Lesson Learned from Technical and Economic Performance Assessment and Benefit Evaluation of CHP-FCS

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ABSTRACT

Wider deployment of combined heat and power (CHP) can lead to significant energy, cost, and emissions savings when compared to conventional forms of power and heat generation. As a result, support from the governments and consequently, interest in CHP installation has increased. Combined heat and power fuel cell systems (CHP-FCSs) provide continuous and near consistent electrical power and utilize the heat normally wasted in power generation for heating or cooling applications. CHP-FCSs also have lower emissions compared to alternative sources. A recent study investigated the utilization of CHP-FCSs in the range of 5 to 50 kWe in various commercial building types and geographic locations. Electricity, heating, and water heating demands were obtained from simulation of the U.S. Department of Energy (DOE) commercial reference building models for various building types. Utility rates, cost of equipment, and system efficiency were used to examine economic payback in different scenarios. As a new technology in the early stages of adoption, CHP-FCSs are more expensive than alternative technologies, and the high capital cost of the CHP-FCSs results in a longer payback period than is typically acceptable for all but early-adopter market segments. However, the installation of these units as on-site power generators also provide several other benefits that make them attractive to building owners and operators. The business case for CHP-FCSs can be made more financially attractive through the establishment of government incentives and when installed to support strategic infrastructure, such as military installations or data centers. The results presented in this paper intend to provide policy makers with information to define more customized incentives and tax credits based on a sample of building types and geographic locations in order to attract more business investment in this new technology.

Introduction

Research and development in the area of distributed generation (DG) have increased over the past decade in an effort to reduce emissions, improve energy efficiency, provide independence from the power grid, provision of ancillary services, and facilitate power demand peak shaving. Many of these concerns are an undesirable result of how power is centrally generated, transmitted and distributed. The power system we are using today is not an efficient system. The historical energy flow in the U.S. indicates that the amount of electricity wasted as rejected energy due to transmission and distribution losses is more than the electricity sold to end-users (EIA 2011). This waste itself is a big source of greenhouse gas emissions. One solution to this problem is wider deployment of DGs.

Combined heat and power fuel cell systems (CHP-FCSs) are DGs that eliminate transmission and distribution losses, and provide continuous and near consistent electrical power and heat with greater overall efficiency and lower emissions than alternative sources. These systems can be used either as baseload, grid-connected, or as off-the-grid power sources.

Systems in the power range of 5 to 50 kWe are considered “micro”-CHP-FCS. A fuel cell directly converts fuels (e.g., hydrogen, natural gas, or methanol) into electricity by reacting it electrochemically with an oxidizer (e.g., oxygen or air). Unlike batteries, which will eventually discharge and require recharging or replacement, fuel cells will continue to provide power as long as fuel and an oxidizer are provided to it. Fuel cells are much more efficient than small power generation systems that rely on combustion. For example, a typical internal combustion engine for a car operates at 28 to 30% efficiency, while a fuel cell generally operates at 30 to 50% efficiency. Heat that is generated and not converted to electricity can be used as part of a CHP-FCS. The efficiency of a CHP-FCS can nearly double when this heat is used to meet building thermal loads, reaching efficiency levels of 60 to 90%.

A significant advantage of fuel cells is that they offer constant power production independent of the electrical grid. A variety of markets should consider micro-CHP-FCSs including those that require both heat and baseload electricity throughout the year. In addition, the reliable power of micro-CHP-FCSs could be beneficial to markets where electrical outages are especially frequent or costly. Another advantage of CHP-FCSs is their low emissions. In a study, Jacoboson et al., examined the effect of replacing fossil-fuel with hydrogen in vehicles and power plants by quantifying air pollution emissions in terms of human health cost (in \$/metric tonne) resulted from air pollution (Jacoboson et al. 2006). Greenhouse gas emission levels from micro-CHP-FCSs are 69% lower, and the human health costs are 99.9% lower, than those attributed to conventional coal-fired power plants[1] (O’Hayre et al. 2009). As a result, FCSs can allow a company to advertise as environmentally conscious and provide a bottom-line sales advantage. As a new technology in the early stages of adoption, micro-CHP-FCSs are currently more expensive than alternative technologies . E.g. a microturbine based CHP system has an installed cost of 2400-3000 \$/kW and an operation and maintenance cost of 0.012-0.025 \$/kWh, while a CHP-FCS is reported to have an installed cost of 5000-6500 \$/kW and an operation and maintenance cost of 0.032-0.038 \$/kWh (EPA Combined Heat and Power Partnership 2008). As the technology gains a foothold in its target markets and demand increases, the costs will decline in response to improved manufacturing efficiencies, similar to trends seen with other technologies.

The objective of this study is to address implementation of micro-CHP-FCS in small commercial buildings in the United States by evaluating the technical and economic performance of micro-CHP-FCSs both today and in the future as fuel cell technologies improve and the market changes. To better understand the benefits of micro-CHP-FCSs, the U.S. Department of Energy worked with ClearEdge Power to install fifteen 5-kWe fuel cells in a variety of commercial buildings in California and Oregon. Pacific Northwest National Laboratory has been monitoring the performance of these systems and evaluating them in terms of economics, operations, and their environmental impact in real-world applications. As expected, the economic analysis has indicated that the high capital cost of the micro-CHP-FCSs results in a payback period of 5-8 years on average. This is longer than what is typically acceptable for all but early-adopter market segments, or institutional customers. However, a payback period of less than 3 years may be expected as increased production and research and development breakthroughs bring system cost down, and CHP incentives are maintained or improved. The main goal of this work is to assist potential future adopters and policy makers in understanding the key factors affecting the economics of micro-CHP-FCS use, possible markets that would

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[1] The human health cost is further discussed in Environmental Benefits section below.

benefit from their use and their anticipated growth as the market changes and fuel cell technologies improve.

In this study, building energy simulations were used in addition to the performance evaluation of actual micro-CHP-FCS to identify and evaluate the market with maximum potential for micro-CHP-FCS implementation. For assessment through modeling, EnergyPlus simulation software was used to determine the electrical and heat usage throughout the year in four different climate zones where electricity prices are high. This modeling was used to identify the locations and applications that are best suited for micro-CHP-FCS, and the results of the demonstration were then used as a case study for better evaluating the current market and identifying areas needing improvement to increase micro-CHP-FCS market viability.

Policy and Regulatory Overview

There are several policy and regulatory drivers that support further U.S. fuel cell deployment. With a lower CO_2 footprint than most conventional coal and gas fired generation plants, fuel cells support President Obama's goal of deriving 80 percent of America's electricity from clean-energy sources by 2035 (White House, 2011) . On the regulatory side, the 2014 directive by the Environmental Protection Agency (EPA) that limits carbon dioxide emissions from power plants indirectly supports fuel cells through its focus on low emission energy. This regulation caps emissions from future coal plants at 1,100 pounds of CO_2 per megawatt-hour and new natural-gas fired plants larger than 100 megawatts at 1,000 pounds per megawatt-hour (Federal Register 2014). With greenhouse gas emissions from CHP-FCS hovering between 500 and 600 pounds per megawatt-hour, fuel cells fall well below the EPA regulation caps.

FCSs receive incentives from both federal and some state governments. On the federal side, the main incentives comes from the Business Energy Investment Tax Credit (ITC), which is available for fuel cell project installed before December 31, 2016 with a minimum capacity of 0.5 kW that have an electricity-only generation efficiency of 30% or higher. The ITC provides up to 30 percent of the cost of the project, capped at $1,500 per 0.5 kilowatt (kW) of capacity (DSIRE 2014a).

Several states, such as New York, New Jersey, Connecticut, and California, have policies and regulations in place that support the installation of FCS-based electricity generators. In the case of California, the 2001 Self Generation Incentive Program (SGIP) provides incentives to customers that generate electricity with FCS, wind turbines, and various forms of CHP. FCSs, specifically, can receive a payment of $2.03 per watt generated. The SGIP pays the total incentive for projects up to 30kW upfront, while projects larger than 30 kW receive half of the incentive upfront, and the remaining 50% based on actual electricity production over the first 5 years (DSIRE 2014b). The incentive payment is capped at 3 MW, translating to a maximum incentive of $5 million or 60% of eligible project costs, whichever is less (CPUS 2011).

Technical and Economic Performance Assessment

As a means of evaluating the technical and economic feasibility of micro-CHP-FCS, two distinct methods of modeling and data analysis were used in this study. To carry out building energy performance modeling, EnergyPlus simulation software was used[2]. Factors that are used

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[2] EnergyPlus is a whole building energy simulation program supported by DOE: http://apps1.eere.energy.gov/buildings/energyplus/

here to determine if a building type is a ‘good’ candidate or not include: 1) maximum electricity utilization and 2) maximum heat utilization. Therefore, the goal is to identify building types that run 24/7 and utilize heat for water heating in addition to space heating. The temperatures required for heating vary by the mechanical systems in the building. For instance, in a building with an air based heating system, the air is heated to 23°C, while in a hydronic space heating system, the fluid is heated to 82°C. This requirement of temperature of heat is used in addition to the quantity of heat required to determine the utilization of the FCS.

In addition to modeling and simulation, field performance monitoring of actual micro-CHP-FCS installations were used. For this purpose, units were installed in different building types located in California and Oregon. Data collection and analysis techniques were then used to analyze performance of micro-CHP-FCSs in operation. This was conducted primarily to examine the true behavior of these systems in terms of their efficiency, availability, electricity and heat utilization, and operation and maintenance cost.

Modeling and Simulation

Modeling and simulation techniques have been generally used in the engineering design and decision making process to evaluate options and make more informed decisions about selection of alternative choices, operation preferences, or system selection. Here, modeling and simulations are used to evaluate heat utilization of different building types to select those with maximum potential for CHP-FC integration.

To study heat utilization, several building types—a small office building, a small hotel, a small hospital, a quick-service restaurant, a small school, and an apartment building—were simulated using DOE’s reference buildings modeled in EnergyPlus simulation software (Field and Deru 2011). Space-heating and service-water heating demand data and electricity demand were extracted over 1 hour time intervals for the course of a year. These data were used to examine the portion of the building heating demand and electric demand that could potentially be served by a micro-CHP-FCS. This was done based on output temperature limitations, the quantity of thermal energy supplied, and electric capacity of the system. The quantity of excess thermal and electrical energy not utilized by the building because of the cyclic profile of building demand was also examined. Such an hourly calculation is necessary because the building heating energy demand varies seasonally based on the weather and hourly based on building occupancy. Therefore, there are times when the thermal energy generated by the micro-CHP-FCS may exceed the quantity required by the building at that hour. In Tables 1 and 2, the quantity and percentage of thermal and electrical energy generated by the fuel cell but not utilized in the building are documented for example cases.

Table 1. Thermal energy generated by FCS not used for Office and Hotel buildings

Building Type	Units	New York	Boston	Chicago	San Francisco
Office	kWh thermal	179,265	176,801	173,411	190,182
	%	93.00%	91.70%	90.00%	98.70%
Hotel	kWh thermal	110,236	103,587	103,587	111,140
	%	57.20%	53.70%	53.70%	57.70%

Electricity generated by the FCS is used entirely in Hotels, Hospitals and Schools because of equipment (e.g. refrigerators) that operates continuously in these buildings. However, in Office buildings (without data centers), because of low demand at night (Table 2), over 60% of the electricity generated is not utilized.

Table 2. Electricity generated by FCS not used for office and restaurant buildings

Building Type	Units	New York	Boston	Chicago	San Francisco
Office	kWh	109,346	111,318	109,931	114,555
	%	62.40%	63.50%	62.70%	65.40%
Restaurant	kWh	19,230	19,521	19,449	19,354
	%	11.00%	11.10%	11.10%	11.00%

A sample simulation result is shown in Figure 1. The plot shows the demand for service-water heating throughout 1 year at a small hotel in Boston. The micro-CHP-FCS provides 22 kW of the base thermal load while the remaining is supplied by an alternative source. In this case, 53% of the total heat output generated by the FCS is used by the hotel (as shown in Table 1). While the peak service-water heating demand of the hotel is greater than 22kW, the cyclic demand profile and the constant operation of the FCS causes 47% of the heat to be not utilized. Office buildings have a lower heat demand because of higher internal heat generation by office equipment as well as lower service hot water use. This results in over 90% of the heat generated by the FCS to be not utilized in office buildings simulated.

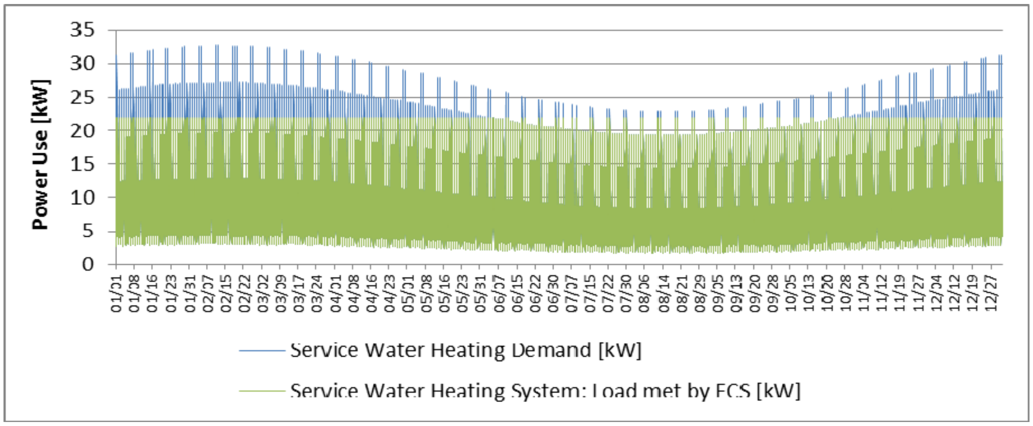

Figure 1. Annual profile for service-water heating demand for a small hotel in Boston with the thermal demand met by an FCS with 22 kW of thermal output.

In order to benefit from the higher system efficiency of the CHP-FCS, steady heat utilization is required. Such usage would include both continuous electricity and heat requirements over the course of a day and throughout the year. Based on the simulation results, a CHP-FCS integrated in a small hotel, hospital, or an apartment building would be able to provide a high fraction of the service hot-water required. These building types would be the best applications for a micro-CHP-FCS. This is especially the case for cities in the northeastern United States. The market that uses the largest fraction of hot water relative to electricity throughout the year is lodging (e.g., hotels and dormitories (Figure 2). A small office, quick-service restaurant, and school tend to have less favorable heat utilization.

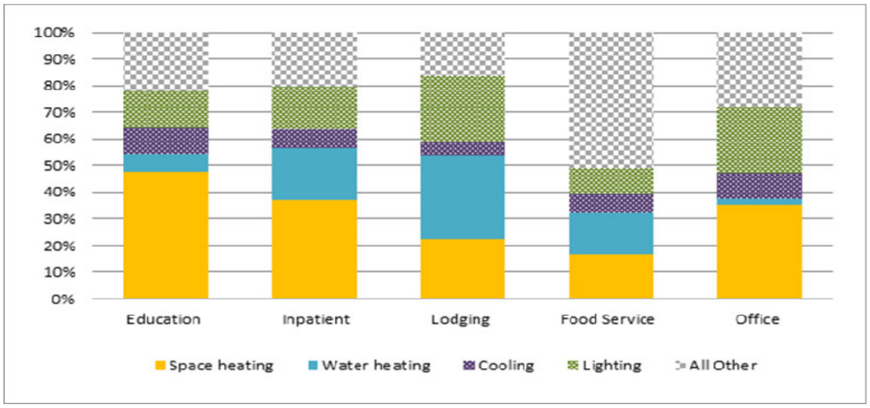

Figure 2. Energy end uses in different building types (EIA 2003) field data analysis.

Another way to analyze the performance of any system, including micro-CHP-FCS, is to evaluate the system in operation. To achieve this, 1) units were installed, 2) operational data were collected, 3) performance of these systems was monitored, and 4) performance was assessed through a Life Cycle Cost (LCC) analysis.

ClearEdge Power installed 15 of their micro-CHP-FCSs for demonstration at four different sites between September 2011 and March 2012. Table 3 shows a summary of the system specifications and Table 4 displays location, building types, number of units installed, and average energy demand of these buildings.

Table 3. Summary of ClearEdge CHP-FCS

Fuel Cell Type	High temperature proton exchange membrane (HTPEM) fuel cell
Fuel Cell Membrane	Polybenzimidazole (PBI)-based membrane
Operating Temperature	160ºC
FCS Fuel	Natural gas
Electrical Output	5 kWe
Heat Recovery Output	5.5 kWth
Electrical Efficiency	36% (higher heating value)
Heat Recovery Efficiency	40% (higher heating value)
Heat Stream Temperature	up to 65ºC

Table 4. Summary of building types, locations, average electricity, and heat demand

Building type	Location	Number of units installed	Average electricity demand [kW]	Average heat demand [kW]
Community College	Oregon	2	77	458
Nursery	South California	3	58	17
Community Center	North California	5	43	89
Grocery Store	North California	5	54	30

An HTPEM FCS has a heat-to-power ratio of approximately 1.1, it has been found that the heat-to-power ratio of approximately 0.33 provided by an SOFC FCS may be better matched to the heat-to-power ratio of an example building in San Francisco of approximately 0.081 (Colella and Srivastava 2012). The suitability of the heat-to-power ratio delivered by a CHP-FCS and hence the utilization is therefore dependent upon the building demand. In this study, most applications identified valued electricity more than heat. Electrical prices tend to be higher than heating prices and as a result, high electrical efficiency is needed.

LCC is a method or process used to evaluate the economic performance of a system over its entire life to make trade-offs between capital costs of a system and long-term cost savings achieved by implementation of such system. This is a way to assess the cost-effectiveness of a system by calculating the 'payback'. The LCC analysis reported in this paper is based on the details of the specific micro-CHP-FCS deployments. This analysis includes upfront operation and maintenance (O&M) costs for replacement of the stack and balance-of-plant (BOP) components as part of the capital costs and depreciation as part of the annual savings[3]. This approach, although more complicated, is more typical of that used for FCSs and provides a more realistic value for payback. As with simple payback, this calculation divides the total costs by annual savings. The payback time with and without government incentives is provided in Table 5.

The resulting payback period varies from 4.95 to 8.66 years when government incentives were excluded from the LCC analysis. The payback period improved to 3.75 to 4.06 years when incentives were included. Note that the community college used in the analysis was not eligible for incentives because of the financial nature and location of this organization. Also, because of its higher installation cost and its location (i.e., Oregon) with much lower electricity costs, this site also has a much higher payback period than the other sites. Therefore the same building types in other locations will have different payback periods and results included here are only illustrative.

Table 5. LCC analysis for 5-year period of performance[4]

Use type	LCC Cost ($/5kW unit)	Payback without incentives (years)	Payback with incentives (years)
Community college	$94K	8.66	NA
Nursery	$76K	4.95	3.75
Community center	$82K	5.32	4.06
Grocery store	$85K	5.43	3.99
Average	$84K	6.09	5.12

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[3] On average, the cost of one Micro-CHP-FCS unit is approximately $83,500. The O&M costs are covered by the warranty, including providing analysis data of the fuel cell performance, technical support, and any needed repairs, are aggregated in the capital cost. The detailed breakout of these costs is business sensitive. The Federal Business Energy Investment Tax Credit (ITC) provided a 30% credit of up to $3,000/kW of installed electrical capacity for fuel cell capital equipment and installation costs only. Under the California Self-Generation Incentive Program, a cash rebate of up to $2,500/kW can be used when using a system fueled by natural gas for installations in California. The DOE cost share varied from 36 to 44% depending on the location. The differences in cost per unit (DOE cost share) arise from the differences in additional equipment costs (vary depending on the infrastructure at a given site), variable sales tax, and fuel costs. For more information, see Brooks et al. 2013.

[4] The initial units were warrantied for 5 years with the ability to extend the 5 year warranty for an additional five years with an additional cost.

Figure 3 shows the average payback period for the current and projected costs (over the next 5 years) of micro-CHP-FCS units. The average payback periods for the current and projected costs are 6.09 and 4.71 years respectively, assuming there are no incentives. A previous study predicted that the cost of 5 kW stationary PEM fuel cells would decrease by 32% by increasing the production of systems from 100/year to 10,000/year (James 2012). The projected costs estimated for the case study included here represent a 25% cost decrease based on an estimated production of 4000 systems/year (Williams 2012). These savings are very close to the results presented in the previous study (James 2012).

The average cost of micro-CHP-FCS units was also calculated for a desired payback period of 3 years and is also shown in Figure 3. For a desired payback period of 3 years, the average cost of micro-CHP-FCS units should be on the order of $41,000 to $45,000, which represents a 50% decrease when compared to today's costs. Based on the expected cost reduction as a function of system production, this decrease can be achieved by increasing system production to more than 50,000 units/year (James 2012).

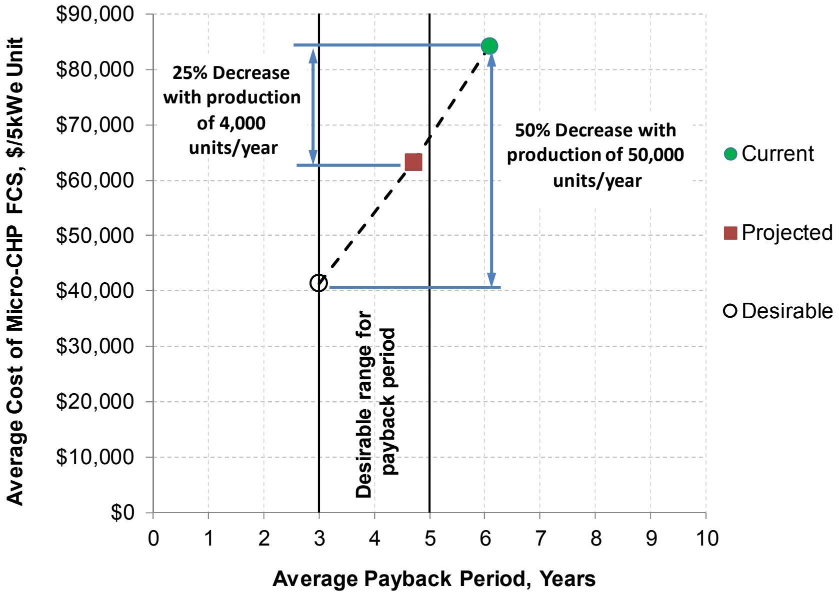

Figure 3. Average payback period versus average cost of the micro-CHP-FCS unit (Brooks et al. 2013).

Evaluation of Benefits

Beside the technical challenges and higher costs of micro-CHP-FCSs, there are different benefits that make integration of such systems attractive and favorable for investors and building owners. These benefits are realized based on a wide range of capabilities offered by CHP-FCSs. These include availability and power resiliency, their use as support for other intermittent renewable sources such as wind and solar, the environmental benefits, and even their quiet operation. These benefits are further defined and evaluated in this section.

Availability and Power Resiliency

A significant advantage of fuel cells is that they offer constant power production independent of the electrical grid. This means that they provide a reliable source of power in case of power outages, which can be not just costly but also life threatening. On average, 500,000 people are affected by power outages in the United States each day, and, the annual cost of these outages is estimated to be approximately $119 billion (Chen 2002). In 2009, the utility grid was given a D+ grade by the American Council of Civil Engineers. At the same time, the power grid supplies to sophisticated equipment, such as computers, high-speed digital processors, and electronic components, are more sensitive than ever to power fluctuations and outages compared to less sophisticated loads such as light bulbs, refrigerators, and water heaters. As a result, many companies that rely on power-sensitive components for their operations and communications (e.g., data centers) are actively seeking more resilient sources of power. According to Palo Alto Networks, data centers are "facilities that centralize an organization's IT operations and equipment, and where it stores, manages, and disseminates its data" (Palo Alto Networks 2014). Since data centers "house a network's most critical systems and are vital to the continuity of daily operations," their security and reliability is a "top priority for organizations."

This priority on security and reliability is rooted in the need for business continuity. Any outage or disruption of service could immediately affect and potentially ruin a business using data centers. For these reasons, as well as reduced environmental emissions, companies operating or relying on large data centers, such as Microsoft, are considering the use of fuel cells. As these companies place high value on the reliability of power supply, fuel cells using natural gas could add benefit due to the extremely high level of gas grid reliability, which -estimated to be at over 99.999 percent - far exceeds the electric grid's levels (Judson 2013). Fuel cells, especially when installed as multiple units, could eliminate diesel generators used for power backup. Lastly, since data centers also have constant cooling requirements, a combination of fuel cell-based micro-CHPs with absorption chillers could further support the business case for fuel cell application in data centers.

In terms of supporting strategic infrastructure, the military sector is another prime candidate for the deployment of fuel cell-based micro-CHPs. The Department of Defense (DOD) is one of the largest energy users in the U.S., spending approximately $4 billion for facility energy use in 2009, with electricity consuming about 64 percent of all energy at DOD installations (Gross et al. 2011). The DOD has thus been aggressively examining ways to reduce its power use and raise the efficiency of its energy portfolio.[5] Beyond their potential to increase energy efficiency and reduce operating costs, fuel cells are also a good candidate for the DOD as they support several of its objectives, such as delivering mission-critical power during emergencies. Most military bases get their electricity from local utilities, thus creating a potential vulnerability in case of local grid disturbances. CHP-FCSs can provide reliable backup power for command and service centers and communication needs, eliminating the risks of disruptions from grid outages, be they technical, weather-based, or rooted in a cyber-attack.

To be Deployed as an Integrated Hybrid Renewable System

Renewable power sources have significant challenges that can be addressed by augmenting them with a hybrid system consisting of CHP-FCS. Renewables such as wind and solar sources have varying availability of their energy sources. CHP-FCSs can be used as a

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[5] Executive order 13514 requires that all new construction, major renovations, repairs, or alterations of federal buildings comply with the Guiding Principles of Federal Leadership in High Performance and Sustainable Buildings. It also requires establishment of reduction targets for greenhouse gas (GHG) emissions. See http://www.whitehouse.gov/assets/documents/2009fedleader_eo_rel.pdf

hybrid system integrated with other renewables to provide a baseload resource to supplement the unpredictable and inconsistent power supply of renewable energy sources.

Fuel cells themselves can be considered a renewable source if powered by hydrogen generated from biomass using renewable sources such as livestock farming, wastewater treatment facilities, landfills, breweries, and wineries. The hydrogen also can be generated from non-renewable sources such as natural gas-, propane-, or other petroleum-based processes. This provides wider flexibility and high power source availability while still minimizing the environmental impact.

Environmental Benefits

To evaluate environmental benefits of micro-CHP-FCSs, the greenhouse gas emissions generated were compared to those of a conventional coal-fired power plant, an average gas-fired plant, and an advanced cogeneration plant in terms of CO_2 and in units of grams per kilowatt-hour (g/kW-hr) . The emission factors of the coal-fired plant, natural gas power plant, and advanced natural gas cogeneration were found to be 1696, 1188, and 602 g/kW-hr respectively (O'Hayre et al. 2009 and NEI 2013). The emission factor of the micro-CHP-FCS, as provided by the system supplier, is equal to 528 g/kW-hr. According to this data, micro-CHP-FCS produces about one-third the emissions of a conventional energy system composed of a coal-fired power plant and one-half the emissions of an average natural gas-fired plant assuming that they produce the same quantity of electricity.

The exhaust gas composition from a micro-CHP-FCS was also examined to quantify the change in air pollution emissions. These exhaust constituents include carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), sulfur oxides (SO_x), and volatile organic compounds (VOC). Air pollution emissions were quantified by calculating the change in human health costs from the release and uptake of these emissions (Collela 2010). Findings indicate that the total human health costs resulting from air pollution by micro-CHP-FCSs are 1/886 of pollutions generated by a conventional coal-fired power plant (O'Hayre et al. 2009), 1/851 of a natural-gas power plant (NEI 2013), and 1/256 of an advanced co-generation system.

Conclusion: What Does This Study Mean in Terms of Policy Decisions

In this study, both simulation and data analysis methods were used to analyze the technical and economic performance of CHP-FCS in order to evaluate limitations, costs, and benefits of these on-site co-generation systems. The main goal of this work was to conduct and report on an evaluation to inform policy decision makers about how to assist with wider deployment of building-scale CHP-FCS. To achieve this, a sample of building types were simulated in different locations to identify building types and locations that have maximum potential for CHP-FCS integration. Then, a LCC analysis was performed to evaluate the economic feasibility of these systems. Further benefits of CHP-FCS integration in terms of a range of factors such as availability, power grid independency, and environmental advantages were also evaluated. Conclusions are reached for energy utilization and LCC.

Energy Utilization: FCS operational characteristics are better suited to serve the building's base load rather than their peak demand. Modeling and simulation results indicated that CHP-FCSs have maximum utility in buildings with constant base load demand for electricity and heat such that the energy generated by the system is used continuously. An hourly calculation method was used to examine the building electricity and heat demand to provide a more accurate estimation of the FCS utilization than monthly utility bills. Results showed that buildings such as Hotels and Hospitals that operate continuously and have higher hot-water usage are better candidates for CHP-FCS integration. This means that efficiency of CHP-FCS will be maximized in such buildings enhancing other benefits of these DG systems. Policy decision makers should perhaps consider giving priority to these buildings by allocating more incentives and tax credits to them.

LCC: The LCC analysis using data collected from units installed yielded a payback period between 3.75 years to 4.06 years when government incentives were included. This is higher than the desired payback, which is 3 years or less. The average cost of micro-CHP-FCS units was also calculated for a desired payback period of 3 years and was found to be 50% less than current costs of these units. Based on the expected cost reduction as a function of system production, this decrease can be achieved by increasing system production to more than 50,000 units/year. This means if government increases its incentives and tax credits, it would encourage more building owners to invest in micro-CHP-FCS. This will eventually result in an increase in system production, which will inherently reduce the capital cost of CHP-FCSs. Government incentives can eventually be reduced or even removed when market reaches its stability.

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