V.F.7 A Total Cost of Ownership Model for Design and Manufacturing Optimization of Fuel Cells in Stationary and Emerging Market Applications

Max Wei (Primary Contact), 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 Manager
Donna Ho
Phone: (202) 586-8000
Email: Donna.Ho@ee.doe.gov

Subcontractors
- University of California, Berkeley, CA
- Strategic Analysis, Arlington, VA

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Project End Date: September 30, 2016

Overall Objectives

- Develop total cost of ownership (TCO) modeling tool for the design and manufacture of fuel cell systems in emerging markets (e.g., combined heat and power [CHP] and back-up power systems) for low temperature (LT) polymer electrolyte membrane (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) 2015 Objectives

- Complete TCO model for HT PEM systems in CHP applications
- Define system design, balance of plant (BOP), bill of materials, and manufacturing process flows for SOFC stationary power and CHP systems
- Develop direct manufacturing cost model for SOFCs in CHP and stationary power applications
- Perform policy and energy system scenario analyses for LT PEM total cost models for CHP and backup power systems

Technical Barriers

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

Fuel Cells (Section 3.4)

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

Manufacturing R&D (Section 3.5)

(A) Lack of High-Volume Membrane Electrode Assembly Processes

(B) Lack of High-Speed Bipolar Plate Manufacturing Processes

Technical Targets

This project is conducting cost of ownership studies of LT PEM, HT PEM, and SOFC fuel cell systems in nonautomotive 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 CHP system equipment cost targets (Table 1).

- LT PEM: For reference, the LT PEM cost from earlier work is shown.
- HT PEM: At the annual production volumes shown, HT PEM CHP system costs are estimated to be 15–25% higher than LT PEM systems. Although the 100 kW cost of $2,235/kW at 1,000 units per year meets the 2015 DOE cost target, the automated stack production processes and assumed high yields are more realistic in the 2020 timeframe.
- SOFC: The SOFC CHP system direct equipment manufacturing cost and equipment cost with a 50% markup in price is shown above. At the annual production volumes shown, the SOFC cost per unit kilowatt is estimated to be about 35% lower than for LT PEM systems.
- Although the 10 kW SOFC system cost of $1,655/kW at 50,000 units per year meets the 2015 DOE target, the automated stack production processes and assumed high yields are more realistic in the 2020 timeframe.
- The 10 kW SOFC CHP system meets the 2020 DOE equipment cost at an annual production volume of 50,000 units per year. The 100 kW CHP system exceeds the 2020 DOE target by 14%.

TABLE 1. DOE Cost Targets vs. Modeled Costs in this Work

System	Units/yr	2015 DOE Equipment Cost Target with Markup	2020 DOE Equipment Cost Target with Markup	LT PEM Equipment Cost with 50% Markup	HT PEM Equipment Cost with 50% Markup	SOFC Direct Equipment Cost with 50% Markup
10 kW CHP System	50,000	$1,900/kW	$1,700/kW	$2,585/kW	$2,925/kW	$1,655/kW
100 kW CHP System	1000	$2,300/kW	$1,000/kW	$1,800/kW	$2,235/kW	$1,140/kW

FY 2015 Accomplishments

- Completed TCO model for HT PEM CHP applications
- Completed BOP, bill of materials, and manufacturing process flows definition for SOFC stationary power and CHP systems
- Completed manufacturing cost model for SOFC power and CHP systems

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INTRODUCTION

Over the last decade, DOE has supported several cost analysis studies for fuel cell systems for both automotive [1,2] and nonautomotive 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 government decisions on funding research, development, and deployment as well as an input to organizations and individuals who make long term investment decisions.

The 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 2015 has been focused on the development of a direct manufacturing cost model for SOFC systems for application in CHP and stationary power and the completion of a TCO cost model for HT PEM CHP applications.

APPROACH

Data for system designs and component costs are derived from (1) existing cost studies where applicable, (2) literature and patent sources, and (3) industry and national laboratory advisors. Stack components that can be made with high-speed roll-to-roll processes, like gas diffusion layer/gas diffusion electrode/catalyst-coated membrane components, and components like BOP components that are largely purchased, are assumed to be part of a vertically integrated manufacturing process. Life cycle or use phase costing utilizes existing LBNL tools [5], a National Renewable Energy Laboratory (NREL) 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], and especially on particulate matter (PM) emissions since PM is the dominant contributor to life cycle impacts [10]. Health impact data from PM is disaggregated by geographical region using existing LBNL health impact models [11] and estimates of the amount of displaced grid based electricity and heating fuel that a fuel cell CHP system in that building type and geographical region would provide.

RESULTS

Direct cost model results for PEM CHP systems are shown in Figures 1 and 2. Full details can be found in LT PEM and HT PEM LBNL reports by Wei et al. [12]. Higher stack costs are found for HT PEM systems because of lower power density, larger plate size, higher Pt loading, and different stack design. Somewhat lower BOP/fuel processer costs are found for HT PEM due to a simpler balance of system design that contributes to a lower fraction of system costs. Overall HT PEM system costs are 10–15% higher at low annual production volumes than LT PTEM, and up to 30% higher cost at 100 kW and high volume. For LT PEM systems, nonstack costs dominate the overall system costs. The conclusion that nonstack costs dominate CHP system costs has further been corroborated by industry inputs from both LT PEM and SOFC system vendors.

The TCO model includes New York, Chicago, Minneapolis, Phoenix, Houston, and San Diego settings with various commercial buildings. Fuel cell CHP is found to be most favorable in regions with higher carbon intensity electricity (Chicago and Minneapolis). Figure 2 shows a small hotel in Chicago with a 10 kW HT PEM system that offsets both water heating and space heating costs. An installed cost of $4,400/kW corresponds to an annual production volume of 100 MW (or 10 kW x 10,000 units per year on Figure 1), coupled with a total corporate markup of (general and administrative, sales and marketing, insurance and fees, and installation) of 100% applied to the direct cost in Figure 1. The total cost of fuel cell provided electricity is seen to drop from 18.8 ¢/kWh to 7.8 ¢/kWh after including heating fuel savings, carbon credits valued at the social cost of carbon ($44/ton of carbon dioxide), and health and environmental savings. This TCO cost of electricity is below the average cost of commercial electricity in Illinois.

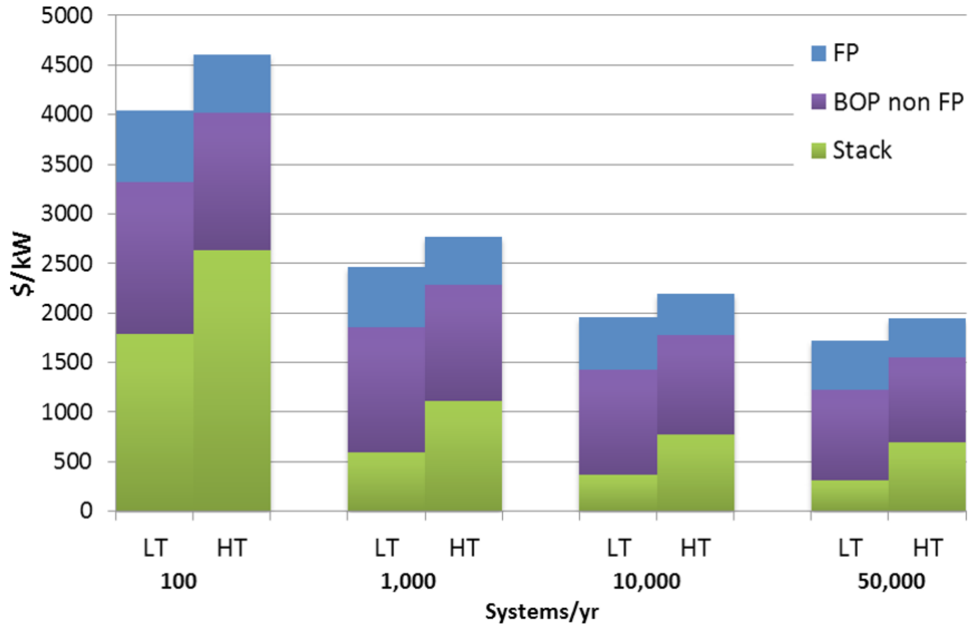
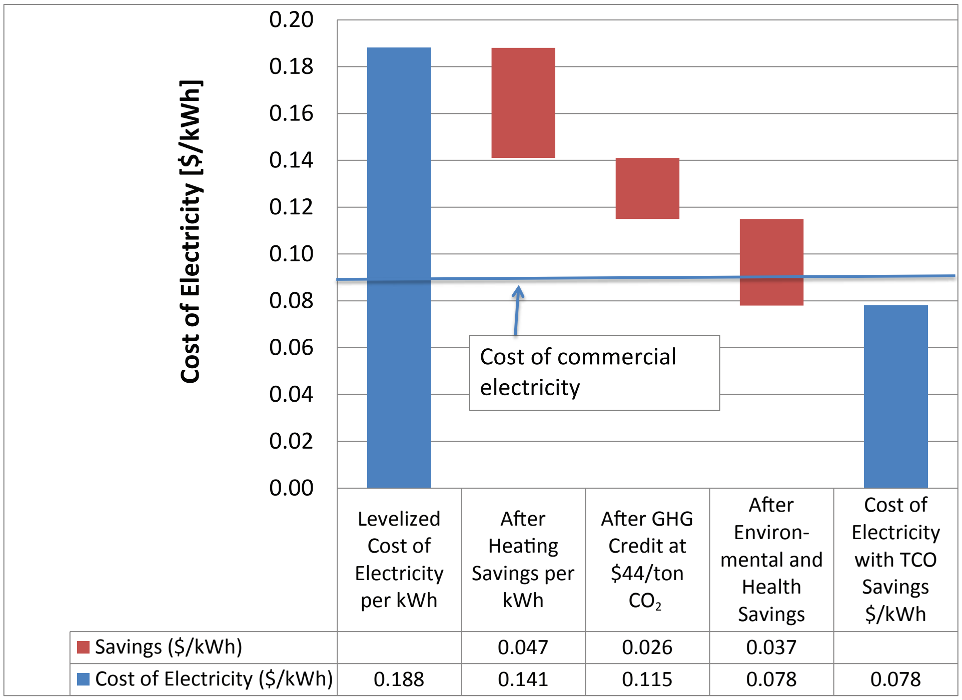


FIGURE 1. Direct cost per kW of 10 kW LT PEM and HT PEM CHP systems vs. annual manufacturing volume (FP = fuel processor; BOP non FP = balance of plant not including FP)



	Levelized Cost of Electricity per kWh	After Heating Savings per kWh	After GHG Credit at $44/ton CO_2	After Environ-mental and Health Savings	Cost of Electricity with TCO Savings $/kWh
🟥 Savings ($/kWh)		0.047	0.026	0.037	
🟦 Cost of Electricity ($/kWh)	0.188	0.141	0.115	0.078	0.078

FIGURE 2. Total cost of electricity with 10 kW HT PEM system in a small hotel in Chicago with water heating and space heating offset by the fuel cell system and an installed cost of $4,400/kW (GHG = greenhouse gas)

Figure 3 shows a plot of direct manufacturing costs as a function of annual production volume for a 10 kW SOFC CHP system. The cost drops from $2,677/kW at low volume to $1,103/kW at high volume (50,000 units per year), driven largely by capital cost reduction at high volume as the capital cost is amortized over a greater number of units. At low volume, 39% of the system cost is from the stack, but this contribution drops to 16% of overall cost at high volume as the stack costs drop more rapidly with increasing production volume than do the costs of non-stack BOP and fuel processing equipment.

Figure 4a shows the stack components are dominated by the electrode-electrolyte-electrode assembly as production volumes increase. Interconnects are a larger fraction at low volumes due to high initial tooling costs. Figure 4b shows 10 kW CHP nonstack component costs for the 10 kW CHP system at 10,000 units/year. The fuel processing, heat management, and power conditioning subsystems make up 70% of nonstack component costs. As system sizes increase, power conditioning equipment makes up the largest portion of BOP costs.

CONCLUSIONS AND FUTURE DIRECTIONS

- Direct costs for SOFC CHP 10 kW systems are found to be $3,240/kW at annual production volumes of 100 systems per year and $1,170/kW at 50,000 systems per year (Figure 3).
- For 100 kW CHP systems with reformate, the 2015 DOE cost target at 1,000 units per year can be met with LT

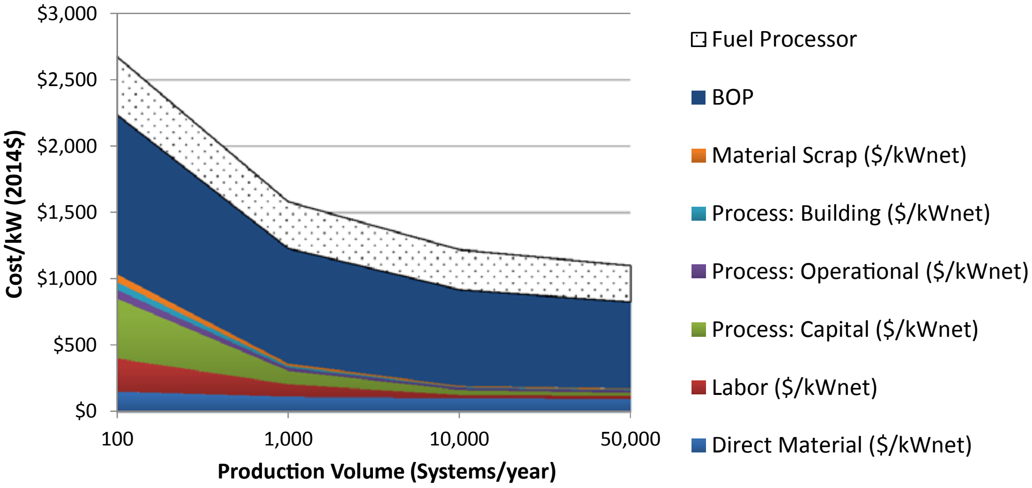


FIGURE 3. Direct system costs vs. production volume for 10 kW SOFC CHP system

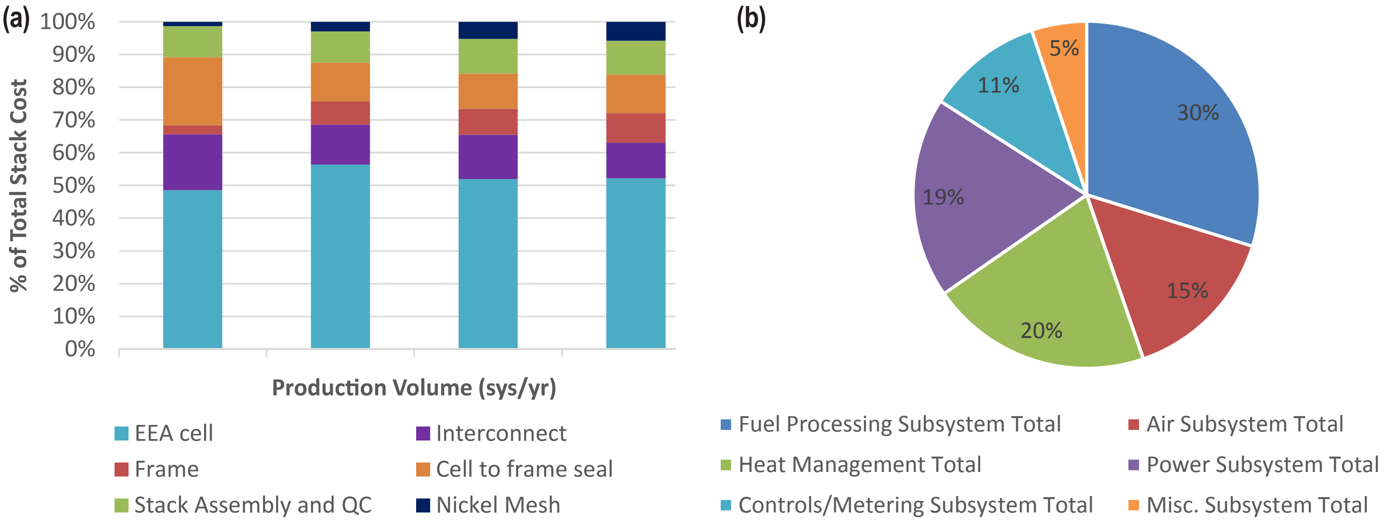


FIGURE 4. (a) Break down of total stack cost and (b) non-stack cost components for a 10 kW SOFC CHP system at annual production volume of 10,000 units per year

PEM, HT PEM, and SOFC 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 any of the three technologies. For 10 kW CHP systems, at 50,000 units per year, both PEM technologies exceed the cost target for both 2015 and 2020 but the SOFC system is close to achieving the $1,700/kW 2020 target.

- Non-stack costs (BOP and fuel processor) are generally found to be the largest component of CHP system costs for LT PEM, HT PEM systems, and SOFC 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.
- Total cost of ownership including greenhouse gas, 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. Fuel cell systems are most economically competitive from a total cost of ownership perspective in regions with high carbon intensity grid electricity.
- The research team is refining the direct cost modeling and completing the TCO model for SOFC CHP systems in the final quarter of FY 2015.
- Scenario modeling is also being done for fuel cell system lifetime costs vs. the no-fuel cell case of grid electricity and conventional heating as a function of fuel and electricity costs, fuel cell system capital costs, the carbon intensity of grid electricity, and state and federal incentives.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. T. Lipman, M. Wei, Ahmad Mayyas, David Gosselin, Shuk Chan, Hanna Breunig, Tom McKone, “A Total Cost of Ownership Model for Low and High Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications,” Fuel Cell Seminar, Los Angeles, CA, November 2014.

2. M. Wei, 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, October 2014.

3. M. Wei, Timothy Lipman, Ahmad Mayyas, Shuk Han Chan, David Gosselin, Hanna Breunig, Michael Stadler, Thomas McKone, “A Total Cost of Ownership Model for High Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications,” Lawrence Berkeley National Lab Report LBNL-6772E, October 2014.

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12. M. Wei, 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, October 2014.