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

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Project Start Date: October 1, 2011
Project End Date: September 30, 2016.

Overall Objectives

- Develop total cost of ownership (TCO) modeling tool for design and manufacturing of fuel cell systems in emerging non-automotive markets (e.g., stationary power, co-generation, and backup power systems) for low-temperature polymer electrolyte membrane (LT-PEM), high-temperature polymer electrolyte membrane (HT-PEM), and solid oxide fuel cell (SOFC) systems from 1-250 kW.
- Demonstrate expanded cost modeling framework by including life cycle analysis and possible ancillary financial benefits—including carbon credits, reductions of health and environmental externalities, end-of-life recycling, and reduced costs of building operation.
- Provide capability for sensitivity analysis to key cost assumptions, externality valuation, and policy incentive structures.

Fiscal Year (FY) 2013 Objectives

- Develop direct manufacturing cost model for LT-PEM combined heat and power (CHP) and backup power systems.
- Complete literature and patent search and functional specification definition for HT-PEM CHP systems.
- Develop TCO model for LT-PEM CHP and backup power systems.

Technical Barriers

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

Fuel Cells

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

Manufacturing R&D

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

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

Technical Targets

This project is conducting TCO 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 CHP system equipment cost targets:

System	2015 Target	2020 Target
10 kW CHP System	$1,900/kW	$1,700/kW
100 kW CHP System	$2,300/kW	$1,000/kW

FY 2013 Accomplishments

- Developed system designs and functional specifications for LT PEM fuel cell systems for backup power (1-50 kW) and CHP applications (1-250 kW) and defined functional specifications for HT-PEM CHP systems (1-250 kW).
- Developed direct manufacturing cost model for LT-PEM fuel cell systems for CHP and backup power applications including key fuel cell stack component costing as a function of manufacturing volume and system size and automated roll-to-roll and assembly processing. The manufacturing and assembly process flow meets DOE cost targets for 2020 for 100-250 kW CHP systems.
- Literature search and patent review completed for HT-PEM fuel cell stack components.

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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. The full value of fuel cell systems cannot be captured without considering the full range of TCO factors. 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 2013 has been focused to date on the development of a direct manufacturing cost model for LT-PEM systems for application in CHP and backup power and demonstration of use-phase cost modeling.

APPROACH

Direct manufacturing costing utilizes bottom up, Design for Manufacturing and Assembly (DFMA®) techniques to optimize system design, materials and manufacturing flows for lowest manufacturing cost. 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. DFMA® manufacturing approaches for each stack component is summarized in Table 1a. Life cycle or use-phase costing will utilize existing LBNL tools [5], characterization of commercial building electricity and heating demand by geographical region, and earlier CHP modeling work by one of the authors [6].

Life cycle impact assessment is focused on use-phase impacts from energy use, carbon emissions and pollutant emissions [8], specifically on particulate matter emissions since they are the dominant contributor to life cycle impacts [9]. Health impact from particulate matter emissions will be characterized using existing LBNL health impact models [10]. A scenario analysis approach will be used where life cycle impact assessment will be characterized as a function of fuel cell system adoption by building type and geographic location. This approach allows the quantification of externalities (e.g. CO_2 and particulate matter) for varying degrees of fuel cell system market adoption in various regions of the U.S.

RESULTS

LT-PEM fuel cell systems and functional specifications have been developed for the range of systems sizes of 1-250 kW for CHP with direct H_2 and reformate fuel and 1-50 kW for backup power systems with direct H_2 fuel. System design for a 100-kW CHP system operating on reformate is shown in Figure 1. It includes an air slip input for greater CO tolerance, a liquid cooling sub-system, and larger stack sizing compared to the direct H_2 case due to slightly lower average stack electrical efficiency. Functional specifications for the 100-kW reformate case are shown in Table 1b. Backup power systems achieve cost reduction through simplification of balance-of-plant components with air cooled system design and once-through H_2 fuel supply.

Key fuel cell stack component costing and related balance-of-plant component costing has been completed as a function of manufacturing volume and system size. Both the catalyst coated membrane (CCM) and gaseous diffusion layer (GDL) are fully automated roll-to-roll processing; membrane electrode assembly (MEA) and stack assembly is fully automated at higher volume; and bipolar plates are semi-automated batch processing. The CCM and MEA frame/seal makes up 63% of overall stack costs at 1,000 systems/year with the plate and GDL at 18% each. The bipolar plate module is shown for illustration in Figure 2. To achieve lower cost at high volume, injection molding is utilized rather than the more common compression molding process. Material costs constitute over 80% of stack costs at high production volume.

TABLE 1. (a) DFMA® manufacturing approaches for LT-PEM CHP and backup power systems. Full DFMA® analysis has been completed on components marked with an asterisk (*). (b) Functional specifications for 100-kW CHP system operating with reformate fuel.

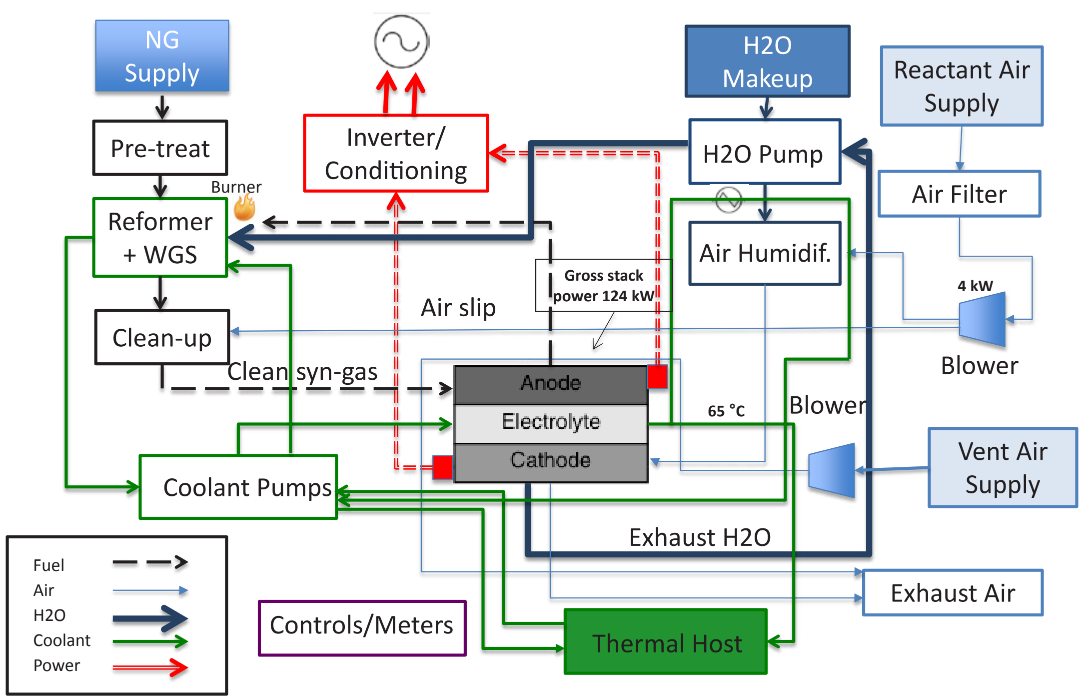
Component	Primary Approach	Reference
Membrane	Purchase Nafion®	Patent review, industry input
CCM*	Dual decal, slot die coating.	Literature, patents, industry input
GDL*	Spray coat MPL	[2,4]
Bipolar Plates*	Injection molded graphite –carbon composite	Literature, patents, industry input
Seal/Frame MEA*	Framed MEA	Patents, [7]
Stack Assembly*	Partial to fully automated	Patents, industry input
Endplate/Gaskets	Graphite composite/ Screen printed	Industry input, [4]
Test/Burn-in	Post assembly 3 hrs	Industry input

(a)

Parameter	Value	Unit
Gross system power	124	kW
Net system power	100	kW
Electrical output	480 V AC	Volts AC or DC
Waste heat grade	65	Temp. °C
Fuel utilization	80-95	%
Average system net electrical efficiency	32	% LHV
Thermal efficiency	51	% LHV
Total efficiency	83	Elect.+thermal (%)
Stack power	9.5	kW
Total plate area	360	cm^2
CCM coated area	232	cm^2
Single cell active area	198	cm^2
Gross cell inactive area	45	%
Cell amps	111	A
Current density	0.56	A/cm^2
Reference voltage	0.7	V
Power density	0.392	W/cm^2
Single cell power	78	W
Cells per stack	122	Cells
Stacks per system	13	Stacks

(b)

MPL – micro-porous layer; LHV – lower heating value; AC - alternating current; DC direct current



NG - natural gas; WGS - water-gas shift

FIGURE 1. System schematic design for 100-kW CHP system with reformate.

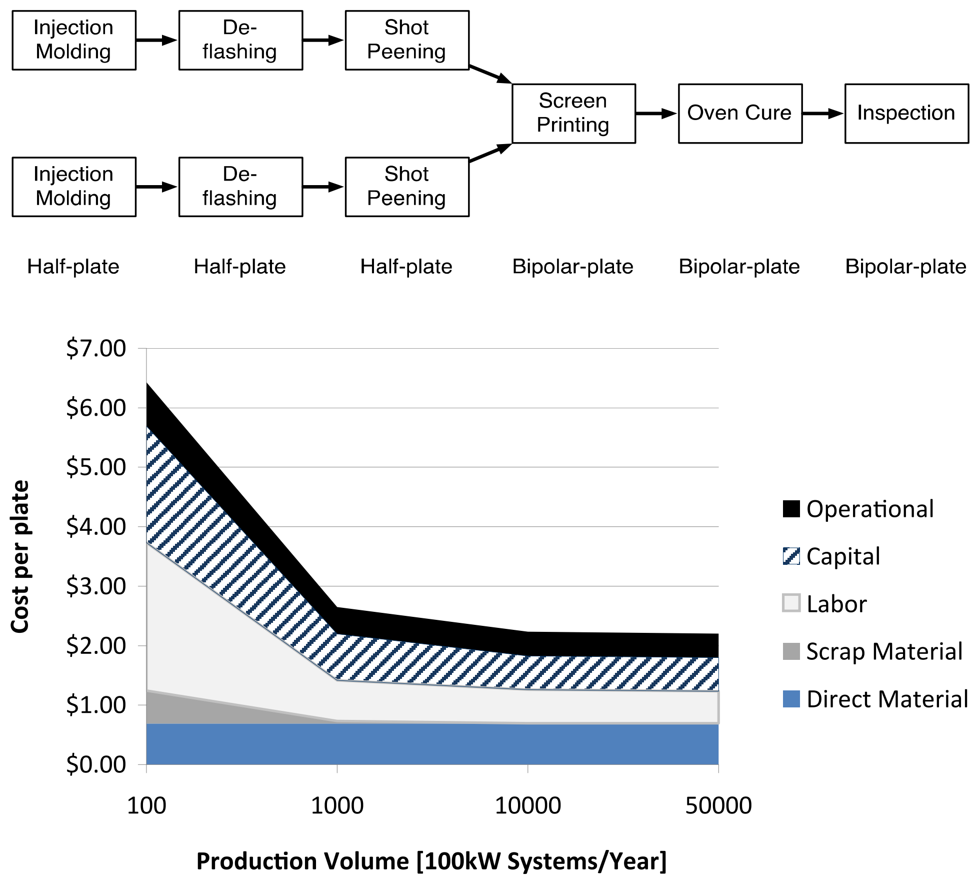


FIGURE 2. DFMA® example – bipolar plate injection molding process flow and cost per part as a function for annual production volume. Shown is the cost per plate for production volumes of 100-50,000 systems per year of 100-kW-size systems.

As manufacturing volume is increased, more cost reduction is achieved in the stack than balance of plant due to the automated production described in the proceeding for the stack. Equipment costs below $1,000/kW for 100-250 kW CHP systems are achieved, meeting the 2020 DOE target. Figure 3 shows cost estimates for the 100-kW CHP with reformate case, and Figure 4 shows cost results for 10-kW backup power systems. Stack cost for backup power systems is similarly reduced more rapidly than balance of plant with increasing production volume, and total cost per kW is estimated to be $1,262/kW at high volume production.

Use-phase modeling has been demonstrated with the LBNL DER-CAM tool [6] for commercial buildings in several different climate zones in California. This provides more realistic load-shapes for use phase modeling. We also developed a scenario analysis methodology for fuel cell system market penetration in commercial buildings using existing LBNL software tools (DER-CAM tool and APEEP models).

CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions

- Stack cost is dominated by cost of materials at production volumes greater than a few thousands of systems per year.
- Stack cost is reduced more rapidly than balance-of-plant components as volume is increased due to the highly automated production process assumed for the stack.
- Mid-range power (100-250 kW) CHP system costs for volumes greater than 1,000 systems per year are consistent with 2020 DOE cost targets ($1,000/kW equipment cost).
- 10-kW backup power system costs are estimated to be less than $1,300/kW at high volume.

Future Directions

- Develop integrated model with scenario analysis and sensitivity analysis capability to assess the impacts

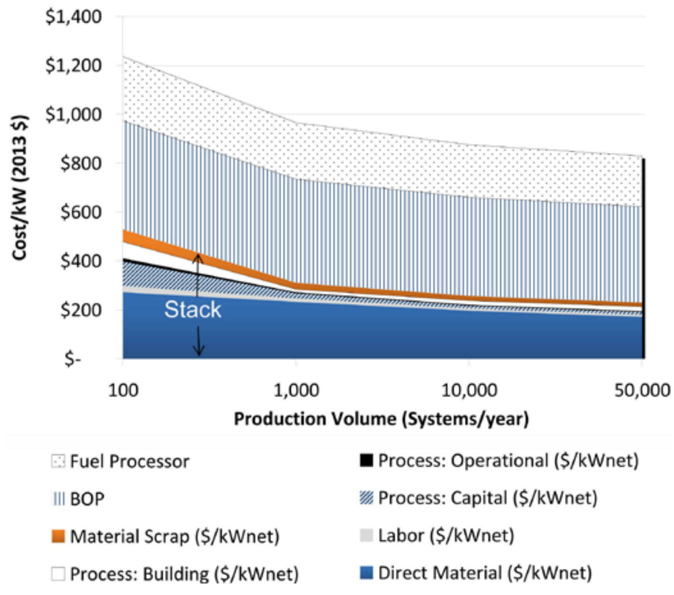


FIGURE 3. Cost results for 100-kW CHP system. Total Pt/Ru loading is assumed to be 0.5 mg/cm^2 Pt and 0.05 mg/cm^2 Ru.

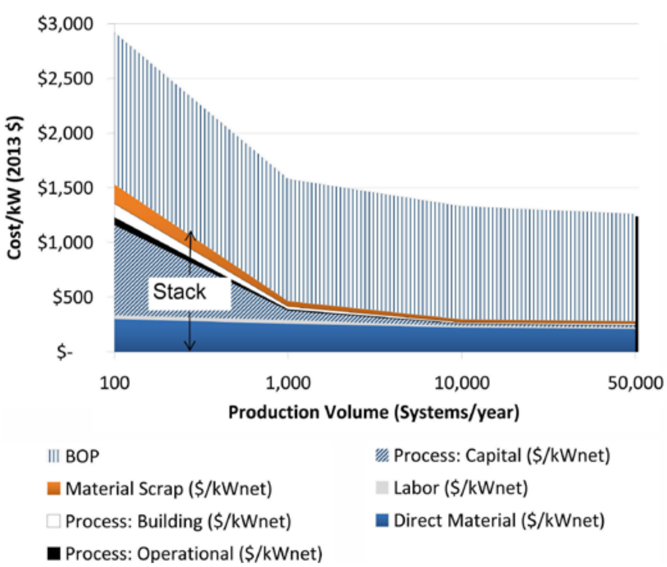


FIGURE 4. Cost results for 10-kW backup power system.

of varying levels of fuel cell system market adoption, externality valuation, and policy incentives.

- Extend the TCO model to include HT-PEM and SOFC in addition to LT-PEM.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. M. Wei, T. McKone, T. Lipman, *A Total Cost of Ownership Model for Design and Manufacturing Optimization of Fuel Cells in Stationary and Emerging Market Applications*, 2013 Annual Merit Review, Arlington, Virginia, May 2013.

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