DOE Hydrogen and Fuel Cells Program Record	
Record #: 11012	**Date:** August 17, 2011
Title: Fuel Cell System Cost - 2011	
Update to: Record 10004	
Originator: Jacob Spendelow and Jason Marcinkoski	
Approved by: Sunita Satyapal	**Date:** September 7, 2011

Item:

The cost of an 80-kW_{net} automotive polymer electrolyte membrane (PEM) fuel cell system based on 2011 technology[1] and operating on direct hydrogen is projected to be $49/kW when manufactured at a volume of 500,000 units/year.

Rationale:

In fiscal year 2011, Strategic Analysis, Inc. (SA)[2] updated the 2010 Directed Technologies, Inc. (DTI) cost analysis of 80-kW_{net} direct hydrogen PEM automotive fuel cell systems, based on 2011 technology and projected to a manufacturing volume of 500,000 units per year [1]. Results from the analysis were communicated to the DOE Fuel Cell Technologies program (FCT) at the DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation [2] and at a meeting of the U.S. Drive Fuel Cell Technical Team (the Tech Team) [3]. The Tech Team found the SA analysis to be rigorous and accurate, and accepted the resulting high-volume cost estimate of $49/kW as a reasonable estimate of 2011 cost status. The SA estimate of $49/kW has been accepted as the FCT 2011 cost status.

The SA cost analysis, which is based on performance at beginning of life, uses a fuel cell model developed at Argonne National Laboratory (ANL) [4] to predict stack performance as a function of operating conditions. The SA analysis assumes use of membrane electrode assemblies (MEAs) containing state-of-the-art 3M nanostructured thin film (NSTF) ternary platinum-alloy catalyst layers on 25.4 micron reinforced Nafion® membranes. The Pt commodity cost of $1100 per troy ounce for the 2011 analysis is consistent with the Program's 2006-2010 analyses. All costs in the 2011 analysis are calculated using 2011 dollars.

SA performed an optimization study in fiscal year 2011 in which four system design points (cathode catalyst loading, maximum operating temperature, maximum operating pressure, and oxygen stoichiometric ratio) were varied to minimize system cost. The optimization study also updated the polarization curve to a new version, provided by ANL. This polarization curve is based on the same 3M MEAs used in the 2010 analysis, but it also includes stack voltage losses, making it a more conservative estimate of stack

[1] The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.
[2] On June 30, 2011 Directed Technologies, Inc. merged with Strategic Analysis, Inc.

performance. The design points used in the 2010 and 2011 analyses, with the resulting cost estimates, are summarized in Table 1.

Table 1: System design points and system cost from the 2010 DTI and 2011 SA analyses.

Characteristic	**Units**	**2010**	**2011**
Stack efficiency at rated power	%	55	55
Cell voltage at rated power	V	0.676	0.676
Oxygen stoichiometric ratio[a]		2.5	1.5
Peak stack operating pressure[a]	atm	1.69	3
Peak stack operating temperature[a]	°C	90	95
Total PGM loading[a]	mg_{PGM}/cm^2	0.15	0.186[b]
MEA areal power density at rated power	mW/cm^2	833	1,110
System cost	$\$/kW_{net}$[c]	51	49

[a] Design point varied in the optimization analysis.
[b] Although areal PGM loading increased in 2011, decreased stack size led to a decrease in total PGM content in the stack.
[c] Dollars are in year of analysis.

In their optimization analysis, SA investigated oxygen stoichiometric ratios from 1.5–2.5, peak pressures from 1.25–3 atm, peak temperatures from 75–95°C, and total PGM loadings from 0.15–0.25 mg/cm^2. As shown in Table 1, optimal values of three of these design points occurred at a boundary of the optimization range (oxygen stoichiometric ratio, peak pressure, and peak temperature). While this observation indicates that lower cost estimates would result from expanding the optimization ranges, the Tech Team indicated that expansion of the ranges is unnecessary, noting that the upper bound of pressure is close to the maximum that would be expected from a single stage compressor, and the temperature upper bound is appropriate for an automotive system.

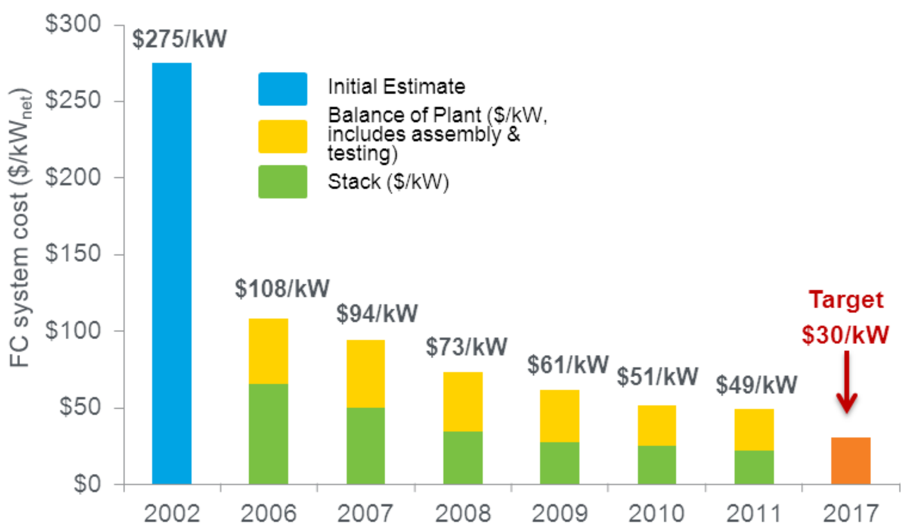

Figure 1. Modeled cost of an 80-kW_{net} PEM fuel cell system based on projection to high-volume manufacturing (500,000 units/year). Cost targets were developed in 2002 using 2002 dollars. Cost status is based on dollars in the year of the analysis.

The current status of $49/kW represents a 33% decrease since 2008 and an 82% decrease since 2002, as depicted in Figure 1. The cost decrease since 2008 stems in part from a reduction in PGM loading and an increase in cell power density, allowing the design of smaller and less expensive stacks. Balance of plant (BOP) cost has also been reduced during this time. Major causes of the reduction in BOP cost since 2008 include reconfiguration of the ejector system based on stakeholder input, redesign of the system controller, and reduction of the radiator size. The reduced radiator size was enabled by improvements in stack components, allowing a higher stack operating temperature.

Key assumptions of the cost analysis are summarized in Table 2, along with a cost breakdown for the years 2007 – 2011 [5-8].

Table 2: Key Assumptions of Cost Analyses and Resulting Cost

Characteristic	Units	2007	2008	2009	2010	2011
Stack power	kW_{gross}	90	90	88	88	89
System power	kW_{net}	80	80	80	80	80
Cell power density	mW_{gross}/cm^2	583	715	833	833	1,110
Peak stack temperature	°C	70-90	80	80	90	95
PGM loading	mg/cm^2	0.35	0.25	0.15	0.15	0.19
PGM total content	g/kW_{gross}	0.6	0.35	0.18	0.18	0.17
PGM total content	g/kW_{net}	0.68	0.39	0.20	0.20	0.19
Pt cost	$/troz. [a]	1100	1100	1100	1100	1100
Stack cost	$\$/kW_{net}$ [a]	50	34	27	25	22
Balance of plant cost	$\$/kW_{net}$ [a]	42	37	33	25	26
System Assembly and Testing	$\$/kW_{net}$ [a]	2	2	1	1	1
System cost	$\$/kW_{net}$ [a]	94	73	61	51	49

[a] Dollars are in year of analysis.

Lower-volume cost estimates were prepared by SA for manufacturing volumes of 1,000, 30,000, 80,000, and 130,000 units per year. The projected effect of manufacturing volume on cost is depicted in Figure 2.

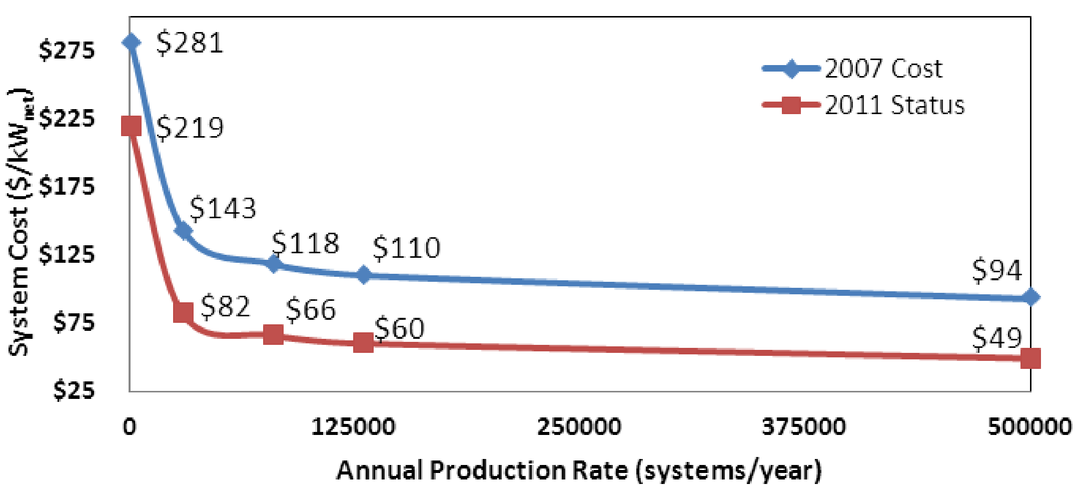

Figure 2. Projected cost of 80-kW_{net} transportation fuel cell systems at 1,000, 30,000, 80,000, 130,000, and 500,000 units/year.

For comparison to the DOE target developed in 2002 and quoted in 2002 dollars ($30/kW by 2017), the 2011 high-volume cost status of $49/kW in 2011 dollars equates to $39/kW in 2002 dollars [9].

References

[1] B. James et al., "Mass Production Cost Estimation for Direct H_2 PEM Fuel Cell Systems for Automotive Applications: 2011 Update," report to the DOE Fuel Cell Technologies Program, in preparation.

[2] B. James et al., "Manufacturing Cost Analysis of Fuel Cell Systems," presentation at the 2011 U.S. DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation. http://www.hydrogen.energy.gov/pdfs/review11/fc018_james_2011_o.pdf

[3] B. James and K. Baum, presentation at the July 13, 2011 meeting of the U.S. Drive Fuel Cell Technical Team.

[4] R. Ahluwalia et al., "Fuel Cell Systems Analysis," presentation at the 2011 U.S. DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation. http://www.hydrogen.energy.gov/pdfs/review11/fc017_ahluwalia_2011_o.pdf

[5] U.S. Department of Energy (Hydrogen Program), "Record 8002: Fuel Cell System Cost - 2007," http://www.hydrogen.energy.gov/program_records.html

[6] U.S. Department of Energy (Hydrogen Program), "Record 8019: Fuel Cell System Cost - 2008," http://www.hydrogen.energy.gov/program_records.html

[7] U.S. Department of Energy (Hydrogen Program), "Record 9012: Fuel Cell System Cost - 2009," http://www.hydrogen.energy.gov/program_records.html

[8] U.S. Department of Energy (Hydrogen Program), "Record 10004: Fuel Cell System Cost - 2010," http://www.hydrogen.energy.gov/program_records.html

[9] Bureau of Labor Statistics CPI Inflation Calculator, http://www.bls.gov/data/inflation_calculator.htm