Manufacturing Competitiveness Analysis for Hydrogen Refueling Stations

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Project Start Date: April 6, 2015
Project End Date: September 30, 2018

Overall Objectives

- Develop manufacturing cost models for the key components in a hydrogen refueling station such as the compressors, dispenser, and on-site hydrogen production systems (proton exchange membrane [PEM] and alkaline electrolyzers).
- Identify cost drivers associated with manufacturing of the key systems in the hydrogen refueling station and on-site production systems to highlight potential cost reduction areas.

Fiscal Year (FY) 2018 Objectives

- Develop a bottom-up manufacturing cost model for the on-site hydrogen production systems (PEM and alkaline electrolyzers).
- Identify potential cost reductions in the manufacturing of PEM and alkaline electrolysis systems.

Technical Barriers

This project addresses the following technical barriers from the Manufacturing R&D section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

(A) Lack of High-Volume MEA Processes

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

(F) Manual Stack Assembly.

Contribution to Achievement of DOE Manufacturing R&D Milestones

This project will contribute to achievement of the following DOE milestones from the Manufacturing R&D section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 1.4: Demonstrate processes for direct coating of electrodes on membranes. (4Q, 2019)
- Milestone 1.5: Demonstrate processes for highly uniform continuous lamination of MEA components. (4Q, 2019)

FY 2018 Accomplishments

- Developed a new set of maps for the major international manufacturers of hydrogen refueling station parts and water electrolysis systems.
- Developed a manufacturing cost model for PEM electrolyzers using different sizes (in kilowatts) and different annual production rates (ranging from 10 to 50,000 electrolyzers per year).
- Developed a manufacturing cost model for alkaline electrolyzers using different sizes (in kilowatts) and different annual production rates (electrolyzers per year).

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

INTRODUCTION

This study is one of a few studies that discuss cost of hydrogen infrastructure. While other studies focus on the big picture by assessing the effect of capital cost reductions on the hydrogen prices, this study provides a detailed bottom-up manufacturing cost analysis for the key systems in the hydrogen refueling station (compressors, pressure vessels, chillers, heat exchangers, and dispensers) and on-site hydrogen production systems (PEM and alkaline electrolyzers). Cost analysis for the key parts and systems in the hydrogen refueling station was completed in FY 2017. In FY 2018, we also developed sets of manufacturing competitiveness analyses for PEM and alkaline electrolyzers to study the effect of cost components (e.g., labor, facilities, and energy costs) in different countries on the electrolyzer cost.

APPROACH

This study is centered around three main analyses: manufacturing competitiveness analysis, supply chain analysis, and effect of qualitative factors on the selection of the manufacturing facility locations for manufacturing of parts and systems used in the hydrogen refueling station and on-site hydrogen production systems. These analyses were completed for the hydrogen refueling station in FY 2015 to FY 2017. In FY 2018, we primarily focused on the manufacturing competitiveness analysis for on-site hydrogen production systems to evaluate relative manufacturing cost in selected countries in North America, Europe, and Asia. The goal of this comparative analysis is to study the advantage of the U.S.-based manufacturers relative to other international manufacturers who could enjoy benefits of the low labor cost, low facilities cost, or low energy cost such as in China and Mexico.

RESULTS

Manufacturing Cost Model

Manufacturing cost models were developed for the key parts in the PEM and alkaline stacks. Table 1 shows important parameters used in developing these cost models for 1-MW systems.

For the PEM electrolyzer stack, we assumed that the catalyst-coated membrane (CCM) is made by depositing catalyst layers (platinum group metals) on both sides of the purchased Nafion membrane[2] to form cathode and anode layers. The porous transport layer (PTL) is made from sintered titanium via a powder metallurgy process. This process allows us to adjust the compaction pressure to get the desired porosity in the PTL (in this analysis, porosity is assumed to be 30% by volume). The CCM and PTL represent the so-called membrane electrode assembly (MEA). Parts in the MEA are held together by the frame that is made from polyphenylene sulfide (PPS) resin mixed with 40% glass fiber. The PPS-based frame provides the flexibility required to hold the MEAs and durability to withstand relatively high operating temperature inside the stack (80°–120°C).

[2] Nafion is a registered trademark for DuPont.

Table 1. Some Parameters Used in Developing Cost Model for PEM Electrolyzer Stack

	PEM		Alkaline	
Part	Assumptions	Notes	Assumptions	Notes
Membrane	Nafion 117 (purchased part)	Alternatives include PFSA (PEEK, PBI) membranes [a]	Tokoyama A201 28 μm (purchased part)	Alternatives include mPBI, LDPE[a]
Catalyst	Pt price = $1,500/tr.oz	DOE current value platinum loadings: Anode = 7 g/m^2 (Pt), Cathode = 4 g/m^2 (Pt-Ir)	n/a	n/a
Electrodes	Slot-die coating of catalyst to get CCM		Raney-Nickel	PVD[b] and selective leaching to get the required porosity
PTL	Sintered porous titanium Ti price = $4.5/kg	Porosity = 30%	Pure nickel sheets	Nickel has good corrosion resistance in alkaline solution
Frame	PPS-40GF or PEEK	0.635 cm from each side for MEA bonding	PPS-40GF or PEEK[c]	
Plates	Stainless steel 316L	Coated (plasma nitriding)	Nickel plates	Surface treatment of high-purity Ni sheets

[a] PFSA – perfluorosulfonic acid, PEEK – polyetheretherketone, PBI – polybenzimidazole, LDPE – low density polyethylene
[b] PVD – physical vapor deposition
[c] PPS-40GF – polyphenylene sulfide with 40% glass fiber filler

The alkaline electrolyzer stack consists of Raney-Nickel electrodes on both sides and Tokoyuma A201 membrane in the middle (alternative membranes include mPBI and asbestos-based membranes, see [1–3] for discussion on characteristic and performance of these membrane technologies in the alkaline electrolyzers). Nickel is known to have good corrosion resistance to the alkaline solutions and good current densities [4]. Seal and frame are made from PPS-40GF: polyphenylene sulfide with 40% glass fiber filler (alternative membrane technologies include perfluorosulfonic acid and PEEK).

The PEM stack cost curve in Figure 1 shows the effect of the annual production rates on the total PEM stack cost. Generally, we can see that stack cost is decreasing with the annual production rates. This figure also shows that PEM stack cost is dominated by the CCM cost, followed by these parts in order from high cost to low cost contributions: PTL, assembly and end-plates, bipolar plates, and frame/seal. We should remember that CCM consists of Nafion membrane and platinum group metals, and both are high-cost materials.

The cost curve and cost breakdown for the alkaline stack as a function of the annual production rate are shown in Figure 2. We can see that the stack cost is dominated by the membrane cost followed by the cost of the following parts in order from high cost to low cost contributions: electrodes, bipolar plates, balance of stack (wiring, housing, insulation, etc.) and assembly and end-plates.

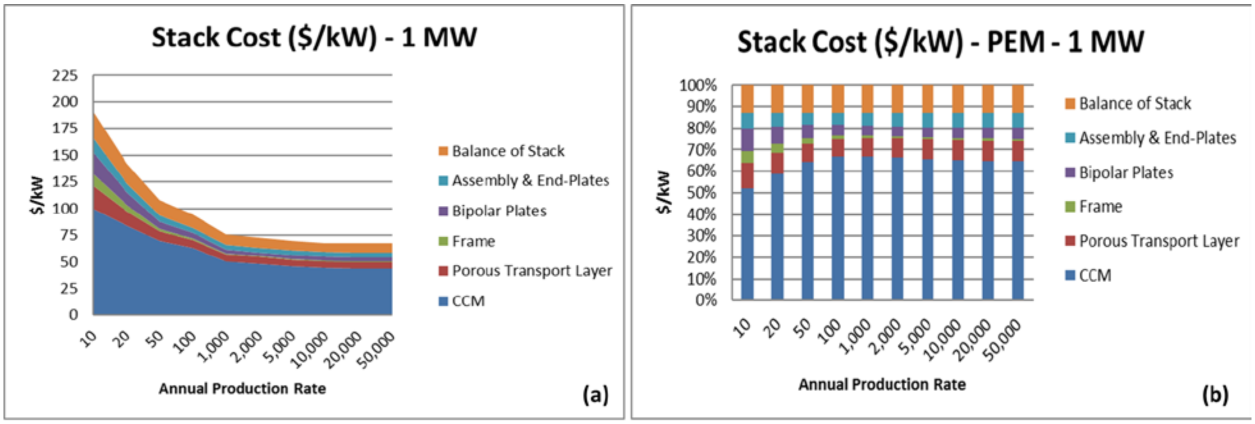

Figure 1. (a) Manufacturing cost curve for 1-MW PEM electrolyzer stack. (b) Cost breakdown for this system at different annual production rates (production capacity = 170 Nm^3/h [367 kg/day]).

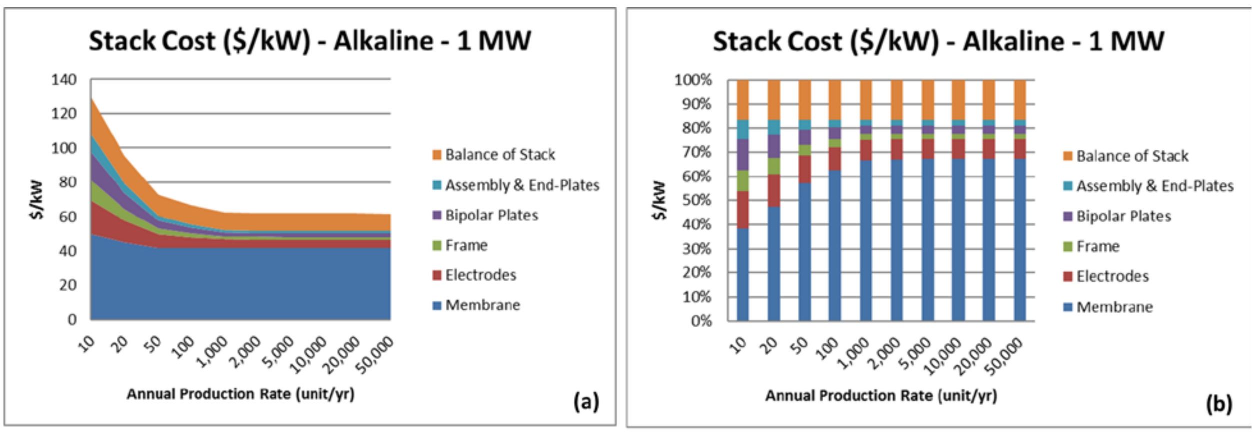

Figure 2. (a) Manufacturing cost curve for 1-MW alkaline electrolyzer stack. (b) Cost breakdown for this system at different annual production rates (production capacity = 110 Nm^3/h [237 kg/day]).

The PEM system cost and cost breakdown are shown in Figure 3a and 3b respectively. Balance of plant (BOP) dominates the total system cost at different annual production rates. Here, we assumed that BOP parts are outsourced from part vendors, so we do not expect economies of scale to have the same impact as in the case of a stack that is manufactured in-house. Power supplies (AC/DC rectifier) dominate the balanceof plant cost followed by the deionized water circulation unit, which contains an expensive water/oxygen separation tank that separates oxygen and water coming out of the stack.

The alkaline electrolyzer system cost and cost breakdown are shown in Figure 3c and 3d, respectively. Like the PEM electrolysis system, the alkaline electrolysis system cost is dominated by the BOP (major contributor is the power supplies). The hydrogen processing unit and electrolyte circulation subsystem each contribute to about 10%–15% in the total system cost.

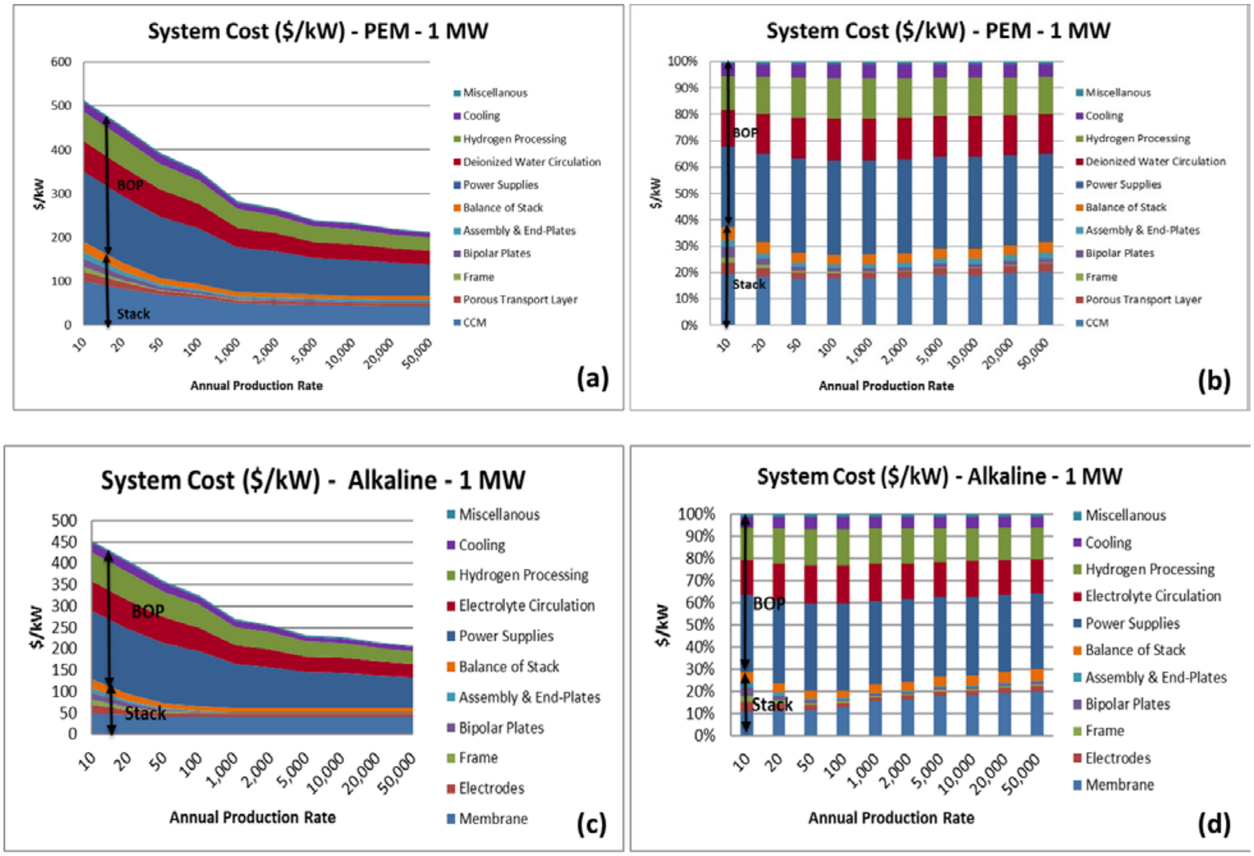

Figure 3. (a) Cost curve for 1-MW PEM electrolyzer system showing cost of the stack and BOP. (b) Cost breakdown for 1-MW PEM electrolyzer at different annual production rates. (c) Cost curve for 1-MW alkaline electrolyzer system showing cost of the stack and BOP. (d) Cost breakdown for 1-MW alkaline electrolyzer at different annual production rates. (Note: Hydrogen production capacity for 1-MW PEM electrolyzer is 170 Nm^3/h [367 kg/day], and hydrogen production capacity for 1-MW alkaline electrolyzer is 110 Nm^3/h [237 kg/day].)

Manufacturing Competitiveness Analysis

Manufacturing competitiveness analysis was used to examine the relative cost of manufacturing PEM and alkaline stacks in several countries and to study the cost advantages of the U.S.-based manufacturers over other international manufacturers. Figure 4 shows the manufacturing cost for 1-MW PEM and alkaline stacks. By looking at these charts we can see that China's advantage relative to the United States is driven by lower labor (including stack assembly, which is a labor-intensive process), building, and energy costs. Mexico's advantage relative to the United States is driven by lower labor (including assembly) and building costs. Relative cost of the stack is higher in Europe because of the higher labor and energy costs. Similarly, the relative cost of the stack is higher in Japan (relative to the United States) because of the higher labor costs in Japan.

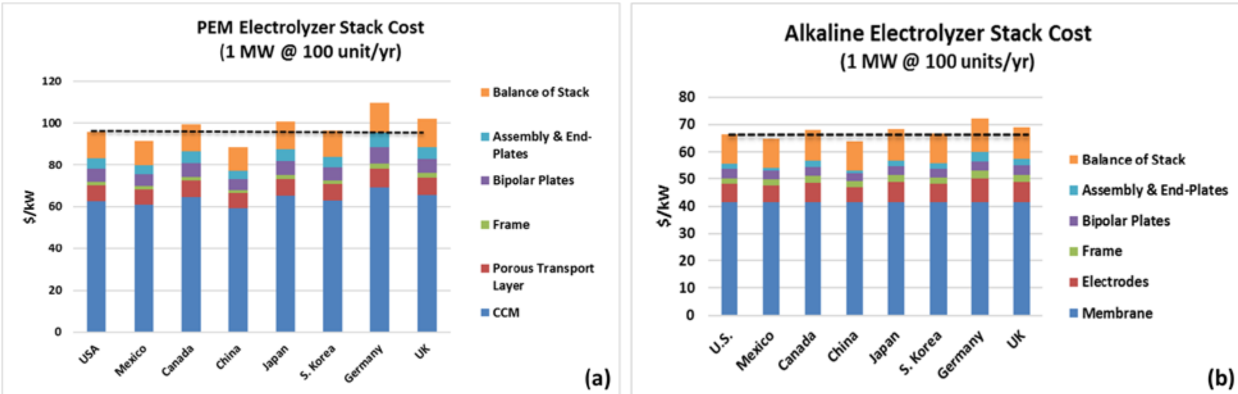

Figure 4. (a) Manufacturing cost for 1-MW PEM electrolyzer stack (production capacity 170 Nm^3/h [367 kg/day]). (b) Manufacturing cost for 1-MW alkaline electrolyzer stack (production capacity 110 Nm^3/h [237 kg/day]).

CONCLUSIONS AND UPCOMING ACTIVITIES

This project discusses manufacturing competitiveness analysis for the hydrogen refueling stations including on-site hydrogen production systems. In FY 2018, we focused on the on-site hydrogen production systems (PEM and alkaline). Bottom-up cost models were developed for the major parts in PEM and alkaline stacks. For a 1-MW system, we found that system costs (total of the stack and BOP) for both PEM and alkaline electrolyzers are dominated by the BOP cost at higher production rates. At the stack level, the CCM in the PEM stack and membrane in the alkaline stack dominates the stack cost.

This project was concluded in September 2018, but we believe that there are many areas that need further investigations to direct future R&D efforts in stack manufacturing and BOP standardization. Roll-to-roll manufacturing of CCM and increasing the automation level in the stack assembly are two important areas where we can see cost reductions in stack manufacturing. Standardization of BOP parts is another area where R&D efforts can be made to lower the cost of BOP, which contributes about two-thirds of the cost of a 1-MW PEM electrolyzer.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. Ahmad Mayyas, "Manufacturing Competitiveness Analysis for Hydrogen Refueling Stations," Presentation at the Annual Merit Review, Washington, D.C., June 4, 2018.
2. Ahmad Mayyas and Margaret Mann, "Emerging Manufacturing Technologies for Fuel Cells and Electrolyzers," Accepted for publication in *Procedia Manufacturing* (2018).
3. Ahmad Mayyas, Margaret Mann, and Mark Ruth, "Manufacturing Competitiveness Analysis for PEM and Alkaline Water Electrolysis Systems," Fuel Cell Seminar and Energy Exposition, Long Beach, CA, November 7–9, 2017.

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4. D. Symes, B. Al-Duri, W. Bujalski, and A. Dhir, "Cost-effective design of the alkaline electrolyser for enhanced electrochemical performance and reduced electrode degradation," *International Journal of Low-Carbon Technologies* 10 (2015): 452–459.