VII.I.9 Cost Analyses of Fuel Cell Stack/Systems

Eric J. Carlson (Primary Contact), Peter Kopf, Jayanti Sinha, Suresh Sriramulu, Yong Yang
TIAX LLC
Acorn Park
Cambridge, MA 02140-2390
Phone: (617) 498-5903; Fax: (617) 498-7295; E-mail: carlson.e@tiaxllc.com

DOE Technology Development Manager: Nancy Garland
Phone: (202) 586-5673; Fax: (202) 586-9811; E-mail: Nancy.Garland@ee.doe.gov

NREL Technical Advisor: Keith Wipke
Phone: (303) 275-4451; Fax: (303) 275-2905; E-mail: keith_wipke@nrel.gov

Contract Number: KA CX-5-44452-01

Start Date: 4/12/2005
Projected End Date: 9/30/2005

Objectives

The objectives for 2005 for the cost assessment project were to

- Establish and develop baseline cost data for an 80 kW fuel cell system assuming today's technology, but based on high volume production of 500,000 units per year
- Obtain feedback from the FreedomCAR Technical Team and component developers on the fuel cell system, component, and stack cost projections and assumptions

The results of this analysis will be used to evaluate the status of transportation fuel cell technology relative to DOE's milestone cost target for 2005 of $125/kW. The analysis only considers the fuel cell stack subsystem and excludes hydrogen storage.

Technical Barriers

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

- B. Cost

Approach

- Obtain feedback from the FreedomCAR Fuel Cell Tech Team on performance and system assumptions prior to initiating the work to update the 2004 system cost estimate and analyses
- Work with ANL to update stack sub-system model and projections of efficiency and sizing of components
- Obtain feedback from component, stack, and system developers on the assumptions and cost projections. Incorporate the developer comments into a revised cost projection.
- Prepare a final written report and the required inputs needed by the DOE to assess the 2005 status of polymer electrolyte membrane fuel cell (PEMFC) cost relative to this year's cost milestone.

Accomplishments

- Updated the 2004 cost projection for PEMFC systems for transportation applications (at this time the value does not reflect developer feedback)

Future Directions

- The project concludes this fiscal year.

Introduction

At the outset of TIAX's cost assessment work for the DOE six years ago, the focus was on the analysis of reformate PEMFC system costs. However, with initiation of the FreedomCAR Program emphasis has shifted to direct hydrogen systems. Consequently, our efforts shifted correspondingly with last year's consideration of compressed hydrogen storage and this year's focus on a direct hydrogen fueled fuel cell subsystem.

Cost analysis of new technologies provides insights into potential barriers to commercialization. The analysis can identify key cost drivers and materials, components, or performance metrics in need of additional R&D. Annual updates of the high volume cost projection provide one metric of the status of PEMFCs for transportation relative to internal combustion engine powertrains and DOE program goals.

Cost analysis of fuel cell systems brings together the technology of fuel cell systems and the manufacturing of materials and engineered systems. Hence, cost projection entails understanding not only the cost of materials and production processes, but also the status of fuel cell stack technology, balance-of-plant components, and system integration. The selected system and its scaling and operating parameters must meet multiple criteria including performance, efficiency, life, weight, volume, and cost. The latter is the focus of this project. At this stage of fuel cell technology development, not all of this information will be available simultaneously.

Approach

To address the question of selection of the system configuration, component technologies, and operating parameters, the Fuel Cell Tech Team was designated to obtain periodic feedback from the auto companies. Of the fuel cell stack operating parameters, power density (and associated cell voltage) is the most critical parameter, as it determines the size of the stack. In conjunction with the system configuration and stack operating parameters, the system model then provides the framework for scaling the components, calculating the efficiency, and determining the gross power of the stack. For example, parasitic power losses in the system typically add 10% to the rated power of the stack. The system model provides a means of assessing the trade-offs betweem stack power and overall system efficiency. The modeling group of Argonne National Laboratory (ANL) continued to conduct these analyses for the project in addition to providing inputs on component technologies, such as water and thermal management.

For the cost analysis, we have conducted bottom-up costing for the key stack components (i.e., membrane, gas diffusion layer [GDL], electrodes, membrane electrode assembly [MEA], and bipolar plates/gaskets). The technical and patent literature was reviewed before defining and costing a process for the membrane. Uncertainties were addressed in cost analysis by conducting a sensitivity analysis to material costs, line speeds, and the scale of the coater (width). In addition to the membrane cost, the cost basis for the bipolar plates and gas diffusion layers were updated. The electrodes and the contribution of platinum continue to be a major cost contributor and the recent high platinum prices were addressed in our sensitivity analysis. We used $29/g ($900/ tr. oz.) for the platinum price to show the impact of recent historic highs, but used the traditional price of $450/tr.oz. as a lower bound in the sensitivity analysis. Balance-of-system components (i.e., compressor-expander, condensers, humidifiers, heat exchangers, pumps, and controls) were considered to be purchased components and their costs were estimated through discussions with developers and experts within TIAX.

After development of the updated baseline system cost and sensitivity analyses we obtained feedback from the developers of stack and system components.

Results

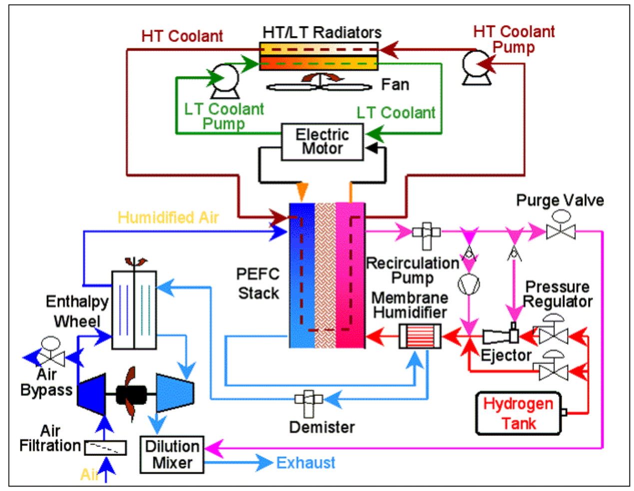
For this year's analysis, the system is defined as the fuel cell subsystem including the stack and the air, thermal, and water management associated with operation of the stack. The fuel (hydrogen storage) subsystem is not included in this cost analysis. Figure 1 shows a high level view of the system configuration modeled by ANL, while Table 1 lists key descriptive parameters for the system at rated power. The gross stack power is approximately 90 kW at the beginning of life. The system efficiency at rated power (0.65V) is approximately 45%.

Table 1. System Components and Parameters

Subsystem	Parameter	Unit	Value
PEMFC Stack	Pressure	atm	2.5
	O_2 Utilization	%	50
	H_2 Utilization per pass	%	70
	Cell Voltage @ rated power	V	0.65
Air Management	Compressor-Expander Module, liquid cooled motor, turndown: 20:1		
Fuel Management	Hybrid ejector – H_2 recirculation pump (=20%)		
Water Management	Enthalpy wheel humidifier for cathode air, 60% relative humidity (RH) at rated power		
	Membrane humidifier for H_2, 60% RH at rated power		

Source: Dr. Rajesh Ahluwalia, ANL

For a 50 µm (2 mil) perfluoro-sulfonic acid membrane, a baseline cost of \$23/m^2 was estimated from the analysis. The impact of critical parameters, including membrane width, coating speed, Nafion® cost, and process yield, is shown in the results of a single variable sensitivity analysis in Figure 2. Materials represented approximately 90% of the membrane cost. The estimated cost is in line with



Source: R.K. Ahluwalia, ANL

Figure 1. Fuel Cell System Layout

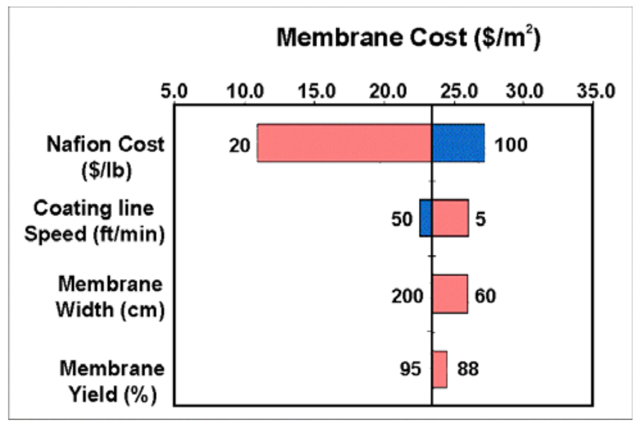


Figure 2. Membrane Sensitivity Cost Analysis

published projections for comparable production volumes [1].

The results of the stack cost update are first presented on an area basis to show the impact of material cost and specification (e.g., thickness of layers, porosity) changes. Consequently, the impact of increasing power density on the final \$/kW cost can then be separated out. Table 2 shows the 2004 and 2005 baseline stack costs and the primary drivers for the changes. On a net basis, the increase in electrode cost (315%) was greater than reductions in membrane (52%), GDL (43%), and bipolar plate (37%) costs. Overall, on an area basis the cost increased by 60% largely driven by increases in the electrode costs.

Table 2. Stack Costs on an Area Basis Compared with 2004 Values

Component	2004 Cost ($/m^2)	2005 Cost ($/m^2)	Cost Drivers/Comments
Membrane	48.9	23.4	TIAX bottom-up analysis
Electrode	67.2	279.0	Loading from 0.3 to 0.75 mg/cm^2, $29/g Pt
GDL	32.0	18.4	Reduction in thickness from 350 to 260 µm
Bipolar Plates	27.7	17.4	Material changed from molded graphite to expanded graphite, thinner plate with less material
Seal	7.3	6.1	Increased amount of material, but switched from fluoropolymer to nitrile rubber ($5/lb)
Balance of Stack	6.9	6.0	
Final Assembly	8.1	10.5	Does not include stack conditioning and QC
Total	225.9	360.8	

Based on discussions with the Fuel Cell Tech Team, the assumed power density increased 70% from 350 to 600 mW/cm^2. The smaller stack size was largely offset by the increased material cost ($/m^2) leading to a slightly lower stack cost, from 72 $/kW to 67 $/kW. Figure 3 shows the percentage contribution of each component to the stack cost. With the increase platinum loading and price the electrodes are approximately 80% of the stack cost, while the bipolar plates and the membrane contribute 5% and 6% respectively.

Figure 4 shows the results of a single variable sensitivity analysis on the area cost. Consistent with the large contribution of the electrodes to the stack cost, the top three factors are power density, platinum cost, and platinum loading. After these factors, membrane and graphite cost are next in importance.

The cost of the balance-of-plant components will be provided in the final report.

Our assessment has tried to capture the dominant cost contributors from the stack materials and

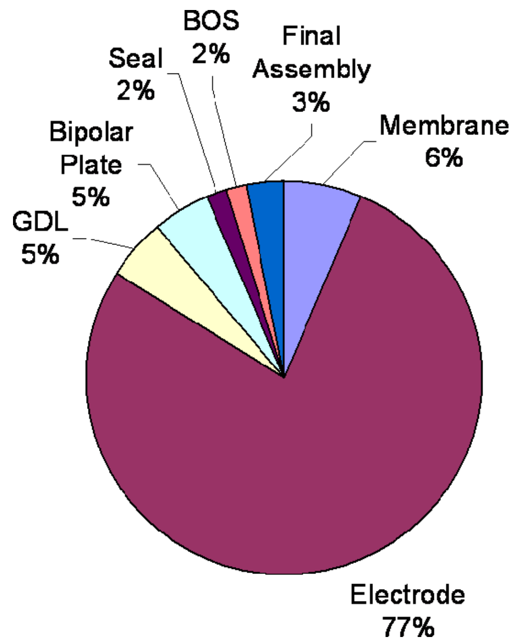


Figure 3. Baseline Cost Estimate for the Stack

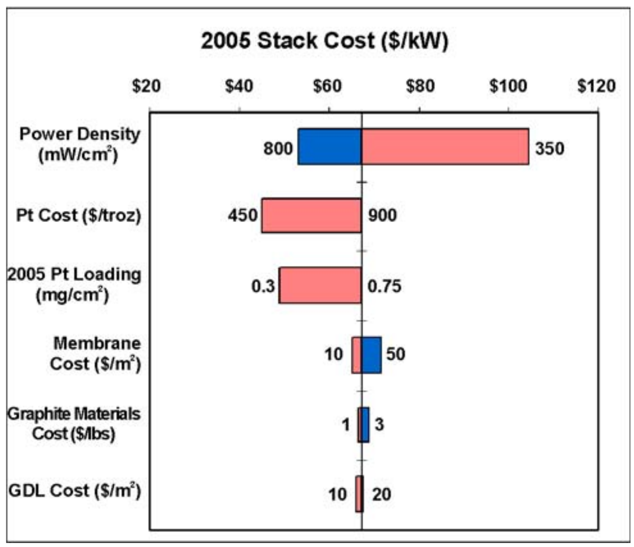


Figure 4. Stack Sensitivity Cost Analysis ($/m^2)

balance of plant (BOP) perspective. However, our analysis to date does not include the following:

- Any additional BOP components or modifications to the stack materials to address start-up in freezing conditions are not factored into the system or cost.
- Quality control tests on sub-assemblies, individual stacks, and the system have not been included. Testing of the stack would also include leak testing, break-in of the stack, and

performance testing. The cost contribution could be significant because break-in/test times could range from several hours to 24 hours and would include capital equipment costs for the gas manifolds, discharge loads, heat exchangers, humidifiers, and consumables such as hydrogen.

- Use of advanced hydrogen storage technologies will add hardware for thermal integration of the stack with the storage system. On a total system basis this could lower cost, but might make the stack subsystem more expensive.

We have also assumed a vertically integrated manufacturing process for the stack components and stack. In practice, many of these components would be purchased and their cost would contain profit and other markups. Consequently, the cost presented represents a minimum cost for the presented assumptions.

Note: the system technology assessed in this analysis does not meet all of the DOE targets, including efficiency and life. The cost would be increased significantly if these requirements had been met by increasing stack size to account for power degradation over the design life or increased cell voltage to meet efficiency targets. It was assumed the specified system would meet these targets simultaneously at some time in the future.

Conclusions

- The stack cost has only decreased slightly from earlier projections because the benefits of increased power density and lower membrane, GDL, and bipolar plates were offset by increased platinum loading and price.
- Assuming that BOP components costs are similar to those projected in 2004, the overall projected fuel cell sub-system cost should meet the 2005 cost target of $125/kW.

References

1. M. Mathias, H. Gasteiger et al., "Can Available Membranes and Catalysts Meet Automotive Polymer Electrolyte Fuel Cell Requirements", Am. Chem. Soc. Preprints, Div. Fuel Chem., 2004, 49(2), 471

FY 2005 Publications/Presentations

1. Presentations to FreedomCAR Fuel Cell Tech Team
2. 2005 Fuel Cell Seminar Presentation