Program Record (Fuel Cell Technologies Office)	
Record #: 18004	**Date:** September 6, 2018
Title: Hydrogen R&D Cost Target Calculation—2018 Update	
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Peer reviewed by: Members of U.S. DRIVE Fuel Pathway Integration (FPITT) and Hydrogen Delivery (HDTT) Technical Teams	
Approved by: Erika Gupta and Sunita Satyapal	**Date:** September 10, 2018

Description:

DOE establishes and periodically revises a hydrogen fuel cost target to guide and prioritize research and development (R&D) for the Hydrogen and Fuel Cells Program. Developed to guide R&D for hydrogen fuel production and delivery technologies, the hydrogen cost target is the cost at which fuel cell electric vehicles (FCEVs) are estimated to be competitive on a cost per mile basis—considering vehicle purchase cost and fuel costs—with competing gasoline vehicles (advanced gasoline internal combustion engine vehicles [ICEVs] in the nearer term, and ultimately with hybrid electric vehicles [HEVs]). The ultimate hydrogen R&D cost target is set at $4/gge (gallon of gasoline equivalent, approximately equal to 1 kg of hydrogen on a lower heating value basis), untaxed and dispensed at the pump; a 2025 cost target is set at $7/gge (targets expressed in 2016$). This record documents the methodology and assumptions used to calculate the hydrogen cost targets.

Principles:

The hydrogen cost target analysis is a "top-down" analysis of the hydrogen fuel cost required for FCEVs to be competitive with gasoline vehicles in the light-duty vehicle (LDV) market. Because the target is market-driven, it is pathway independent and provides a means to assess technology performance on a competitive basis. This aligns with a priority for DOE R&D which is enabling *affordability* of clean, energy efficient technologies. The analysis is based on a stochastic modeling of projected competitive conditions to be faced by FCEVs in the 2020–2030 timeframe, assuming FCEVs would compete with both advanced ICEVs and, ultimately, HEVs. The calculation considers a range of vehicle technologies, performance, and fuel economy values for both FCEVs and competing ICEVs and HEVs.

Previous Target:

The previous hydrogen cost target was set in 2011 at $4/gge (2007$), representing the cost at which FCEVs were projected to be competitive with HEVs on a cost per mile basis in 2020 [1]. This previous target was revised, as explained below, to reflect updated projections of the purchase prices of FCEVs, ICEVs, and HEVs, as well as updated projections of gasoline price.

Calculation Methodology and Results:

The hydrogen cost target analysis methodology uses Monte Carlo stochastic simulations to identify the range of hydrogen fuel costs that lead to cost-competitive FCEV ownership costs on a cost per mile basis compared to gasoline ICEVs and HEVs, considering fuel costs and vehicle purchase costs.

Variability in future fuel efficiency, competing gasoline fuel costs, and incremental vehicle purchase costs are reflected in probability distributions used to calculate per-mile vehicle and fuel costs.

The analysis is structured to consider the cost of driving for the consumer, including fuel cost and vehicle purchase cost. Other vehicle operating costs such as maintenance, repairs, insurance, registration, tires, etc. are not considered, consistent with other DOE analysis such as for battery electric and plug-in vehicles. (As the analysis considers FCEVs in comparison to gasoline vehicles, these operating costs are presumed to be equivalent across vehicle types and thus do not factor into an incremental cost analysis.)

Overall, the analysis sets the consumer's cost of driving a FCEV on a per-mile basis to be equivalent to the cost of driving a gasoline vehicle (generically GV, which is either an ICEV or HEV) using the following equation:

$$\frac{Hydrogen\ cost\ (\frac{\$}{gge})}{FCEV\ fuel\ economy\ (\frac{mi}{gge})} + FCEV\ incremental\ cost\ (^{\$}/_{mi}) = \frac{Gasoline\ cost\ (\frac{\$}{gal})}{GV\ fuel\ economy\ (\frac{mi}{gal})}$$

Consistent with other DOE analyses and because the value of taxes may vary, the analysis does not include sales or fuel taxes for the hydrogen cost or for gasoline prices.

Since the *hydrogen cost* is the desired result, the equation is manipulated to:

$$H_2\ cost\ (\frac{\$}{gge}) = \left[\frac{Gasoline\ cost\ (\frac{\$}{gal})}{GV\ fuel\ economy\ (\frac{mi}{gal})} - FCEV\ incr.cost\ (^{\$}/_{mi}) \right] * FCEV\ fuel\ economy\ (\frac{mi}{gge})$$

While the equation above is used to determine hydrogen cost in relation to gasoline vehicle cost and performance, the analysis is structured as a stochastic analysis with probability distributions considered for gasoline cost, gasoline vehicle (either ICEV or HEV) fuel economy, FCEV fuel economy, and incremental FCEV purchase cost relative to a gasoline vehicle.

A base set of assumptions and input parameters was chosen to conduct the analysis using the best available projections for market and technology status in the 2025–2030 timeframe. The cost target analysis uses vehicle cost and fuel economy data from Argonne National Laboratory's (ANL) "Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways" [2].

The base set of assumptions are shown in Table 1. The analysis considers the cost and performance of a midsize passenger vehicle modeled with ANL's Autonomie model, as reported in the Cradle-to-Grave (C2G) study [2][3]. ICEVs are chosen as the competing technology for light-duty vehicles for the 2025 hydrogen cost target since they make up the majority of the vehicle fleet today. HEVs are chosen as the competing technology for the ultimate hydrogen cost target because HEVs are currently the most widely available advanced technology vehicles on the road; these vehicles could be a dominant fuel-efficient vehicle technology in the 2025–2030 timeframe.

Table 1. Assumptions used in the hydrogen cost target analysis

Parameter	Modeling Assumption
Modeled Vehicle	Midsize passenger vehicle (Autonomie modeled) [2] [ICEV, HEV, FCEV]
Model Year	2025 (2020 lab technology) [2]
Vehicle Lifetime	178,100 miles / 15 years [2][4]
Competing Vehicles	Gasoline ICEVs (2025 target) and HEVs (ultimate target)
Analysis Window	15 years (full vehicle lifetime)
Dollar Reference Year	$2016
Discount Rate	5% [2]
FCEV tax credits and incentives	None
Gasoline Price Source	EIA 2017 Annual Energy Outlook [5]

To evaluate the competitiveness of FCEVs against ICEVs and HEVs, the hydrogen cost target analysis considers vehicle and fuel costs over a full 15-year vehicle lifetime, consisting of about 178,000 miles [2][4]. Gasoline prices for the competing ICEVs and HEVs are taken from EIA's 2017 Annual Energy Outlook [5]. Costs and results are reported in 2016 dollars, reflecting the reference year dollars used in AEO 2017. Vehicle purchase costs for the FCEV, ICEV, and HEV come from the C2G study based on Autonomie modeling of midsize vehicles, which included extensive input and peer review by automakers. The cost target analysis also uses the C2G methodology to calculate vehicle cost on a per-mile basis.

Since each of the parameters used in the hydrogen cost target calculation (shown in the hydrogen cost formula above) is not known definitively, a probability range for each parameter is included in the stochastic analysis. To account for uncertainty in future fuel costs, vehicle purchase cost and vehicle performance, the analysis uses triangular probability distributions for gasoline cost, incremental FCEV purchase cost, and vehicle fuel economy. Ranges for each parameter are defined as triangular probability distributions representing the 10th percentile, most likely, and 90th percentile values for these input parameters, as shown in Table 2.

The gasoline cost distribution was developed from the Energy Information Administration's 2017 Annual Energy Outlook (Reference and High- and Low-Oil Price cases for 2025) [5]. Distributions for vehicle fuel economy were based on data from the U.S. DRIVE Cradle-to-Grave lifecycle analysis of light-duty vehicles, using the study's baseline, low, and high fuel economy data for ICEVs, HEVs, and FCEVs [2]. The probability distributions for incremental FCEV purchase cost assume set a minimum value of $0 incremental cost over the competing ICEV or HEV (that is, assumes that FCEVs have the same purchase cost). The 90th percentile values reflect the incremental FCEV costs assumed in the 2016 C2G study. Namely, FCEVs cost $7,000 more than ICEVs and $5,000 more than HEVs (based on C2G vehicle sales prices of $31,500 for FCEVs, $24,500 for ICEVs, and $26,600 for HEVs [updated to 2016$]). The stochastic analysis leaves room for the potential that FCEV purchase cost will improve over the C2G estimates (reflecting for example, R&D advancements in fuel cell stack costs or hydrogen storage costs), and sets the most likely FCEV incremental vehicle cost at one-half the 90th percentile value (FCEV incremental cost of $3,500 over an ICEV or $2,500 over an HEV).

Table 2. Triangular probability distributions for input parameters in the stochastic analysis

Parameter	10th Percentile	Most Likely	90th Percentile
Gasoline Price (untaxed, $/gallon)	$1.70	$3.00	$5.60
ICEV Fuel Economy (mpgge)	30	35	39
HEV Fuel Economy (mpgge)	44	53	60
FCEV Fuel Economy (mpgge)	63	72	81
FCEV Incremental Cost vs ICEV ($/mi)	$0.00*	$0.03	$0.06
FCEV Incremental Cost vs HEV ($/mi)	$0.00*	$0.02	$0.04

* The minimum value was set to $0.00/mile instead of the 10th percentile

The stochastic analysis for the hydrogen cost target uses a 10,000 trial Monte Carlo technique to randomly select the value of each input parameter based on its probability function, simultaneously varying gasoline cost, vehicle fuel economy, and FCEV incremental cost. 10th percentile, most likely, and 90th percentile values for the fuel economy and incremental vehicle cost input parameters are shown in Figure 1 and Figure 2, respectively.

The results of the stochastic analysis are shown in Figure 3, which shows the range of hydrogen fuel costs that lead to cost-competitive FCEV ownership costs in comparison to HEVs and ICEVs. Considering the 20th to 80th percentile range, FCEVs can be competitive with ICEVs on a per-mile cost basis with hydrogen in the range of $2.10/gge to $7.80/gge. Similarly, considering the 20th to 80th percentile range, FCEVs can be competitive with HEVs on a per-mile cost basis with hydrogen in the range of $1.25/gge to $5.10/gge.

Figure 1. Vehicle fuel economy input parameter ranges for stochastic analysis

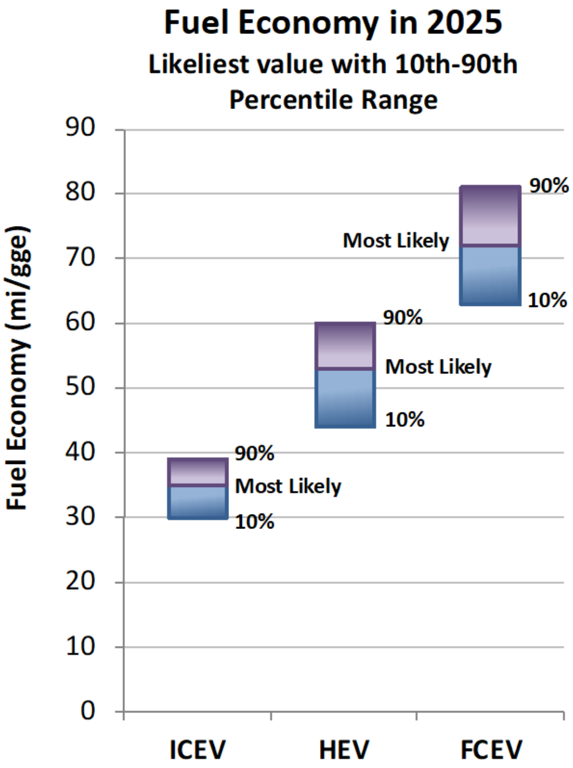
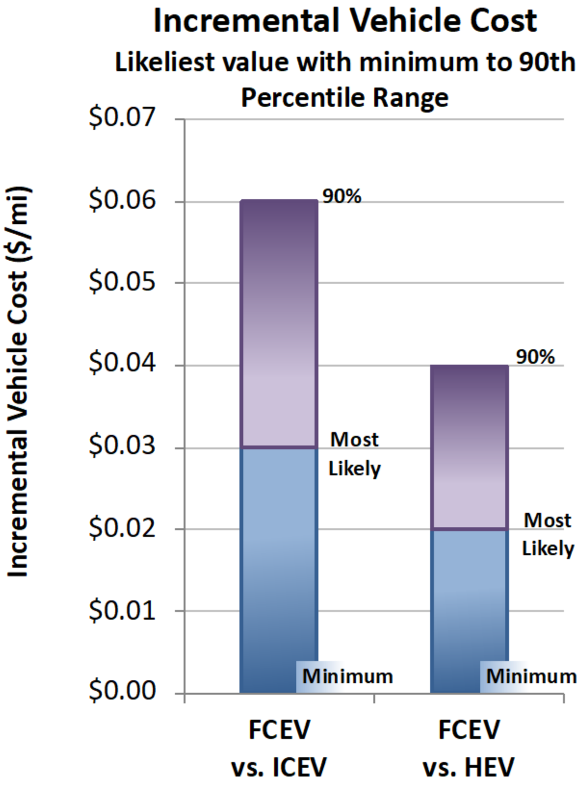
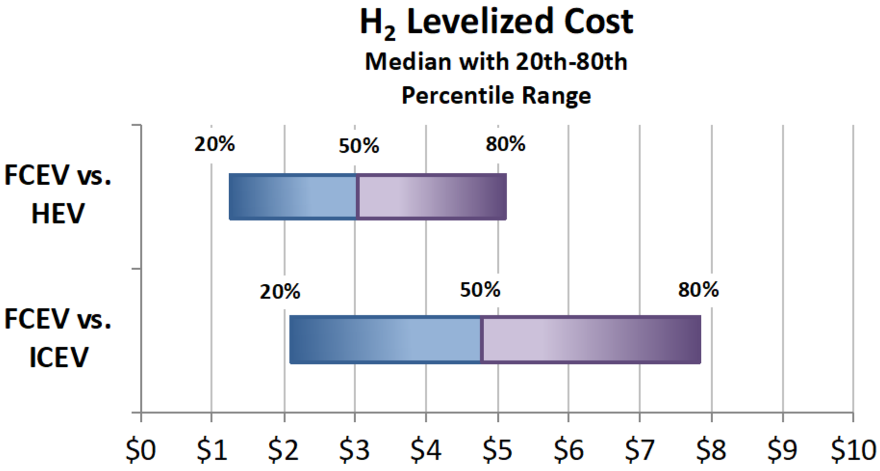


Figure 2. Incremental vehicle cost input parameter ranges for stochastic analysis



Based on these results, DOE is setting the 2025 hydrogen cost target (untaxed and dispensed to the vehicle) at $7/gge and is setting the ultimate hydrogen cost target at $4/gge (in 2016$). The 2025 target of $7/gge represents the 75th percentile hydrogen cost in comparison to ICEVs. The ultimate target of $4/gge represents the 65th percentile cost in comparison to HEVs. In other words, given the range of gasoline cost and vehicle costs and performance shown in Table 2, FCEVs are expected to be competitive with ICEVs at least 25% of the time when hydrogen costs $7/gge, representing an early market target. Similarly, FCEVs are expected to be competitive with HEVs at least one-third of the time when hydrogen costs $4/gge. A longer term target of $4/gge allows FCEVs to be more competitive over a wider distribution as shown in the stochastic analysis.

Figure 3. Hydrogen cost target results



Review Process:

The hydrogen R&D cost target selection and the underlying stochastic analysis methodology and inputs were reviewed by energy company and automobile industry stakeholders through the U.S. DRIVE partnership.

<u>References:</u>

[1] DOE Fuel Cell Technologies Office, Program Record 11007, 2011. “Hydrogen Threshold Cost Calculation.”

[2] Elgowainy et al., 2016. *Cradle-to-Grave Lifecycle Analysis of U.S. Light Duty Vehicle-Fuel Pathways.* Argonne National Laboratory, Argonne, IL. https://greet.es.anl.gov/publication-c2g-2016-report

[3] Moawad et al., 2016. *Assessment of Vehicle Sizing, Energy Consumption and Cost through Large Scale Simulation of Advanced Vehicle Technologies*. Argonne National Laboratory, Argonne, IL. Report ANL/ESD-15/28. http://www.autonomie.net/publications/fuel_economy_report.html

[4] NHTSA (National Highway Traffic Safety Administration), National Center for Statistics and Analysis, 2006. *Vehicle Survivability and Travel Mileage Schedules*. http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf

[5] DOE EIA (Energy Information Agency), 2017. *Annual Energy Outlook 2017 with projections to 2040.*