V.J.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 (FY) 2013 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

Because our system has an integrated reformer that will process both natural gas and renewable liquid feedstocks, it also addresses technical barriers in the Hydrogen Production section of the DOE Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) Reformer Capital Costs and Efficiency

(B) Operations and Maintenance (O&M)

(C) Biomass Feedstock Issues

(E) Control and Safety

(F) Capital Cost

(G) System Efficiency And Electricity Cost

Technical Targets

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

TABLE 1. Progress toward Meeting Technical Targets for Integrated Stationary Fuel Cell Power Systems Operating on Reformate[a], and Distributed Forecourt Production of Hydrogen from Bio-Derived Renewable Liquids

Characteristic	Units	2015 Target[c]	2020 Target	InnovaTek 2013 Status[d]
Electrical Energy Efficiency[b] @ Rated Power	%	42.5	>45%	41
Equipment Cost, 5-kW System	$/kW$_e$	1,700	1,500	2,361
H_2 Production Energy Efficiency	%	70	75	70
H_2 Levelized Cost[e]	$/kg	5.90	2.30	6.31

[a] Includes fuel processor, stack, and all ancillaries.
[b] Regulated alternating current net/lower heating value of the 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
[e] Assumes ethanol cost of $2.41/gal for 2015, $0.85/gal for 2020, and $2.47/gal for 2013 (InnovaTek status) and volume production of capital equipment

FY 2013 Accomplishments

- Developed highly efficient thermally integrated system design for producing 43,800 kWh/yr of distributed power.
- Completed solid model, bill of materials (BOM), and piping and instrumentation diagram that was used to estimate manufacturing costs.

- Used Design for Manufacturing and Assembly (DFMA®) to reduce part count by approximately 74% and cost by 40%.
- Obtained 41% system efficiency.
- Completed analyses using the H2A and HOMER models to determine cost of hydrogen production and cost of power using InnovaTek's technology.
- Manufactured a proprietary prototype system, including hardware, software, and catalysts and used it to demonstrate 2.2 kW power from bio-kerosene, sending electricity to the grid.
- Supported three 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 integrates the fuel processor 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. Modeling and simulations were completed to compare designs for prototype components and to analyze process flow for alternative system configurations. A major effort to reduce system complexity and cost was completed using DFMA® software tools. An optimized integrated system design was selected, components were fabricated, and a prototype 2.2-kW system 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 SOFC 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 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 – takes place after down-selection of the final design. Several complete systems are built for demonstration to gain performance data necessary to validate the design and operation of the system.

RESULTS

System Design and Fabrication

The system design produced in 2012 was further optimized in 2013 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 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 BOM was prepared for all subsystems of the fuel cell power plant. This BOM 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 fuel processor prototype, part count was reduced by 74% and cost was reduced by 40% (Table 2). System efficiency was increased to 41% (from 37.5% in 2012) as a result of improved 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.

FIGURE 1. InnovaGen® Fuel Cell Power System

Performance Testing

Initial testing of the prototype fuel cell system was successful in achieving 2.2 kW net power production. Longer-term testing is continuing in order to determine durability and maintenance interval.

Cost Analysis

The H2A and HOMER models were used with data from our manufacturing cost analysis and system performance determinations to estimate cost of power and levelized cost of hydrogen using our technology. The results of these analyses are presented in Table 2.

TABLE 2. Fuel Processor Cost Reduction

Prototype System	Labor Cost	Material Cost	Total Cost	Number of Parts	Approximate Volume (L)
2012	$10,201	$4,951	$15,152	159	13.87
2013	$6,374	$3,997	$10,371	66	6.88

CONCLUSIONS AND FUTURE DIRECTIONS

- On the basis of careful systems modeling and component integration using CAD and thermal systems design an overall system electrical efficiency of 41% is possible.
- DFMA® analyses and demonstration results indicate that system cost, performance, and durability targets established by DOE are within feasibility for InnovaTek's technology.
- Results from prototype testing will be used to optimize the design for a field-ready system to utilize for long-term durability and performance testing.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. Irving, P.M., Renewable Distributed Energy Generation, oral presentation, WA State Energy Symposium, Seattle WA, November 2012.

2. Irving, P.M., InnovaTek's Energy Systems Technology Development, oral presentation, Pasco Kennewick Rotary Club, July 10, 2013.

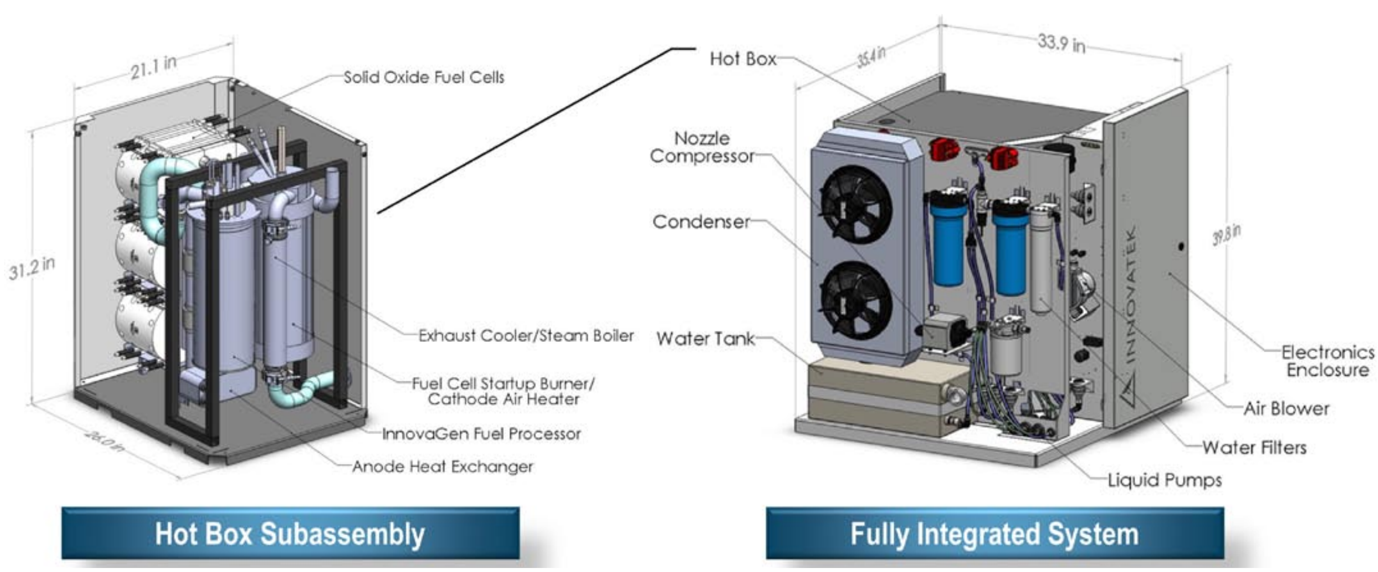

FIGURE 2. Solid Models used for Assembly of Fuel Cell Power System Components

3. Ming, Q., P.M. Irving, The role of the fuel cell system in sustainable power generation, oral presentation, IEEE Conference on Technologies for Sustainability, Portland OR, August 2013.

REFERENCES

1. Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan, U.S. Department of Energy, 2013. http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/