V.K.1 Power Generation from an Integrated Biomass Reformer and Solid Oxide Fuel Cell (SBIR Phase III)

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Overall Objectives

- Establish design to meet technical and operational needs for distributed energy production from renewable fuels
- Design, optimize, and integrate proprietary system components and balance of plant in a highly efficient system
- Demonstrate the technical and commercial potential of the technology for energy production, emissions reduction, and process economics

Fiscal Year 2014 Objectives

- Achieve 40% system operating efficiency with revised/optimized system design
- System performance proves superior energy efficiency and emissions reductions compared to conventional technology
- Analysis of process economics supports commercial feasibility

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the DOE Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) Durability

(B) Cost

(C) Performance

Technical Targets

InnovaTek's research plan addresses several DOE technical targets for stationary applications for 1-10 kW_e fuel cell power systems operating on natural gas [1]. Progress in meeting DOE's technical targets is provided in Table 1.

TABLE 1. Progress toward Meeting Technical Targets for Integrated Stationary 5-kW Fuel Cell Power Systems Operating on Reformate[a] from Bio-Derived Renewable Liquids

Characteristic	Units	2015 Target[c]	2020 Target	InnovaTek 2014 Status[d]
Electrical Energy Efficiency[b] @ rated power	%	42.5	>45%	42
Equipment Cost, 5-kW system	$/kW$_e$	1,700	1,500	1,722
Operating Lifetime	hr	40,000	60,000	1,000+
Start-up Time at 20°C ambient	min	30	20	10

[a] Includes fuel processor, stack, and all ancillaries.
[b] Regulated AC net/lower heating value of fuel
[c] For a fuel cell system using natural gas as fuel
[d] For a solid oxide fuel cell (SOFC) and fuel reformer system using bio-kerosene as fuel. InnovaTek lifetime test limited to 1,000 hours. Start-up time is for reformer only.

FY 2014 Accomplishments

- Completed design innovations to improve equipment lifetime, efficiency, and cost objectives.
- A heat exchanger was added to the distributed power generator as an option to increase efficiency and expand commercial applications.
- Manufactured a highly efficient 2.6-kW fuel processor for producing 22,776 kWh/yr of distributed power with a SOFC operating on natural gas or liquid biofuel.
- Manufactured critical parts using three-dimensional printing, an additive manufacturing approach that helps reduce equipment costs.
- Obtained 42% system efficiency.
- Completed analyses using the HOMER model and determined that cost of power using InnovaTek's technology operating on natural gas is competitive with current power prices.
- Completed initial system testing that confirms operational performance and began long-term performance evaluation.
- Supported two students and continued partnerships with Pacific Northwest National Laboratory, Washington

State University, Boeing, City of Richland, Impact Washington, Breakthrough Technologies Institute, 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. 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 conducted to develop proprietary steam reforming technology that uses multiple fuel types, including renewable liquid bio-fuels, and to integrate the reformer with a SOFC. A highly efficient integrated system design with an SOFC was developed that reduces the loss of heat through effective thermal management. A third generation optimized system design was completed, components were fabricated, and a prototype 2.6-kW fuel processor was assembled and tested during this period to determine costs and performance.

APPROACH

The technological approach utilizes a steam reforming reactor to convert bio-fuel derived from lignocellulosic biomass to hydrogen rich reformate that fuels an integrated solid oxide fuel cell for power generation. The project has evolved through three developmental stages.

1. 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.
2. Design for manufacturing and field operation – requires continued modeling and analysis such as failure modes and effects analysis and Design for Manufacturing and Assembly (DFMA®) and several iterations of component manufacturing 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.
3. System demonstration and validation for commercial applications – is the current and final stage of the project. Two complete systems have been manufactured for demonstration to gain performance data necessary to validate the design, operation, and cost of the system.

RESULTS

System Design and Fabrication

The system design produced in 2013 was further optimized in 2014 using manufacturability and integrated product development concepts to achieve cost and performance targets for a pre-commercial fuel cell energy system. Various design concept alternatives were evaluated against DFMA® objectives to help reduce both capital equipment costs and maintenance cost while increasing lifetime and robustness. CAD and computational fluid dynamics modeling was used for cost effective development and analysis of design alternatives (Figure 1). 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 bill of materials was prepared for all subsystems of the fuel cell power plant. This was used to obtain cost estimates for prototype fabrication and for volume production from potential vendors and fabricators. Suppliers were down-selected based on pricing and quality of products. A solid model of the integrated system was prepared (Figure 2) and used as a guide for system assembly. Compared to the 2012

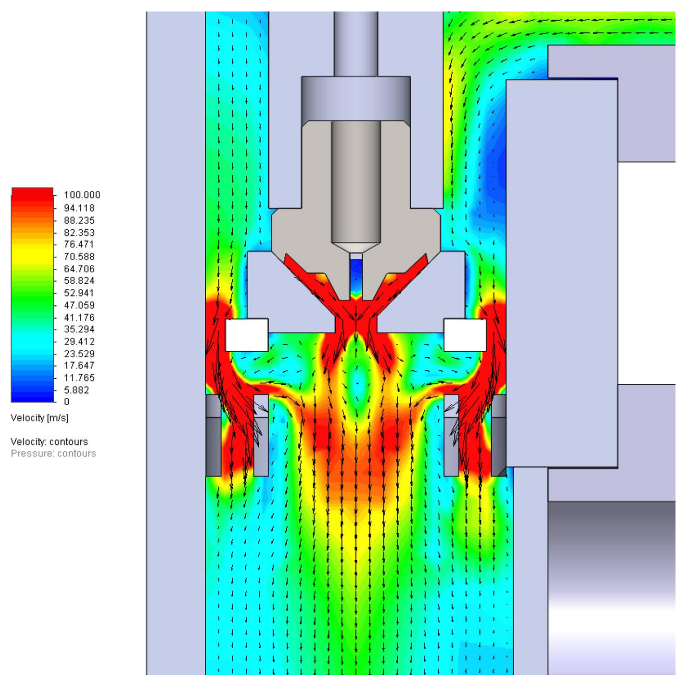

FIGURE 1. Computational fluid dynamics model results illustrating velocity and trajectory in InnovaTek's proprietary fuel injector/mixer.

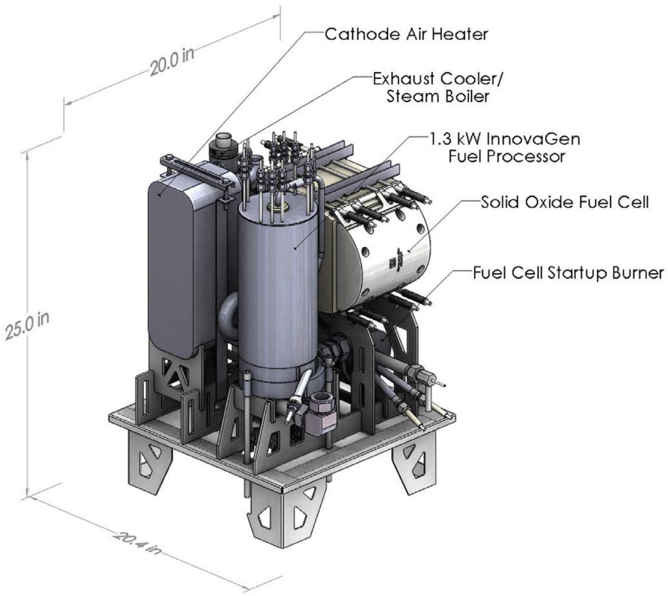

FIGURE 2. Solid model used for assembly of fuel cell power system components.

fuel processor prototype, part count was reduced by 63% and cost was reduced by 51% (Table 2).

Some of the critical parts for the system were manufactured using Direct Metal Laser Sintering and a three-dimensional printing process that fuses high-temperature metal powder. This process produces prototypes quickly and less expensively, thereby reducing non-recurring engineering costs. It also allows the creation of component geometries that cannot be prototyped by any other means.

TABLE 2. Fuel Processor Volume, Part and Cost Reduction

Prototype System	Number of Parts	Approx Volume (L)	Manufactured Cost[1] ($/kW)
2012	159	37.8	3,489
2013	66	11.3	2,388
2014	59	4.8	1,722

[1] Assumes production volume of 50,000 units/year

System efficiency, estimated at 42% (from 37.5% in 2012), was improved as a result of increased stack electrical efficiency, lower parasitic power due to lower stack pressure drop, less waste heat loss through improved thermal integration and heat transfer, and higher methane content in the reformate which reduced stack cooling needs.

Performance Testing

Initial performance of two manufactured prototype fuel processing systems was successful in producing hydrogen for 2.6-kW net power production in each system. In one of the prototypes an advanced catalyst structure was incorporated to improve heat and mass transfer. Performance test results indicate that the system with the structured catalyst starts up more rapidly, reforms efficiently at a significantly lower temperature, and produces more hydrogen per unit volume of fuel than the system with the pellet catalyst. These factors will improve system efficiency and lifetime. Several hundred hours of testing has been completed and longer term testing is continuing in order to determine durability and maintenance interval.

Cost Analysis

The HOMER model was used with data from our manufacturing cost analysis and system performance determinations to estimate cost of power using our technology. The results of these analyses indicate that the cost of power using InnovaTek 5-kW fuel cell generator operating on natural gas would be competitive at $0.096/kWh when volume production brings capital costs down.

CONCLUSIONS AND FUTURE DIRECTIONS

- On the basis of careful systems modeling and component integration using computer-aided design and thermal systems design an overall system electrical efficiency of about 42% is possible for InnovaTek's 5-kW distributed power system operating on natural gas or liquid biofuels.
- An optimized field-ready prototype system has been manufactured and is undergoing long-term durability and performance testing.
- Although an economic analysis indicates that cost of power from the 5-kW fuel cell distributed power system would be competitive, until there is a large scale market for small residential distributed energy, the technology is not economically viable.
- Therefore, early markets for auxiliary power units for trucks, marine systems, and military systems are being pursued.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. Ming, Q., and Irving, P.M., The Role of the Fuel Cell System in Sustainable Power Generation, IEEE Conference on Technologies for Sustainability, Portland, OR, 1-2 August 2013.

2. Irving, P.M., Hybrid Power System for Sustainable Energy Production, oral presentation, DOE Clean Energy Technology Showcase, Stanford University, 15 April 2014.

REFERENCES

1. Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan, U.S. Department of Energy, Table 3.4.5. http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-program-multi-year-research-development-and-10