V.K.4 Power Generation from an Integrated Biomass Reformer and Solid Oxide Fuel Cell

Patricia Irving (Primary Contact), Quentin Ming
InnovaTek, Inc.
3100 George Washington Way, Suite 108
Richland, WA 99354
Phone: (509) 375-1093
E-mail: irving@innovatek.com; ming@innovatek.com

DOE Manager
HQ: Kathi Epping Martin
Phone: (202) 586-7425
E-mail: Kathi.Epping@ee.doe.gov

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Fiscal Year (FY) 2011 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.
- Develop and demonstrate a 5-10 kW power plant with at least 40% efficiency that is located in the Tri-City Research District Innovation Zone Renewable Energy Demonstration Park.

Technical Barriers

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

(A) Durability
(B) Cost
(C) Performance
(E) System Thermal and Water Management

Technical Targets

InnovaTek's research plan addresses several DOE technical targets for stationary applications for fuel processors. Progress in meeting DOE's technical targets is provided in Table 1. DOE has also established technical targets for integrated stationary proton exchange membrane (PEM) fuel cell power systems operating on natural gas or liquefied petroleum gas (LPG) [1]. Although the InnovaTek system includes a solid oxide fuel cell (SOFC) rather than a PEM fuel cell and reforms bio-oil rather than natural gas, our research plan is addressing the same characteristics for energy efficiency and cost, Table 2.

TABLE 1. Progress toward Meeting Technical Targets for Stationary Fuel Processors for Stationary Applications

Characteristic	Units	2011 Target	InnovaTek 2011 Status
Cost	$/kW$_e$	220	1,160[a]
Cold start-up time to rated power @ -20°C ambient	minutes	<30	<30
Transient response time (for 10% to 90% power)	minutes	<1	<1
Durability[b]	hours	40,000	To be determined
Survivability (min and max ambient temp)	°C	-25 +40	To be determined

[a] Includes projected cost advantage of high-volume production (30,000 units per year). Does not include integrated auxiliaries, battery and power regulator for unassisted start.
[b] Time between catalyst and major component replacement.

TABLE 2. Progress toward Meeting Technical Targets for Integrated Stationary Fuel Cell Power Systems Operating on Reformate[a]

Characteristic	Units	2011 Target[c]	InnovaTek 2011 Status[d]
Electrical Energy Efficiency[b] @ rated power	%	40	40
Cost	$/kW$_e$	750	3,500

[a] Includes fuel processor, stack, and all ancillaries.
[b] Ratio of direct current output energy to the lower heating value (LHV) of the input fuel average value of rated power over life of power plant; theoretical calculation.
[c] For a PEM fuel cell system using natural gas or LPG as fuel.
[d] For an SOFC system using bio-oil as fuel.

FY 2011 Accomplishments

- A design requirements document was established that specifies system subcomponents that meet required safety, codes and standards for a fuel cell distributed energy system.

- An optimum process configuration was selected for the production of electricity from pyrolysis oil based on the integrated results of four process models developed by InnovaTek – bio-oil reforming model, SOFC model, anode off gas combustor model, and heat exchanger models.
- A complete mass and energy balance was conducted for the integrated system's 26 different process streams. The results indicate that the system has a theoretical total electrical efficiency of about 40%. This result will be confirmed during testing.
- A prototype system design was completed that will reduce costs through improved thermal management, lower materials cost, and reduced catalyst loading.

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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 bio-oil with an 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 completed during this period.

Approach

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

1. <u>Optimization of SOFC and fuel processor integration</u> – 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 as well as 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. <u>Design for manufacturing and field operation</u> – requires continued modeling and analysis such as failure mode effects analysis 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.
3. <u>System demonstration and validation for commercial applications</u> – 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. Type tests (requirements validation) and routine tests will be performed before and during the demonstration, and system durability will be assessed.

Results

Design Requirements

The functional and safety requirements for a distributed energy application were identified for a 5 kW fuel cell power plant, including hydrogen production capacity, output power and conditioning requirements, parasitic power use, minimum system efficiency, physical size, feed input and requirements, and lifetime. Criteria were determined for:

- Site establishment
- Enclosure and external surfaces
- Power system design requirements
  - Identify all reasonably foreseeable hazards throughout the anticipated equipment lifetime.
  - Estimate the risk of all hazards from a combination of their probability of occurrence and their foreseeable severity.
  - Eliminate or reduce all hazards as far as practical.
  - Use components that are listed or certified by a nationally recognized testing laboratory.
- Marking
- Technical documents

Process Configuration and Modeling

Important system processes were evaluated to determine materials and energy balances, product yields, and equipment size. The steps in process analysis were: 1) mathematical specification of the process, 2) detailed analysis to obtain mathematical models describing the process, and 3) synthesis and presentation of results to ensure full understanding of the process. In this task, we used process simulation tools to analyze the system configuration and to develop an optimal system design with detailed mass and energy balance. The mass and energy balance information and component simulations were used for the design of the reactor and heat exchangers. For example our microchannel heat exchanger analyses indicate that our proprietary designs meet the criteria for high heat transfer density with low pressure drop (Figure 1). The appropriate management of thermal systems determines the overall system efficiency; therefore, special attention was placed on the thermal and water management in the system, the two most technically challenging aspects of system integration. Mass and energy balance calculations for the system were used to determine system input requirements and to estimate product output and exhaust rate and composition. This information allowed us to calculate a system electrical efficiency of about 40% based on LHV of fuel input.

Prototype System Design

Manufacturability and integrated product development concepts were used to achieve cost and performance targets for a pre-commercial fuel cell energy system. Various design concept alternatives were considered early in the process. The alternatives were evaluated against design for manufacturing objectives to help reduce both capital equipment costs and maintenance cost while increasing lifetime and robustness. CAD/computer-aided engineering was used to aid in cost effectively developing and analyzing design alternatives. Finite element analysis and other design analysis tools were used to assess the ability of the design to meet functional requirements prior to manufacture as well as assess a part's or product's robustness. Solids modeling helped to visualize the individual part; understand part relationships, orientation and clearances during assembly; detect errors and assembly difficulties; and design the integrated system enclosure (Figure 2).

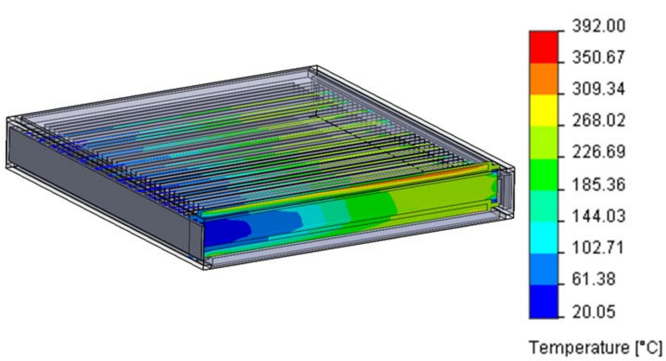

FIGURE 1. Micro channel heat exchanger component simulation — temperature profile through water channel. Results verified that pressure drop across channels meets design criteria; the design results in high heat transfer density; heat transfer meets design criteria.

FIGURE 2. Solid Model of InnovaGen Fuel Cell Distributed Energy 5 kW Power Plant System

Conclusions and Future Directions

- Modeling and analyses indicate that a 5 kW fuel cell distributed energy system that is fueled with renewable, non-food bio-oil 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, we calculate an overall system electrical efficiency of 40% is possible.
- Prototype construction is underway and testing will verify modeling and simulation results. These results 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.
- Fabrication and demonstration results will be used to determine whether system cost, performance, and durability targets for a commercially viable system can be met.

Patents Issued

1. Received Notice of Allowance for Canadian Patent Application No. 2,593,413 entitled "Hydrocarbon Fuel Reforming Catalyst and Use Thereof".

FY 2011 Publications/Presentations

1. A presentation regarding the project was made by Patricia Irving at DOE Headquarters to DOE staff having oversight or interest in the project and to other Phase III awardees on March 30, 2011.

References

1. Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, U.S. Department of Energy, 2007. http://www.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.