IX.1 Fuel Cell Combined Heat and Power Commercial Demonstration

Kriston P. Brooks (Primary Contact),
Atefe Makhmalbaf
Pacific Northwest National Laboratory
P.O. Box 999/K6-28
Richland, WA 99352
Phone: (509) 372-4343
Email: Kriston.brooks@pnnl.gov

DOE Manager
Peter Devlin
Phone: (202) 586-4905
Email: Peter.Devlin@ee.doe.gov

Subcontractor
ClearEdge Power, Hillsboro, OR

Project Start Date: August 2010
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Deploy and monitor combined heat and power (CHP) fuel cell systems in the range of 5-50 kWe in commercial applications.
- Evaluate the engineering, economics, and environmental impact to provide end-users with an independent assessment of the technology.
- Monitor the long-term performance of the systems. As funding allows, we have a contract in place to monitor the systems for five years.
- Demonstrate the viability of the technology to potential customers by developing a business case.

Fiscal Year (FY) 2014 Objectives

- Monitor fuel cell performance with new M5 systems and compare their performance to the previous CE5 systems,
- Finalize business case for micro-CHP fuel cell systems (FCSs) and incorporate comments from an industrial review.

Technical Barriers

This project addresses the following technical barriers for Market Transformation from the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(F) Inadequate user experience for many hydrogen and fuel cell applications

(H) Utility and other key industry stakeholders lack awareness of potential renewable hydrogen storage application

(I) Lack of cross cutting information on how to use hydrogen and fuel cell systems in combination with energy efficiency and renewable energy technologies with existing projects

Technical Targets

Applicable DOE 2015 Technical Targets for 1-10 kWe CHP fuel cell systems (FCSs) operating on natural gas:

- Electrical efficiency at rated power = 38.4% (higher heating value)
- System equipment cost, 5 kW = $1,700/kW
- Degradation with cycling = 0.5%/1,000 hrs
- Operating Lifetime = 40,000 hrs
- System Availability = 98%

FY 2014 Accomplishments

- Completed "Business Case for a Micro-Combined Heat and Power Fuel Cell System in Commercial Applications" (PNNL-22831).
- Completed evaluation of the performance of the 15 CE5 systems. These original polybenzimidazole (PBI)-based fuel cell systems have been shut down. Ten of these systems have been replaced with new phosphoric acid-based fuel cell M5 systems.
- Performed a comparison between the CE5 and M5 data. Results indicate an increase in electrical and heat output, availability and efficiency as a result of this upgrade.
- Determined heat utilization for systems with augmented instrumentation. As a result of this analysis, the augmented instrumentation on the systems at Roger's Garden was moved to Oakland Hills Tennis Club where the heat was being better utilized.
- After operating for more than 14,600 hours each over the last two years, the 15 CE5 systems were shut down and replaced with new improved M5 systems.
- As of June 30, 2014, 10 M5 systems have been installed and operated for more than 3,100 hours each.

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INTRODUCTION

PNNL provides support to the Market Transformation program with the objective to aid in the development of the fuel cell and associated hydrogen markets. The strategy is to identify near-term niche markets where fuel cells have potential, work with the DOE and stakeholders to develop activities in those areas, analyze the business case, and present the results to the community.

APPROACH

The objective of this project is to demonstrate micro-CHP FCSs and assess their performance to help determine and document market viability. In FY 2012, PNNL worked with a vendor to provide 5-kWe CHP systems, called CE5, at several small industrial buildings. The CE5 used high-temperature PEM fuel cells (PBI) as their basis. Data from these systems were collected for approximately two years. At the end of FY 2013 and early FY 2014, these CE5 systems were shut down and 10 of them were replaced with new M5 systems. The M5 provides similar power but the fuel cell is based on phosphoric acid technology. The gathered information from these new systems was compared to the original CE5s in terms of heat and power produced, system efficiency, and reliability.

This project also developed a business case that could be provided to industry to estimate the size of the market and its growth potential, identify possible niche markets, and compare the micro-CHP FCS with its alternatives in terms of economics, engineering and environmental impact. It has also utilized techno-economic-environmental optimization models to analyze the business case for micro-CHP FCSs. Model results elucidated competitive strengths of this technology by building type, load curve, and climate. Analyses under this effort incorporated market characteristics that will strengthen the business case such as electricity and gas prices and impacts of power outages.

RESULTS

Demonstration Evaluation

During the last year the original CE5 units installed in the demonstration sites were shut down and replaced with new M5 units as shown in Table 1. These M5 units operate based on phosphoric acid fuel cell technology originally developed by UTC power. In addition to the fuel cell upgrade, the M5 systems have front access to simplify repair and permit the systems to be located adjacent to each other. They are also grid independent, allowing them to load follow in the event of a power outage. As of June 30, 2014, averages of 3,100 hours of data were collected from each of these 10 new systems. While significantly less than the 14,700 hours of data collected with the CE5 systems, comparisons can be made between the two units.

TABLE 1. Micro-CHP Fuel Cell System Demonstration Site Information

Partner/Site	Location	Number of Systems	Data Collection Start Date	Days of Operation as of 3/1/14	Date of M5 Upgrade
College	Portland, OR	2	9/2011	771	2/2014
Nursery	Corona Del Mar, CA	3	11/2011	921, 731, 731	7/2013 2/2014
Recreation	Oakland, CA	5	12/2011	749, 742, 742, 732, 874	8/2013 1/2014
Grocery	San Francisco, CA	5	3/2012	487 (Not running)	Not Upgraded

A comparison of the average data analyzed for both the CE5 and M5 systems are shown in Table 2. The values provided are averages for all operating systems. These values can be compared to the manufacturer stated value for each parameter. The net electric power, heat recovery and heat recovery for the M5 system is very close to the manufacturer stated values. In contrast, the set point of the CE5 was reduced from 5 kWe and 4 kWe during the demonstration to provide better system stability. As a result, the manufacturer stated efficiency was not being met. The CE5 did provide a higher water temperature than the M5, although both are lower than the manufacturer stated value.

TABLE 2. Performance Comparison of New M5 System to Original CE5 System

Parameter	Unit	Manufacturer Stated Value	Average Value for CE5 Systems	Average Value for M5 Systems
Number of Operating Units	--	--	15	10
Average Net Electric Power Output	kWe	5.0	4.1	4.9
Average Net Heat Recovery	kWt	5.5	4.6	5.6
Temperature Heated Water to Site	°C	Up to 65	50.5	42.9
Average Net System Electric Efficiency	%	36	32	35
Average Net System Heat Recovery Efficiency	%	40	37	40
Overall Net System Efficiency	%	76	70	76
Availability	%	--	93	97

The most significant difference is a comparison of the efficiency with respect to time (see Figure 1). The

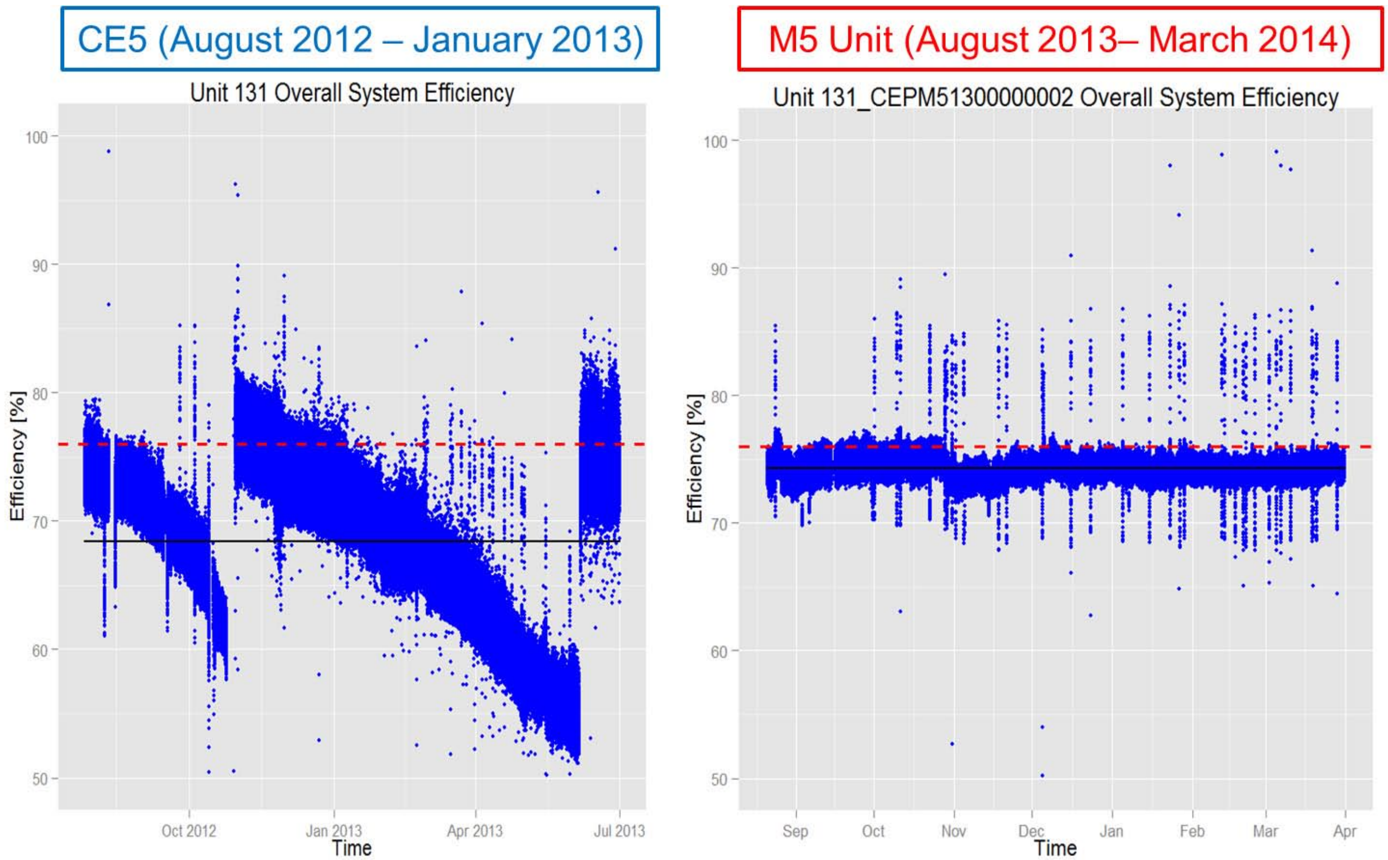

FIGURE 1. Comparison of Efficiencies between One CE5 System and its Replacement M5 System

efficiency of the Roger's Garden CE5 was compared to that of the M5 that replaced it. The efficiency of the CE5 continuously decreases over time while the M5 does not. The discontinuities represent system shut down and part replacement. During a similar period of time, the M5 shows no significant change in the efficiency. These results highlight the significant benefit of the M5 system and its phosphoric acid fuel cell relative to the PBI system.

Additional monitoring equipment was installed at two sites to gather data on the electricity and heat that was being utilized by the facility relative to the amount being produced. All of the electricity and nearly all of the heat (greater than 90%) produced by the CHP FCS was being used by the grocery store. Although all of the electricity was being used by the plant nursery, none of its heat was being utilized. As a result of this discovery, the additional monitoring equipment at the nursery was moved to the recreation facility where the heat would be used to warm the pools and saunas.

Business Case

A business case was developed for the 5-50 kWe CHP fuel cell system. In this business case the primary drivers were described in terms of system siting and market. Locations with high spark spread provide a good indication of areas where the economics for fuel cell systems can be promising. Spark spread indicates locations with high electricity prices and low natural gas prices. These locations provide a justification for the additional costs required to install and operate a distributed power source such as a micro-CHP FCS rather than use power from the grid. Figure 2 indicates that the cost of electricity relative to natural gas is generally high in the Northeast, Midwest, California, and the noncontiguous states of Alaska and Hawaii [1,2].

In addition to a high spark spread, there are economic drivers for high heat utilization. If both the electricity and heat generated by the micro-CHP FCS can be utilized, a better business case can be achieved. Using sample businesses in DOE's commercial reference building models and evaluating them with the Energy Plus Software over the course of the year, the highest utilization of heat was found to be 69% for a small hotel in Boston. Schools and small hospitals also have high utilization in Boston and Chicago as compared to relatively low heat utilization found at quick-service restaurants and office buildings in places like San Francisco.

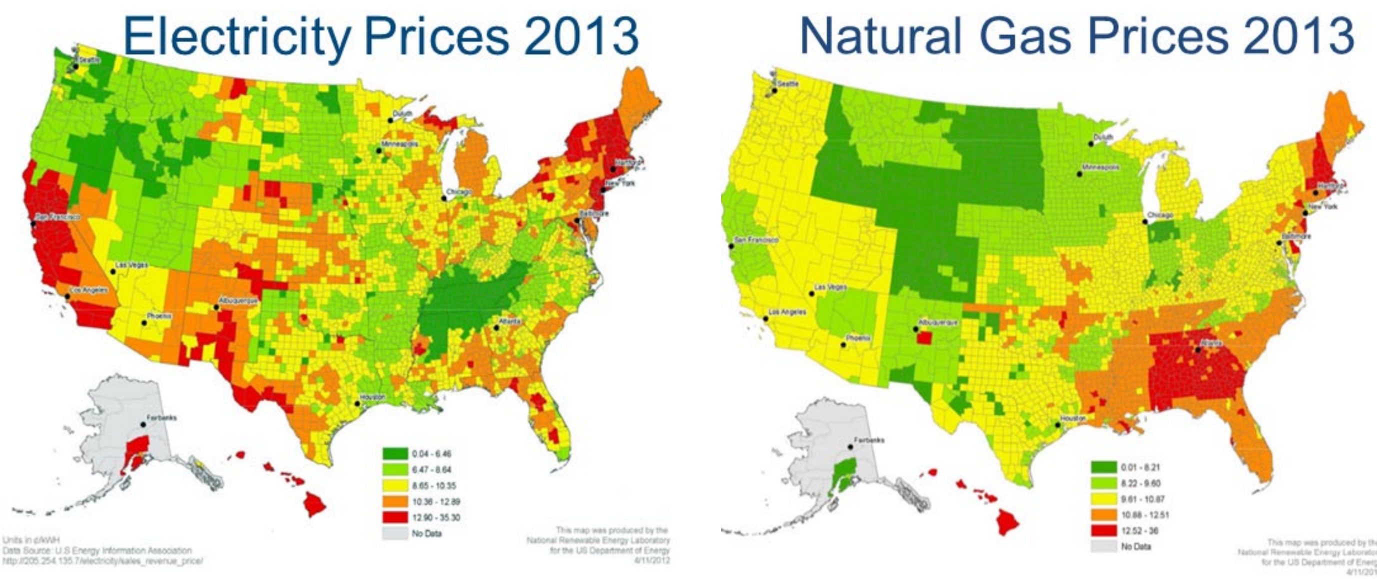

FIGURE 2. Electricity and Natural Gas Prices for 2013 based on EIA Data

The benefits of distributed power such as a micro-CHP FCS was also evaluated by estimating the yearly cost of grid interruptions for a small facility with modest outages. SAIC estimated that the commercial outage value of service would be $40-68/kWh [3]. For only three hours of total facility interruptions, an annual cost of the outages would be $12,000. Information technology intensive businesses could be much higher and have been documented as high as $100,000/hr for power interruptions [4].

By using available information on the expected growth of micro-CHP FCSs and estimating the decrease in system cost as a function of higher global capacity, the projected future cost of these systems can be estimated. Systems both with and without government incentives were considered at four different locations (see Figure 3). Results indicate that although the systems may not be cost competitive now, with continued increases in the electricity costs and reduced system cost associated with higher installed capacity, and benefits from continued research and development, the cost per unit of installed heat and power are expected to decrease by 40%. If this is the case and current government incentives continue, a fuel cell system may become economical in 2017.

CONCLUSIONS AND FUTURE DIRECTIONS

The conclusions of the fuel cell CHP work for FY 2014 are as follows:

- Performed a comparison between the M5 and CE5 in terms of initial power, efficiency and reliability. The

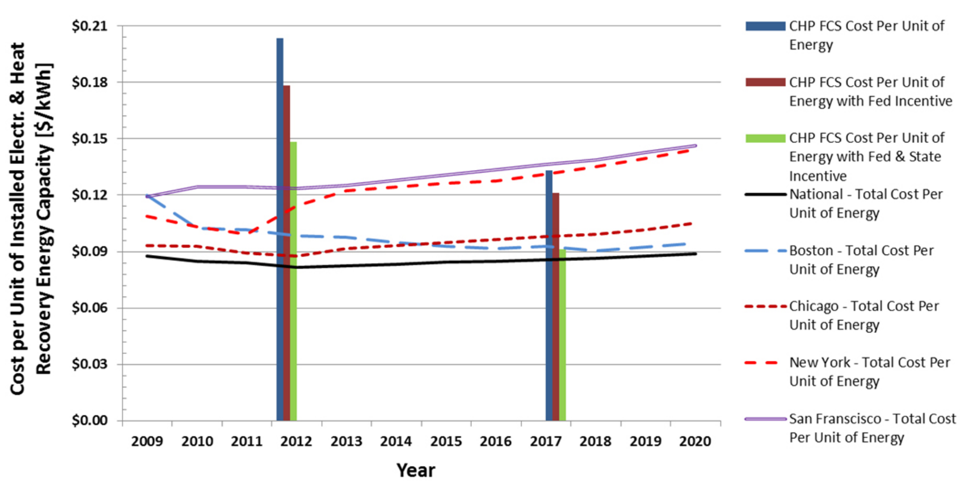

FIGURE 3. Current and Projected Future Costs of a Micro-CHP Fuel Cell

results indicate significant improvement in power and heat produced, efficiency and reliability.

- Additional monitoring equipment installed in Roger's Garden indicated that the heat being generated by the CHP was not being used.

The future work for the fuel cell CHP work in FY 2015 is as follows:

- Future work will continue to monitor the micro-CHP systems and analyze the long-term performance of the M5 systems.
- Future work will also assist ClearEdge in evaluating the trade-offs between higher water temperature and reduced efficiency.
- Business case will be updated to include the life-cycle costs for the new M5 systems and an evaluation of other possible markets.

SPECIAL RECOGNITIONS & AWARDS

1. Received Poster Award for 2013 at the Fuel Cell Seminar & Exposition, Columbus, OH, October 24, 2014.

FY 2014 PUBLICATIONS/PRESENTATIONS

Publications

1. Brooks KP, A Makhmalbaf, DM Anderson, SP Pilli, V Srivastava, and JF Upton. 2013. *Business Case for a Micro-Combined Heat and Power Fuel Cell System*, PNNL-22831, Pacific Northwest National Laboratory, Richland, WA.

2. Brooks KP, A Makhmalbaf, DM Anderson, SP Pilli, V Srivastava, and JF Upton, 2014, "Business Case for a Micro-Combined Heat and Power Fuel Cell System in Commercial Applications," Unpublished, Submitted to Journal of Fuel Cell Science & Technology, May 2014.

Presentations

1. Makhmalbaf, A.; Pilli, S.; Brooks, K, "Independent Analysis of Real-Time Performance Data from Co-Generative Fuel Cell Systems Installed in Commercial Buildings," Invited speaker to the Interagency Working Group, Washington, D.C., March 18 2014.

2. Brooks, K.P.; Pilli, S.; Anderson, D.; Srivastava, V.; Makhmalbaf, A.; "Economic and Engineering Assessment of Combined Heat and Power Fuel Cell Systems Installed in Commercial Buildings," 2013 AIChE Annual Meeting, San Francisco, CA, November 4, 2013.

3. Brooks, K.P.; Pilli, S.; Anderson, D.; Srivastava, V.; Makhmalbaf, A.; "Economic and Engineering Assessment of Combined Heat and Power Fuel Cell Systems Installed in Commercial Buildings," Fuel Cell Seminar & Energy Exposition, Columbus, OH, October 22, 2013.

4. Pilli, S.; Brooks, K.P.; Anderson, D.; Srivastava, V.; Makhmalbaf, A.; "Micro Fuel Cell Combined Heat And Power Commercial Demonstration," Fuel Cell Seminar & Exposition, Columbus, OH, October 24, 2013.

5. Makhmalbaf, A.; Brooks, K.P .; Pilli, S.; Srivastava, V.; Foster, N.; "Lesson Learned from Technical and Economic Performance Assessment and Benefit Evaluation of CHP-FCS," 2014 ACEEE Summer Study on Energy Efficiency in Buildings, to be presented Aug 2014.

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3. Centolella P, "Estimates of the Value of Uninterrupted Service for The Mid-West Independent System Operator." SAIC, Available at: http://www.hks.harvard.edu/hepg/Papers/2010/VOLL%20Final%20Report%20to%20MISO%20042806.pdf.

4. Vision Solutions (2008), "Assessing the Financial Impact of Downtime: Understand the factors that contribute to the cost of downtime and accurately calculate its total cost in your organization." visionsolutions.com, Available at: http://www.strategiccompanies.com/pdfs/Assessing%20the%20Financial%20Impact%20of%20Downtime.pdf.