V.I.7 A Total Cost of Ownership Model for PEM Fuel Cells in Combined Heat and Power and Backup Power Applications

Max Wei (Primary Contact), Hanna Breunig, Michael Stadler, Thomas McKone
Lawrence Berkeley National Laboratory (LBNL)
1 Cyclotron Road, MS 90R-4000
Berkeley, CA 94706
Phone: (510) 486-5220
Email: mwei@lbl.gov

DOE Managers
Donna Ho
Phone: (202) 586-8000
Email: Donna.Ho@ee.doe.gov

Reg Tyler
Phone: (720) 356-1805
Email: Reginald.Tyler@ee.doe.gov

Subcontractors
- University of California, Berkeley, CA
- Ballard Power Systems, Burnaby, British Columbia, Canada
- Strategic Analysis, Arlington, VA

Project Start Date: October 1, 2011
Project End Date: 2016

Overall Objectives

- Develop total-cost-of-ownership (TCO) modeling tool for design and manufacturing of fuel cell systems in emerging markets (e.g. co-generation and back-up power systems) for low-temperature proton exchange membrane (LT PEM), high-temperature (HT) PEM, and solid oxide fuel cell (SOFC) technologies
- Expand cost modeling framework to include life-cycle analysis and possible ancillary financial benefits, including carbon credits, health/environmental externalities, end-of-life recycling, and reduced costs for building operation
- Perform sensitivity analysis to key cost assumptions, externality valuation, and policy incentive structures

Fiscal Year (FY) 2014 Objectives

- Develop TCO modeling tool for HT PEM fuel cells in combined heat and power and stationary power applications
- Complete literature/patent summary and functional specifications SOFC systems in combined heat and power generation and stationary power

Technical Barriers

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

(B) Cost: Expansion of cost envelope to total cost of ownership including full life-cycle costs and externalities

Technical Targets

This project is conducting cost of ownership studies of LT PEM, HT PEM, and SOFC fuel cell systems in non-automotive applications. Insights gained from these studies can be applied toward the development of lower cost, higher volume manufacturing processes that can meet the following DOE combined heat and power system equipment cost targets listed in Table 1.

LT PEM: Although the 100-kW cost of $1,800/kW meets the 2015 target of $2,300/kW, the automated stack production processes and assumed high yields are more realistic in the 2020 timeframe. Compared to the 2020 targets, cost estimates for 10-kW and 100-kW exceed the target by 70% and 80%, respectively. (A 50% corporate markup is assumed for both system sizes.)

HT PEM: Although the 100-kW cost of $2,200/kW meets the 2015 target, the automated stack production processes and assumed high yields are more realistic in the 2020 timeframe. Compared to the 2020 targets, cost estimates for 10-kW and 100-kW exceed the target by 90% and 120%, respectively. (A 50% corporate markup is assumed for both system sizes.)

TABLE 1. Project Technical Targets

System	Units/yr	2015 Target	2020 Target	LT PEM direct cost	HT PEM direct cost	LT PEM cost with markup	HT PEM cost with markup
10-kW CHP System	50,000	$1,900/kW	$1,700/kW	$1,900	$2,100	$2,900	$3,200
100-kW CHP System	1,000	$2,300/kW	$1,000/kW	$1,200	$1,470	$1,800	$2,200

CHP – combined heat and power

FY 2014 Accomplishments

- Completed TCO model for LT PEM CHP and backup power applications
- Completed direct cost model for HT PEM CHP applications
- Completed literature/patent summary and functional specifications for SOFC systems in co-generation and stationary power

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INTRODUCTION

The DOE has supported over the last decade several cost analysis studies for fuel cell systems for both automotive [1,2] and non-automotive systems [3,4]. These studies have primarily focused on the manufacturing costs associated with fuel cell system production. This project expands the scope and modeling capability from existing direct manufacturing cost modeling in order to quantify more fully the benefits of fuel cell systems by taking into account life-cycle assessment, air pollutant impacts and policy incentives. TCO modeling becomes important in a carbon constrained economy and in a context where health and environmental impacts are increasingly valued. TCO is also critical as an input to industry and governments decisions on funding research, development and deployment as well as an input to organizations and individuals who make long term investment decisions.

Three components of the TCO model are (1) direct manufacturing costs, (2) life-cycle or use- phase costs such as cost of operations and fuel, and (3) life-cycle impact assessment costs such as health and environmental impacts. FY 2014 has been focused on the development of a direct manufacturing cost model for HT PEM systems for application in CHP and work in SOFC CHP systems functional specifications and literature review of industry data and patent data.

APPROACH

Data for system designs and component costing is derived from (1) existing cost studies where applicable; (2) literature and patent sources; and (3) industry and national laboratory advisors. Vertically integrated manufacturing is assumed for stack components with high-speed roll-to-roll processes for gas diffusion layer/gas diffusion electrode/catalyst-coated membrane components and largely purchased components for balance-of-plant components. Life-cycle or use-phase costing utilizes existing LBNL tools [5], a National Renewable Energy Laboratory database of commercial building electricity and heating demand profiles by building type and geographical region [6], and earlier CHP modeling work by one of the authors [7].

Life-cycle impact assessment is focused on use-phase impacts from energy use, carbon emissions and pollutant emissions [9]—specifically on particulate matter emissions since particulate matter is the dominant contributor to life-cycle impacts [10]. Health impact from particulate matter is disaggregated by geographical region using existing LBNL health impact models [11] and an estimation of the amount of displaced grid-based electricity and heating fuel for a fuel cell CHP system in that building type and geographical region.

RESULTS

A sampling of direct cost results is shown in Figures 1-3. Full details can be found in the publication Wei (2014). LT PEM 10-kW backup power system direct costs are found to be less than $1,000/kW above 1,000 units per year. A large declination in stack cost from 100 to 1,000 units per year is due to a sharp increase in tool utilization above 100 units per year. The catalyst-coated membrane is 43% of stack cost at 1,000 units per year increasing to 50% at 50,000 units per year. At the highest volume, stack cost is $240/kW. BOP is simplified relative to CHP systems with air cooling vs. liquid cooling for CHP systems.

Figures 2 and 3 show direct cost vs. annual manufacturing volume for 50-kW LT and HT PEM CHP systems, respectively. LT PEM system cost varies from $1,500 to $1,100/kW from 1,000 units per year to 50,000 units per year. The rate of cost reduction in the stack is about twice that of balance-of-plant components from 1,000 to 10,000 units per year (28% vs 14%), since stack components

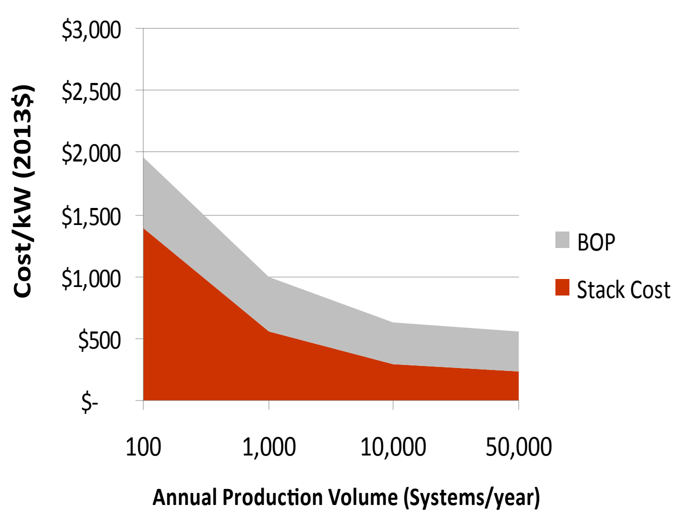

FIGURE 1. Direct Cost per kW for 10-kW LT PEM Backup Power System

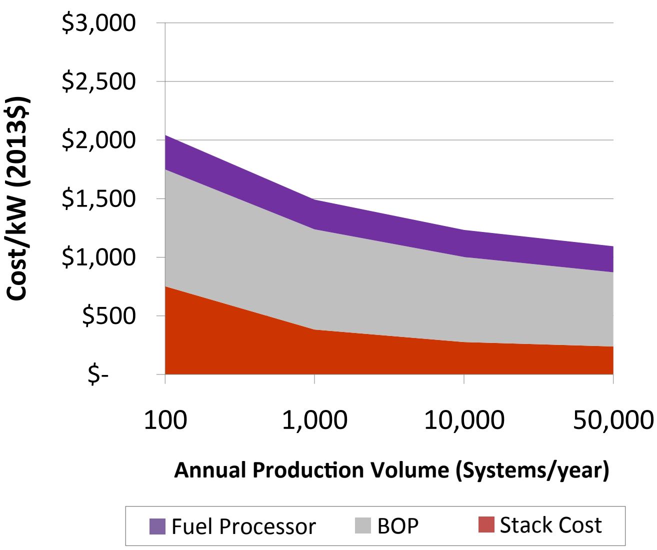

FIGURE 2. Direct Cost per kW for 50-kW LT PEM CHP System with Reformate Fuel

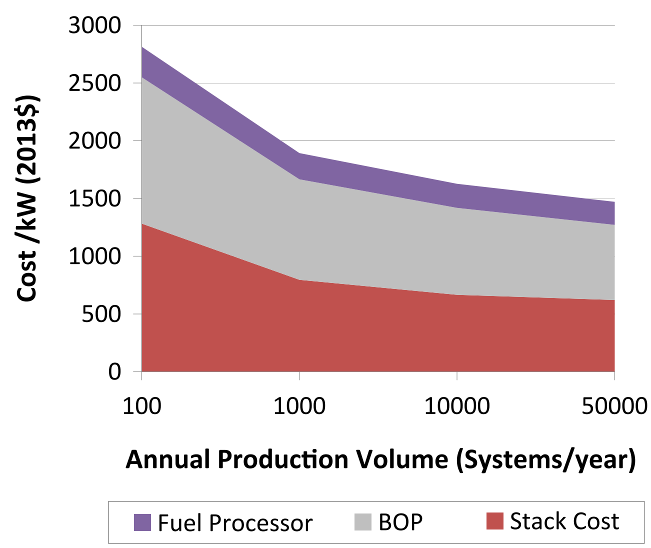

FIGURE 3. Direct Cost per kW for 50-kW HT PEM CHP System with Reformate Fuel

are assumed to achieve greater economies of scale e.g., higher tool utilization and increasing yield with higher volume, than purchased balance of plant components. Across the range of production volumes considered, the fuel cell stack cost constitutes 37% to 22% of total system cost.

At 50,000 systems per year, the 50-kW HT PEM system is projected to have 34% higher cost than the LT PEM CHP system despite slightly lower cost for the fuel processor and balance of plant. This is due to several factors: lower current density and higher cell area, higher platinum catalyst loading (0.7 vs. 0.5 mg/cm^2), more complex plate architecture, and slightly lower yield assumed due to less mature process technology. A compression-molded plate with a barrier layer to phosphoric acid is modeled for the HT PEM case for reliability and lifetime whereas injection molded plates are assumed for LT PEM CHP stacks. For HT PEM CHP across the range of production volumes considered, stack costs constitute 46% to 42% of overall system direct costs.

TCO cost of electricity for LT PEM is shown in Figure 4 for one building/geography pair (small hotel in Minneapolis). Other buildings and geographies were also modeling (hospitals, large and small office buildings) and several other cities across the U.S. (San Diego, Phoenix, Chicago, New York, and Miami). Figure 4 shows a waterfall chart of the cost of electricity starting from "levelized cost of electricity" (r=5%, 15-year system lifetime) and then successively including credits from offset heating fuel, carbon credits, and health and environmental externalities. Installed cost is taken to be $2,900/kW based on 100 MW of production per year, corporate markup of 50%, and an installation cost factor of 33%. In this particular case, heating fuel reduction contributes 5.5% savings, greenhouse gas (GHG), and health and environmental impacts contribute 23.4% savings, for an overall savings of 29% compared to the levelized cost of electricity. The TCO cost of electricity in this case is still slightly higher than the average commercial price of electricity in Minnesota ($0.092/kWh) but is much more competitive. Levelized cost of electricity is a strong function of fuel cost and capital cost, while TCO cost of electricity benefits from more fuel cell waste heat utilization, higher carbon price, and higher carbon intensity of displaced grid based electricity or conventional heating fuels.

CONCLUSIONS AND FUTURE DIRECTIONS

- Direct costs for LT PEM 10-kW backup power systems are found to be $1,959/kW at annual production volumes of 100 systems per year and $556/kW at 50,000 systems per year.
- For 100-kW CHP systems with reformate, the 2015 DOE cost target at 1,000 units year can be met with LT and HT PEM systems, but this volume of production is more realistic in the 2020 timeframe and the $1,000/kW cost target for 2020 is not met. For 10-kW CHP systems, 50,000 units per year, both PEM technologies exceed the cost target for both 2015 and 2020.
- Balance of plant is generally found to be the largest component of CHP system costs for LT and HT PEM systems. HT PEM CHP systems are projected to be higher cost than LT PEM systems due to lower power density, higher catalyst loading, more complex plate design, and lower process yield assumptions due to less overall technology maturity.

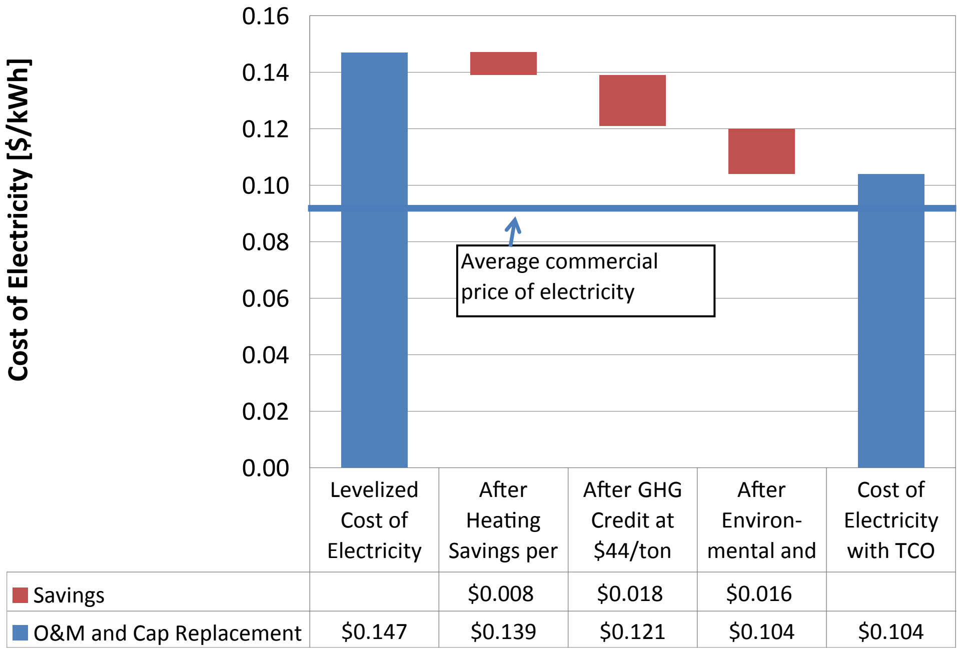

FIGURE 4. Total Cost Of Electricity Example for 50-kW LT PEM CHP System with Reformate Fuel in a Small Hotel in Minneapolis

- TCO including greenhouse gas and environmental and health externalities is very dependent on fuel costs, capital costs, waste heat utilization and the carbon intensity of displaced grid-based electricity and conventional heating fuels.
- The research team is refining the direct cost modeling and completing the TCO model for HT PEM CHP systems in the final quarter of FY 2014. SOFC direct cost modeling will be done in the fourth quarter of FY 2014 and the first quarter of FY 2015.
- The team is also completing an automated model for the LT and HT PEM TCO in the fourth quarter of FY 2014 which allows users to input cost assumptions and provides automated sensitivity analysis.

FY 2014 PUBLICATIONS/PRESENTATIONS

Publications

1. M. Wei 2014, Timothy Lipman, Ahmad Mayyas, Joshua Chien, Shuk Han Chan, David Gosselin, Hanna Breunig, Michael Stadler, Thomas McKone, Paul Beattie, Patricia Chong, Whitney G. olella, Brian D. James, "A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications," Lawrence Berkeley National Lab Report, July 2014.

Presentations

1. M. Wei, T. Lipman, A. Mayyas, S.H. Chan, D. Gosselin, H. Breunig, T. McKone, "A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup power applications," Grove Fuel Cell Conference, Amsterdam, Netherlands, April 3-4, 2014.

2. D. Gosselin, M. Wei, "A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications," ASME 2014 12th Fuel Cell Science, Engineering and Technology Conference, Boston, MA, June 2014.

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