DOE Hydrogen and Fuel Cells Program Record	
Record #: 20002	**Date:** 8/14/2020
Title: Early Market Transportation Fuel Cell Cost	
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<u>Item:</u>

The cost of commercially available automotive fuel cell systems is estimated to be $165/kW[1] at a manufacturing volume of 3,000 systems/year, which is representative of the manufacturing volumes of commercial fuel cell electric vehicles (FCEVs) in the 2018 timeframe.

<u>Assumptions:</u>

Modeled and Estimated Costs of Fuel Cell Systems for Commercially Available FCEVs

The Hydrogen and Fuel Cell Technologies Office (HFTO) within the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy supports projects that perform detailed analysis of fuel cell systems to benchmark the technology status and guide R&D activities. Strategic Analysis, Inc. (SA) conducts an annually updated analysis of transportation fuel cells using design for manufacture and assembly (DFMA) methods.[2] This analysis projects the cost of state-of-the-art, lab-demonstrated technologies at varying manufacturing scales. This provides a benchmark that is useful to inform early-stage R&D efforts toward lowering fuel cell system cost. Due to the lack of long term validated durability data, these analyses have traditionally estimated the cost of a model system meeting beginning-of-life performance requirements without fully considering durability requirements.

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[1] Fuel cell system costs listed in this Record are in 2016$, represent the fuel cell power sub-system (i.e., fuel cell stacks and associated balance of plant components but excluding power electronics, battery, and chassis), and are costs, not prices (i.e., they do not include business markup [administration, R&D, warranty, profit, etc.] for the fuel cell system manufacturer).

[2] Brian D. James, Jennie M. Huya-Kouadio, Cassidy Houchins, Daniel A. DeSantis, "Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2018 Update," Strategic Analysis Inc., December 2018. https://www.energy.gov/sites/prod/files/2020/02/f71/fcto-sa-2018-transportation-fuel-cell-cost-analysis-2.pdf

As FCEVs become commercially available, it is also important to track the current status of early-market, on-the-road technology. Three FCEV models have become available in the U.S. in recent years: the Toyota Mirai, the Hyundai Nexo, and the Honda Clarity Fuel Cell. For early-market FCEVs, low-volume manufacturing and durability are important factors in the fuel cell system cost. Currently, two automakers are manufacturing FCEVs at the rate of a few thousand per year; estimates include around 3,000 Toyota Mirai vehicles sold worldwide in 2018[3] and a similar or greater number of Hyundai Nexo vehicles in 2019.[4] These vehicles are sold with competitive powertrain warranties, such as an 8-year/100,000 mile warranty for the Toyota Mirai fuel cell system,[5] and a 10-year/100,000 mile warranty for the Hyundai Nexo powertrain.[6] Ensuring sufficient fuel cell durability for these competitive warranties requires the use of higher cost fuel cell components than those used in the baseline SA model system, such as high loadings of platinum group metal (PGM) catalysts and corrosion-resistant bipolar plate materials, in addition to system control strategies to reduce fuel cell degradation.

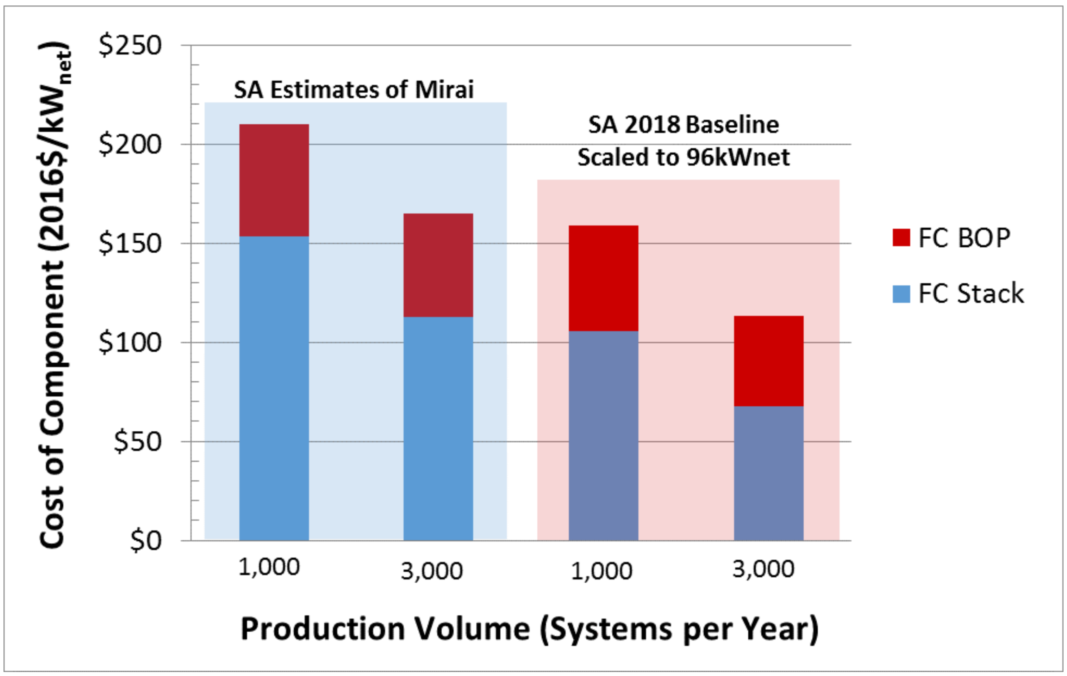

Figure 1: Modeled cost of a representative on-road automotive fuel cell (FC) system (96 kW_{net} Toyota Mirai), stack, and balance of plant (BOP) at different production volumes (left). For comparison, the baseline automotive system modeled by SA (assuming state-of-the-art, lab-demonstrated technology) is scaled to the same power output (96 kW_{net}) with the cost shown at different production volumes (right).

To evaluate the cost of a representative example of on-road fuel cell technology, SA conducted a DFMA cost analysis of the 2017 model-year Toyota Mirai,[1] which has a 96 kW_{net} fuel cell

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[3] "The Fuel Cell Industry Review 2018," E4Tech, December 2018. http://www.fuelcellindustryreview.com/archive/TheFuelCellIndustryReview2018.pdf

[4] "The Fuel Cell Industry Review 2019," E4Tech, December 2019. https://www.e4tech.com/news/2018-fuel-cell-industry-review-2019-the-year-of-the-gigawatt.php

[5] https://www.toyota.com/owners/resources/warranty-owners-manuals/mirai/2019, accessed July 29, 2020.

[6] https://www.hyundaiusa.com/us/en/vehicles/nexo/compare-specs, accessed July 29, 2020.

system that was assessed in detail by Argonne National Laboratory.[7] The estimated cost of the Mirai fuel cell system, shown in Figure 1, is \$210/kW_{net} at a manufacturing rate of 1,000 systems per year, and \$165/kW_{net} at a manufacturing rate of 3,000 systems per year. For comparison, SA also estimated the cost of fuel cells using state-of-the-art lab-demonstrated technology, scaled to match the 96 kW_{net} size of the Mirai system. The cost per kW of the 96 kW model system is slightly (about 10%) lower than the standard 80 kW baseline system assumed in the regular SA analysis. The estimated cost of the scaled baseline fuel cell system, shown in Figure 1, is \$159/kW_{net} at a manufacturing rate of 1,000 systems per year and \$113/kW_{net} at a manufacturing rate of 3,000 systems per year.

The estimated cost of the Mirai system is about \$50/kW_{net} higher than the scaled baseline system as a result of two main factors: durability requirements and the delay between laboratory demonstration and commercial deployment of state-of-the-art technology. On-road technology lags several years behind laboratory technology, and since the initial release of the Toyota Mirai, research and development have demonstrated improved performance[8] and durability[9] with lower cost materials. To ensure that the Toyota Mirai could meet the required durability with the materials available at the time production was initiated, the fuel cell stack uses a high catalyst loading of 0.365 mg_{PGM}/cm^2 (compared to 0.125 mg_{PGM}/cm^2 for the SA baseline) and titanium as a corrosion-resistant base metal for its bipolar plates (compared to coated stainless steel for the SA baseline). Together, the higher PGM loading and titanium bipolar plates account for an additional \$45–\$50/kW_{net} in cost for the Mirai compared to the SA model system.

To estimate the cost of on-road automotive fuel cell technology, a manufacturing rate of 3,000 systems per year is assumed as representative of current commercial FCEVs. Based on the estimated cost of the Toyota Mirai fuel cell system, the on-road cost status is documented in this DOE Record as \$165/kW_{net}. SA has estimated the uncertainty in the projected cost of its baseline fuel cell system using Monte Carlo methods.[2] Using the relative uncertainty estimated for the baseline system and including uncertainty in the manufacturing scale, SA has estimated that the cost of the Mirai system is between \$158/kW and \$195/kW with a 90% confidence level. A rigorous, model-based estimate of the cost impact of meeting durability requirements using state-of-the-art technology will be published in fiscal year 2021.

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[7] Henning Lohse-Busch, Michael Duoba, Kevin Stutenberg, Simeon Iliev, Mike Kern, Brad Richards, Martha Christenson, Aaron Loiselle-Lapointe, "Technology Assessment of a Fuel Cell Vehicle: 2017 Toyota Mirai," Argonne National Laboratory, 2018. https://publications.anl.gov/anlpubs/2018/06/144774.pdf
[8] D. Papageorgopoulos, "Fuel Cells R&D Overview," in *2018 U.S. DOE Hydrogen and Fuel Cell Annual Merit and Peer Review*, Washington D.C., 2018.
https://www.hydrogen.energy.gov/pdfs/review18/fc01_papageorgopoulos_2018_o.pdf
[9] U.S. Department of Energy, "On-Road Fuel Cell Stack Durability," DOE Hydrogen and Fuel Cell Technologies Program Record, November 9, 2016.
https://www.hydrogen.energy.gov/pdfs/16019_fuel_cell_stack_durability_2016.pdf