V.J.4 Power Generation from an Integrated Biomass Reformer and Solid Oxide Fuel Cell (SBIR Phase III)

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Fiscal Year (FY) 2012 Objectives

- Establish the requirements and design for an integrated fuel cell and fuel processor that will meet the technical and operational needs for distributed energy production.
- Develop and integrate key system components – including the fuel cell stack, fuel processor, water management, thermal management, burner, air handling, control system and software.
- Demonstrate that component and mechanical design for the proposed energy system proves the technical and commercial potential of the technology for energy production, emissions, and process economics.

Technical Barriers

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

(A) Reformer Capital Costs
(B) Reformer Manufacturing
(C) Operation and Maintenance
(D) Feedstock Issues
(E) Greenhouse Gas Emissions
(F) Control and Safety

Technical Targets

InnovaTek's research plan addresses several DOE technical targets for stationary applications for fuel cell power systems. DOE has also established technical targets for integrated stationary fuel cell power systems operating on natural gas [1]. Progress in meeting DOE's technical targets is provided in Table 1. Although the InnovaTek system was developed for use with multiple fuel types including liquid bio-fuels as well as natural gas, our research plan is addressing the same characteristics for energy efficiency and cost identified in DOE's targets.

TABLE 1. Progress toward Meeting Technical Targets for Integrated Stationary Fuel Cell Power Systems Operating on Reformate[a]

Characteristic	Units	2015 Target[c]	InnovaTek 2012 Status[d]
Electrical Energy Efficiency[b] @ rated power	%	42.5	40
Equipment Cost, 5-kW system	$/kW$_e$	1,700	3,500

[a] Includes fuel processor, stack, and all ancillaries
[b] Regulated alternating current net/lower heating value of fuel
[c] For a fuel cell system using natural gas as fuel
[d] For a solid oxide fuel cell and fuel reformer system using bio-kerosene as fuel

FY 2012 Accomplishments

- Developed system design to meet safety codes and standards for a fuel cell distributed energy system.
- Completed simulation and modeling studies to develop superior component/system designs.
- Developed optimized catalysts for liquid biofuel reforming.
- Fabricated and integrated proprietary system hardware, software, and catalysts.
- Demonstrated 1.2 kW power production from bio-kerosene and sent power to grid.
- Began Design for Manufacturing and Assembly (DFMA®) analyses to reduce system complexity and costs.
- Supported five students and developed partnerships with the Pacific Northwest National Laborator, Washington State University, Boeing, City of Richland, Impact Washington, and the Mid-Columbia Energy Initiative.

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Introduction

Alternative energy sources must be sought to meet energy demand for our growing economy and to improve energy security while reducing environmental impacts. Power generation from biomass, along with solar energy, wind energy, nuclear energy, geothermal energy, and others will inevitably be the ingredients of our future energy mix [2]. In addition to facilitating the use of a renewable fuel source, cost and durability are among the most significant challenges to achieving clean, reliable, cost-effective fuel cell systems. Therefore this project is focusing on lowering the cost and increasing the durability of a fuel cell distributed renewable energy system, while also assuring that its performance meets or exceeds that of competing technologies. Work was performed to develop proprietary steam reforming technology that will make it possible to use multiple fuel types, including renewable liquid bio-fuels, with a solid oxide fuel cell (SOFC). A highly efficient integrated system design with an SOFC was developed that reduces the loss of heat through an effective thermal design and the use of micro-channel heat exchangers. Modeling and simulations were completed to produce designs for prototype components and to analyze process flow for alternative system configurations. Design alternatives were compared and an integrated system design was fabricated and tested during this period. A major effort to reduce system complexity and cost was initiated using DFMA (design for manufacturing and assembly) software tools.

Approach

The technological approach utilizes a steam reforming reactor to convert bio-fuel derived from residual biomass to hydrogen-rich reformate that fuels an integrated SOFC for power generation. The project will evolve through three developmental stages. Meeting DOE targets for system performance, cost, and durability will be emphasized at each stage.

- Optimization of SOFC and fuel processor integration – is completed using process simulation and analysis to optimize system design and produce a complete mass and energy balance for individual components of the system. Process flow and piping and instrumentation diagrams are prepared to analyze possible system configurations using MathCAD® and FEMLAB® models to simulate the process flow paths in the system.
- Design for manufacturing and field operation – requires continued modeling and analysis such as failure modes and effects analysis, DFMA® and several iterations of component builds and tests to compare design options. The dimensions, geometries and flow patterns defined from optimization modeling work completed in stage 1 are translated into three-dimensional computer-aided design (CAD) images and drawings.
- System demonstration and validation for commercial applications – takes place after down-selection of the final design. Several complete systems will be built to meet the required codes and standards for demonstration at a field site to gain performance data necessary to validate the design and operation of the system. Requirements validation and routine tests will be performed before and during the demonstration, and system durability will be assessed.

Results

System Design and Fabrication

Our design objective for the integrated fuel processing and fuel cell system is to optimize the product design with the production system which includes suppliers, material handling systems, manufacturing processes, labor force capabilities and distribution systems. Design alternatives were evaluated and design tools were used to develop a more mature and producible design before final design selection. Manufacturability and integrated product development concepts were used to achieve cost and performance targets for a pre-commercial fuel cell energy system design. During the design process there was also a primary focus on addressing safety issues, in particular the potential fire hazards from leaking liquid fuel and hydrogen-rich gas.

Various design concept alternatives were evaluated against design for manufacturing objectives to help reduce both capital equipment costs and maintenance cost while increasing lifetime and robustness. CAD was used to aid in cost effectively developing and analyzing design alternatives. All drawings, specifications, and price quotes were consolidated for subsystem components along with the specifications developed. This information formed the detailed design package for building a prototype system. A list was prepared for all fabricated parts and components supplied by vendors. Critical specifications, including materials, welds, and tolerances, were described for each part.

The component list was used to prepare a bill of materials for all subsystems of the fuel cell power plant. The bill of materials was used to obtain cost estimates from potential vendors and fabricators. Requests for quotations were sent for all fabricated parts such as the reformer, heat exchangers, burner, and condenser, while pricing comparisons were made for manufacturer items. Suppliers were down-selected based on pricing and quality of products.

Significant cost reductions were realized for many of the fuel processor components compared to previous designs that were completed during Phase II. For example, the design for the catalytic reforming reactor was simplified, resulting in lower materials and fabrication costs. A total cost reduction of 47% was achieved (Figure 1). The cost of the air recuperator was reduced by about half because we found an

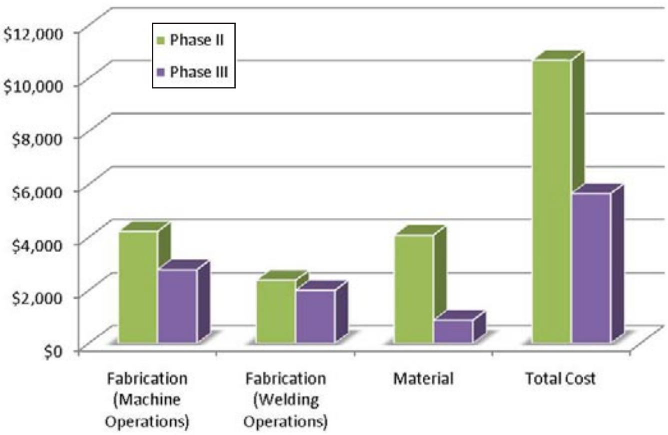

FIGURE 1. Phase III fuel processor reformer costs for materials and fabrication compared to Phase II

FIGURE 2. InnovaTek proprietary hydrogen burner components

FIGURE 3. InnovaTek proprietary catalytic steam reforming reactor

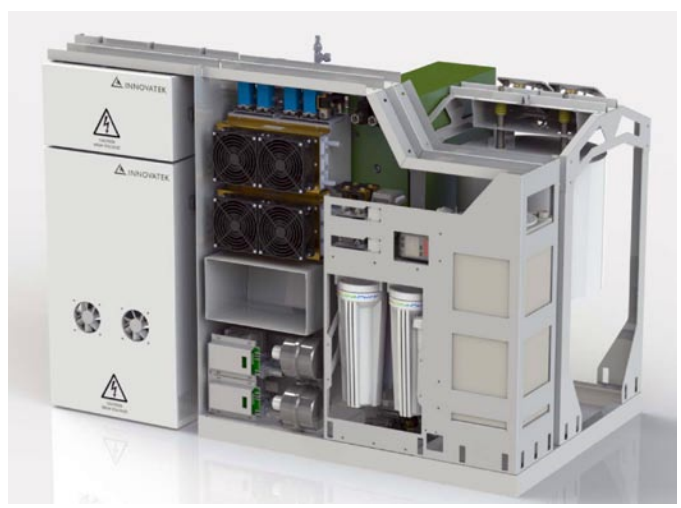

FIGURE 4. Fully integrated InnovaGen Power System that produces 1-3 kW power from liquid bio-fuel

original equipment manufacturer substitute for one that had previously been fabricated by InnovaTek.

Purchase orders were prepared for all materials and components required for the system, and fabrication of proprietary components was completed. A photo of the burner components is provided in Figure 2 and the catalytic reforming reactor in Figure 3. In addition to the hardware, the catalysts for the system were manufactured at InnovaTek's catalyst development lab. All subcomponents, including the SOFC manufactured by Topsoe, were assembled into an integrated system using the CAD model we developed for an optimized integration scheme (Figure 4).

System Test

Initial testing of the integrated fuel cell system successfully achieved 1.2 kW net power production and a major milestone was achieved when full water neutrality was demonstrated during operation on bio-kerosene. The important goal of optimized thermal management was also achieved when the heat requirement for the reformer was fully met by recycling anode off-gas from the fuel cell to the burner in the reformer.

Conclusions and Future Directions

- Test results from InnovaTek's prototype technology indicate that a fuel cell distributed energy system that operates on renewable, non-food bio-kerosene is possible through integration of InnovaTek's steam reforming technology and a SOFC.
- On the basis of careful systems modeling and component integration using CAD and thermal systems design with micro-channel heat exchangers, an overall system electrical efficiency of 40% is possible.
- Results from prototype testing will be used to optimize the design for field-ready systems to be constructed and demonstrated in the City of Richland Renewable Energy Park where they will be tied to the electric utility grid.
- DFMA® analyses and demonstration results will be used to determine whether system cost, performance, and durability targets for a commercially viable system can be met.

FY 2012 Publications/Presentations

1. Irving, P.M., Q. Ming, and P. Griffin; Distributed Power Generation from a Bio-Oil Reformer and Solid Oxide Fuel Cell; oral presentation, Fuel Cell Seminar, November 2011.

2. Griffin, P. Design Optimization and Validation of Fuel Processing Systems Using CFD and FEA Simulators; poster presentation, Fuel Cell Seminar, November 2011.

References

1. Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan, U.S. Department of Energy, 2011. http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/

2. Duane B. Myers, Gregory D. Ariff, Reed C. Kuhn, and Brian D. James; Hydrogen from Renewable energy sources: Pathway to 10 quads for transportation uses in 2030 to 2050. Hydrogen, Fuel Cells, and Infrastructure Technologies, 2003 DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Progress Report.