DOE Fuel Cell Technologies Program Record	
Record #: 12020	**Date:** August 21, 2012
Title: Fuel Cell System Cost - 2012	
Update to: Record 11012	
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Approved by: Sunita Satyapal	**Date:** September 14, 2012

Item:

The cost of an 80-kW$_{net}$ automotive polymer electrolyte membrane (PEM) fuel cell system based on 2012 technology[1] and operating on direct hydrogen is projected to be \$47/kW when manufactured at a volume of 500,000 units/year.

Rationale:

The DOE Fuel Cell Technologies Program supports analysis projects that perform detailed analysis to estimate cost status of fuel cell systems, updated on an annual basis [1]. In fiscal year 2012, Strategic Analysis, Inc. (SA) updated their 2011 cost analysis of an 80-kW$_{net}$ direct hydrogen PEM automotive fuel cell system, based on 2012 technology and projected to a manufacturing volume of 500,000 units per year [2]. 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 [3] and at a meeting of the U.S. Drive Fuel Cell Technical Team (the Tech Team) [4], as well as through subsequent direct discussion between FCT and SA. The Tech Team accepted the resulting high-volume cost estimate of \$47/kW as a reasonable estimate of 2012 cost status. The SA estimate of \$47/kW has been accepted as the FCT 2012 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) [5] to predict stack performance as a function of operating conditions. The 2012 analysis used an updated 2012 polarization curve from ANL, based on analysis of additional 3M test results. The ANL and SA analyses assume use of membrane electrode assemblies (MEAs) containing state-of-the-art 3M nanostructured thin film (NSTF) ternary platinum-alloy catalyst layers on 25 micron reinforced Nafion® membranes. The Pt commodity cost of \$1100 per troy ounce for the 2012 analysis is consistent with the Program's 2006-2011 analyses. The cost estimate is based on price quotes obtained between 2010 and 2012. Quoted prices were not adjusted for inflation. All calculations were performed using nominal dollars.

SA performed an optimization study in fiscal year 2012 in which three system design points (cathode catalyst loading, maximum operating temperature, and maximum operating pressure) were varied to minimize system cost. The design points used in the 2010 through 2012 analyses, with the resulting cost estimates, are summarized in Table 1.

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[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.

Table 1: System design points and system cost from the 2010 through 2012 cost analyses.

Characteristic	Units	2010	2011	2012
Stack efficiency at rated power	%	55	55	55
Cell voltage at rated power	V	0.676	0.676	0.676
Oxygen stoichiometric ratio[a]		2.5	1.5	1.5
Peak stack operating pressure[a,b]	atm	1.69	3	2.5
Peak stack operating temperature[a,b,c]	°C	90	95	87
Total PGM loading[a,b]	mg_{PGM}/cm^2	0.15	0.186	0.196
MEA areal power density at rated power	mW/cm^2	833	1,110	984
System cost	$\$/kW_{net}$	51	49	47

[a] Design point optimized in the 2011 analysis.
[b] Design point optimized in the 2012 analysis.
[c] Peak stack temperature is defined as the stack coolant outlet temperature. ANL modeling predicts the cathode gas outlet temperature to be 5°C higher.

In their optimization analysis, SA investigated peak pressures from 1.5–2.5 atm, peak temperatures from 75–95°C, and total PGM loadings from 0.09–0.24 mg/cm^2. Due to a lack of available data, the upper bound of peak operating pressure in the 2012 optimization analysis (2.5 atm) was lower than the 2011 upper bound (3.0 atm), contributing to a drop in areal power density in 2012. Given that the optimum value was found to be the upper bound, it is expected that a true optimum would occur at a pressure higher than 2.5 atm. Work is underway at ANL to extend the model to higher pressures.

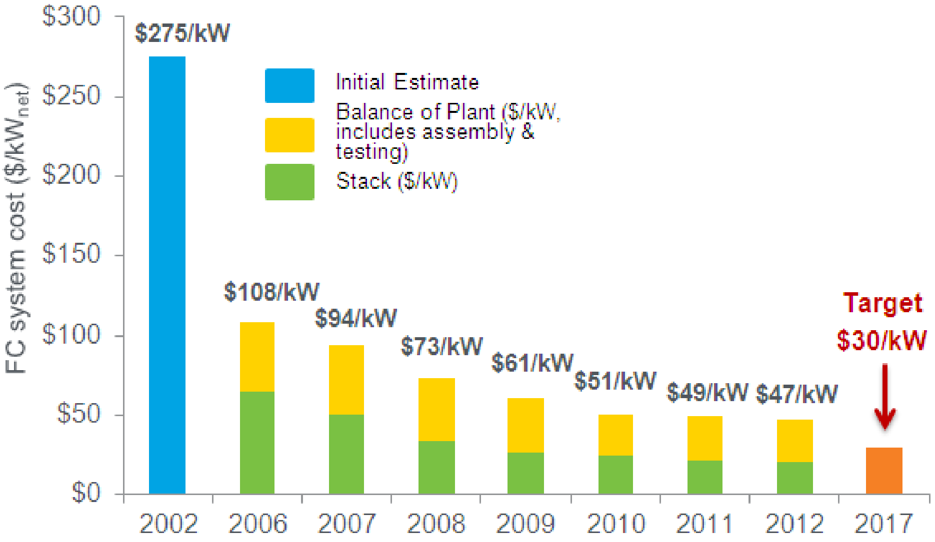

Figure 1. Modeled cost of an 80-kW_{net} PEM fuel cell system based on projection to high-volume manufacturing (500,000 units/year).

The current status of $47/kW represents a 36% decrease since 2008 and an 83% 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 modification of the ejector system based on stakeholder input, improved design 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. Since 2011, an additional \$2 reduction of the fuel cell stack cost to \$20/kW resulted primarily from adoption of a lower cost gasket manufacturing process described in a recent 3M patent [6], and from adoption of lower cost GDLs from Ballard Material Products, which were developed through a DOE-supported project that led to a 55% decrease in GDL costs since 2008 [7]. Key assumptions of the 2012 cost analysis are summarized in Table 2, along with a cost breakdown for the years 2007 – 2011 [8-12].

Table 2: Key Assumptions of Cost Analyses and Resulting Cost

Characteristic	**Units**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Stack power	$\mathrm{kW_{gross}}$	90	90	88	88	89	88
System power	$\mathrm{kW_{net}}$	80	80	80	80	80	80
Cell power density	$\mathrm{mW_{gross}/cm^2}$	583	715	833	833	1,110	984
Peak stack temperature	°C	70-90	80	80	90	95	87
PGM loading	$\mathrm{mg/cm^2}$	0.35	0.25	0.15	0.15	0.19	0.20
PGM total content	$\mathrm{g/kW_{gross}}$	0.6	0.35	0.18	0.18	0.17	0.20
PGM total content	$\mathrm{g/kW_{net}}$	0.68	0.39	0.20	0.20	0.19	0.22
Pt cost	\$/troz.	1100	1100	1100	1100	1100	1100
Stack cost	$\mathrm{\$/kW_{net}}$	50	34	27	25	22	20
Balance of plant cost	$\mathrm{\$/kW_{net}}$	42	37	33	25	26	26
System Assembly and Testing	$\mathrm{\$/kW_{net}}$	2	2	1	1	1	1
System cost	$\mathrm{\$/kW_{net}}$	94	73	61	51	49	47

Lower-volume cost estimates were prepared by SA for manufacturing volumes of 1,000, 10,000, 30,000, 80,000, and 130,000 units per year. The projected effect of manufacturing volume on cost is depicted in Figure 2 and Figure 3, which show the data in linear and logarithmic plots, respectively.

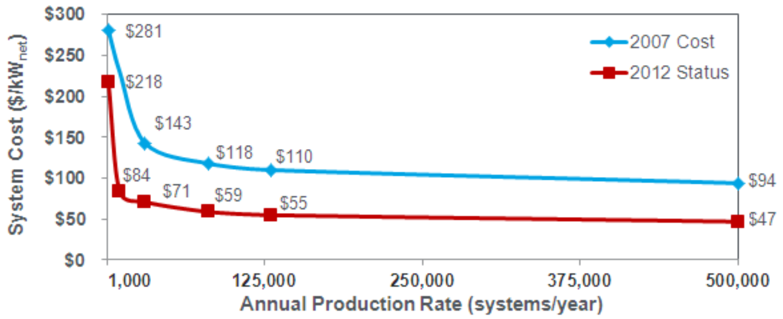

Figure 2. Projected cost of 80-$\mathrm{kW_{net}}$ transportation fuel cell systems at 1,000, 10,000, 30,000, 80,000, 130,000, and 500,000 units/year.

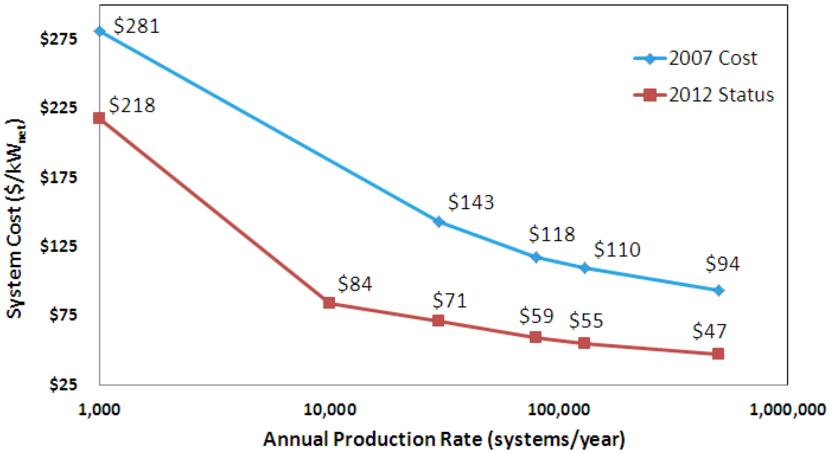

Figure 3. Projected cost of 80-kW$_{net}$ transportation fuel cell systems at 1,000, 10,000, 30,000, 80,000, 130,000, and 500,000 units/year.

Table 3. Parameter values for stack and system cost Monte Carlo simulations.

Parameter	Unit	Minimum Value	Likeliest Value	Maximum Value	Bounds Rationale
Power Density	**mW/cm2**	833	**984**	1464	Low end: 2010 performance High end: FCTT guidance
Pt Loading	**mgPt/cm2**	0.15	**0.196**	0.3	FCTT guidance
Ionomer Cost	**$/kg**	$45.65	**$75.06**	$148.55	Low end: automotive OEM study provided to SA for analysis High end: earlier SA cost estimate
GDL Cost	**$/m2**	$3.23	**$4.45**	$5.80	Low end: Ballard low end projection High end: Ballard high end projection
Bipolar Plate & Coating Cost Factor		1	**1**	1.5	Low end: baseline Treadstone coating with high speed laser welding (15m/min) High end: Au Nanoclad plates with slower laser welding (2.5m/min)
Membrane Humidifier Cost	**$/system**	$61.00	**$61.00**	$100.00	Low end: DFMA analysis. High end: Gore mass production estimate.
Product of Compr/Expander/ Motor&MotorController Efficiencies		0.415	**0.51**	0.54	Low end: 71/73/80% compr/exp/motor-controller efficiency corresponding to "ANL Map," product of terms= 41.5% High end: 75/80/90% corresponding to DOE 2017 targets, product of terms = 54%
Air Compressor Cost Factor		0.8	**1**	1	Low end is 20% reduction of calculated cost
Balance of Air Compressor Cost	**$/system**	$97.53	**$146.30**	$219.45	Low end: 2/3 of likeliest value High end: 1.5x likeliest value
Hydrogen Recirculation System Cost	**$/system**	$160.25	**$240.38**	$360.57	Low end: 2/3 of likeliest value High end: 1.5x likeliest value

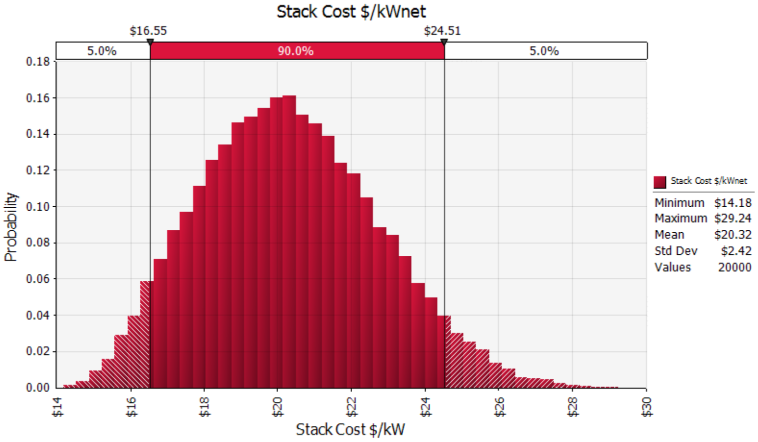

Figure 4. Monte Carlo analysis of stack cost probability.

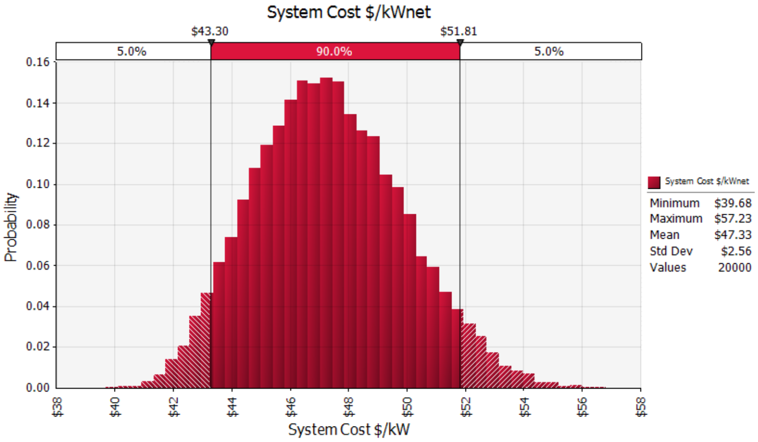

Figure 5. Monte Carlo analysis of system cost probability.

Uncertainty in stack and system cost was evaluated through a Monte Carlo analysis using estimated parameter value distributions listed in Table 3. Based on the Monte Carlo results, the stack cost status is projected with 90% certainty to be between $17/kW and $25/kW (Figure 4), while the system cost is projected with 90% certainty to be between $43/kW and $52/kW (Figure 5). These cost uncertainty levels reflect uncertainty in the underlying parameter values listed in Table 1, but do not include uncertainty associated with modeling assumptions and parameter values not included in Table 1.

References

[1] J. Marcinkoski et al., "Manufacturing process assumptions used in fuel cell system cost analyses," J. Power Sources 196 (2011) 5282-5292.

[2] B. James et al., "Mass Production Cost Estimation for Direct H_2 PEM Fuel Cell Systems for Automotive Applications: 2012 Update," report to the DOE Fuel Cell Technologies Program, in preparation.

[3] B. James et al., “Fuel Cell Transportation Cost Analysis, Preliminary Results,” presentation at the 2012 U.S. DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation. http://www.hydrogen.energy.gov/pdfs/review12/fc018_james_2012_o.pdf

[4] B. James, presentation at the July 18, 2012 meeting of the U.S. Drive Fuel Cell Technical Team.

[5] R. Ahluwalia et al., “Fuel Cell Systems Analysis,” presentation at the 2012 U.S. DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation. http://www.hydrogen.energy.gov/pdfs/review12/fc017_ahluwalia_2012_o.pdf

[6] 3M Patent Application [US2011/0151350A1], June 2011.

[7] J. Morgan, "Reduction in Fabrication Costs of Gas Diffusion Layers,” 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/mn002_morgan_2011_o.pdf

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

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

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

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

[12] U.S. Department of Energy (Hydrogen Program), "Record 11012: Fuel Cell System Cost - 2011,” http://www.hydrogen.energy.gov/program_records.html