reproducibility of the SOFCs. The focus of development efforts will be to optimize the catalytic materials and operating conditions that will be utilized in the construction and evaluation of a 400 W_e stack with a power density of 0.35 W/cm^2.

- Fabricate 150 single cells with a minimum power of 10 Watts and a power density of 0.35 W/cm^2 on hydrogen at 800°C.
- Optimize the fabrication process to achieve a cell production yield of at least 70%.
- Optimize cell operating conditions for biogas (fuel flow rate, feed gas composition, temperature) to achieve maximum power.
- 200-thermal cycling test on single cell.
- 500-hour endurance test on single cell using biogas.
- 400 W stack design that will allow for modular integration in to kilowatt-class applications.
- 400 Watt stack test with hydrogen and biogas at varied compositions.

Accomplishments

- Achieved cell fabrication yields above 60% associated with a 50% reduction in cell cost and 58% reduction in processing time.
- Cell materials have been optimized for obtaining desired microstructure and composition yielding higher power output.
- Achieved >525 mW_e/cm^2 producing >9.5 W_e on biogas.
- Operated the cell for >200 thermal cycles.
- Achieved stable power output for >500 hours on biogas.
- Designed a single module stack that has been successfully tested on biogas.

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Introduction

Increased demand for fossil fuels is imposing massive impact on the environment and also leading to unprecedented fuel prices. Efficient power conversion technologies that utilize secure renewable energy are urgently needed. High-efficiency clean energy technologies such as SOFCs have shown great potential to reduce carbon emissions, reduce the nation's dependence on petroleum-based fuels, and utilize a wide range of fuel resources including biomass gas.

The scope of this project is to develop and demonstrate a 400 Watt stack using advanced SOFC technologies. The stack will employ single fuel cells manufactured by a cost-effective manufacturing approach that is suitable for scaling to larger systems. In addition to hydrogen fuel, the stack will be operated on biogas.

Approach

To achieve the project objectives, novel cell fabrication route will be implemented and optimized for materials and cell microstructure. This new fabrication process will enable quick turnover of the cells with reliable and efficient performance in addition to reduced costs associated with both materials and labor.

The cells are designed to: (1) operate on both hydrogen and biogas (methane + carbon dioxide) with an integrated catalytic layer to perform fuel processing; (2) withstand >200 thermal cycles from 200-800°C; and (3) provide stable performance for >500 hours on biogas fuel. All these properties will be enabled by a careful selection and consideration of conductivity, chemical stability, thermal expansion coefficient mismatch, physical stability, and activity of the fuel cell materials.

A 400 W stack will be designed, constructed and tested utilizing the cells produced by the above process. The stack feasibility test will involve power generation via hydrogen and biogas at different compositions.

Results

One of the prime objectives was to achieve high power densities at higher power output. The fabrication process was optimized to obtain the desired microstructure by considering the material combinations, process conditions, physical and chemical stability, thermal and electrical conductivity, and thermal expansion coefficient of the materials. Optimization of the SOFC materials resulted in improved power output, manufacturing yield, and decreased processing time. Processing times have been decreased by 58% compared to the extrusion process.

Figure 1 shows a comparison of gravimetric and volumetric power densities of different cell technologies. The cells made with the new fabrication process and optimized material set outperformed the ones that were made with conventional process, demonstrating a three-fold increase in the performance by packing more power per unit mass, volume and specific surface area. These higher power densities were made possible by optimizing the anode and cathode materials/process to obtain a porous structure for lowering the mass transfer resistance.

In addition, these cells demonstrated very high electric efficiency (electric power produced vs. fuel's energy value) and fuel utilization because of the enhanced microstructure. Experiments were conducted to find out the effect of fuel flow rate on the power output and efficiency of the cell. The cells utilized in

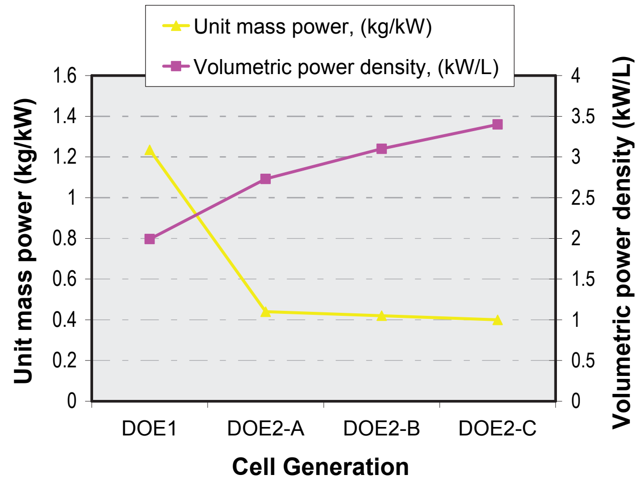

FIGURE 1. Power Density Comparison of Different Cell Technologies

the previous phase of this project showed a significant decrease in power output at lower flow rates. However, the newer SOFCs utilized under the current project showed relatively little decrease in power inspite of 40% drop in the fuel supplied. This translates to a higher overall efficiency, as shown in Figure 2, the cell power reaches as high as 9 watts at 50% electric efficiency and 12 Watts at 37% efficiency. These cells also showed very high performance even at lower operating temperatures, where the cell produced 83% of the peak power at 700°C compared to its peak operating temperature of 800°C.

One of the major considerations in utilizing biogas for an SOFC system is its composition, which depends entirely upon the raw material fed into the decomposition unit processors, such that the fuel composition would be unique to each processing facility. In order to develop a biogas-fed SOFC, the cells must have a high performance over a wide range of biogas compositions. An experiment was hence conducted by feeding biogas containing same energy value (lower heating value of methane) with different concentrations viz. 60%, 50% and 40% of methane and a balance of carbon dioxide resulting in rich, equimolar and poor quality feed streams that is typical of different waste treatment plants. The power output varied by ~5.5% as the gas quality changed from rich to poor quality. This is a direct result of the oxidant concentration in the feed stream which in turn affects the amount of electrochemically oxidizable species.

Similar to the hydrogen performance, the cell's efficiency to convert the available energy of biogas in to electricity increased at lower flow rates, reaching up to 40% while producing >8 Watts of electric power (Figure 3). It has to be noted that the tests were performed by flowing the feed through an SOFC in a single pass. This efficiency can be further improved on a stack scale by recycling some of the exhaust. For a

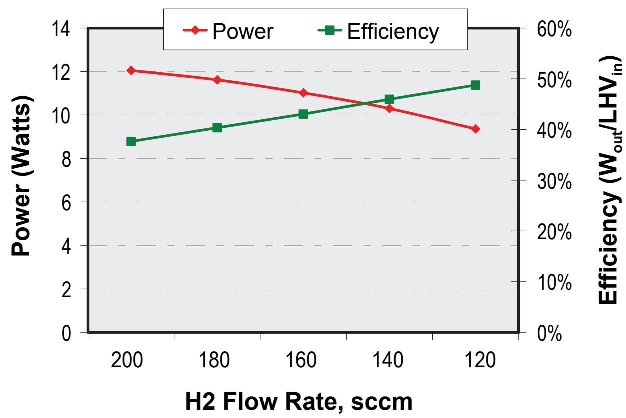

FIGURE 2. Effect of Fuel Flow Rate on Power Output and Efficiency of the Modified SOFC

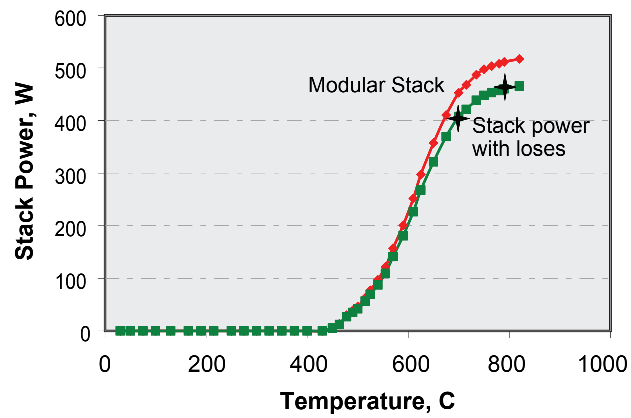

FIGURE 4. Estimated Power Output from the SOFC Stack as a Function of Operating Temperature on Biogas Fuel

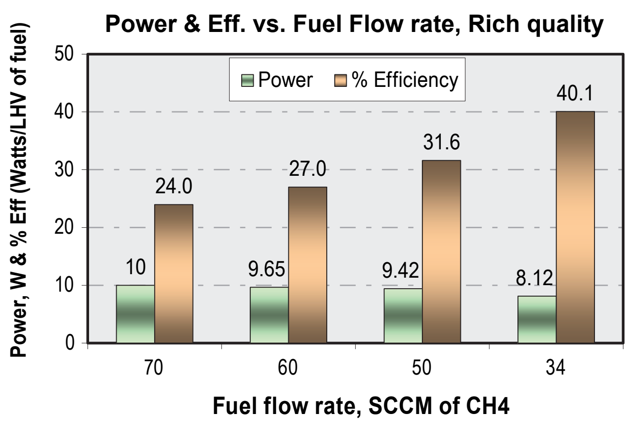

FIGURE 3. Effect of Rich-Quality Biogas Flow Rate on Power Output and Electric Efficiency of a SOFC Operated at 800°C

portable system, efficiencies above 40% are considered to be a significant achievement.

All of the above results show excellent performance of the SOFC at wide range of operating conditions producing 8-12 Watts of electric power depending on the fuel type and flow rate. It is important that these cells demonstrate stable performance with time especially under the conditions of direct internal reforming of the biogas fuel via dry reforming. For this purpose, a long-term test was conducted to find out the SOFC's stability by supplying rich-quality biogas while the cell was maintained at 800°C. Total power remained stable over a period of 525 hours, clearly demonstrating the stable performance of the advanced SOFC technology.

The total power output from a stack containing multiple number of cells was extrapolated based on the power output measured from a single cell. However, typical stack construction will usually result in ~10% lower power due to the losses associated with series connections between the SOFCs in addition to thermal and flow gradient throughout the volume of the stack. Figure 4 shows this projected power output along with the expected power after losses. The red line represents the projected power output from the stack as a function of temperature after extrapolating from a single cell measurement. The expected power output after losses is shown as a green line in the same plot. Based on these observations, it is possible to achieve 400+W at temperatures above 700°C and at a power density of >500 mW/cm^2 while supplied with biogas fuel at different compositions.

Conclusions and Future Directions

A new SOFC fabrication route was successfully implemented. This process offers numerous benefits over conventional methods: cost-effective; automated; light-weight fuel cells; and high energy efficiency.

- SOFCs with high volumetric (3.4 kW/liter), gravimetric (2.56 kW/kg) and specific power densities (0.63 W/cm^2) were fabricated and tested on hydrogen and biogas.
- SOFCs demonstrated up to 50% and 40% electrical efficiencies on hydrogen and biogas, respectively.
- Different biogas compositions were evaluated on the multi-layer SOFC via internal reforming at temperatures of 700-800°C.
- SOFCs demonstrated good resistance to thermal shock, thermal cycling and showed stable performance for >500 hours of continuous operation on biogas.

The major focus for the remainder of the project will involve design, construction and evaluation of a 400 W stack on both hydrogen and biogas. All of the reporting obligations, most notably the final report, will be fulfilled.

FY 2009 Publications/Presentations

1. P.K. Cheekatamarla and C.M. Finnerty, "Biogas Fueled Solid Oxide Fuel Cell Stack" presented at the 2009 DOE Hydrogen Program Annual Merit Review and Peer Evaluation Meeting, VA, May 22, 2009. Presentation: fc_49.