DOE Fuel Cell Technologies Office Record	
Record #: 14013	**Date:** Sept 16, 2014
Title: Early Market Hydrogen Cost Target Calculation	
Originator: Fred Joseck and Erika Sutherland	
Approved by: Sunita Satyapal	**Date:** 10/06/2014

Description

DOE establishes and adopts cost targets to guide and prioritize R&D for the Hydrogen and Fuel Cells Program. The early market hydrogen cost target, a pathway independent target to guide R&D for production and delivery technologies for hydrogen fuel, is set at $7/gge, untaxed and dispensed at the pump. This target is the cost at which hydrogen fuel for fuel cell electric vehicles (FCEVs) is projected to be competitive on a cost per mile basis with gasoline fuel for competing vehicles [gasoline internal combustion engine vehicles (ICEVs)] in the early market timeframe of 2015 to approximately 2020. This record documents the methodology and assumptions used to calculate that early market hydrogen cost target.

Target Selection

The cost target of $7/gge was selected for the early market based on the results of a stochastic analysis of the variables impacting the cost of FCEVs and comparative gasoline ICEVs on a dollars per mile basis. This analysis calculates a target hydrogen cost of $6.98/gge (approximated to $7/gge) to be the most likely[1] cost competitive with ICEVs.

Principles

The early market hydrogen cost analysis is a "top-down" analysis of the hydrogen fuel cost required for FCEVs to be competitive with ICEVs. Because the target is market-driven, it is pathway independent and provides a means to assess technology performance on a competitive basis. The calculation considers a range of vehicle technologies, performance, fuel economy values (for both FCEVs and the competing ICEVs), and the federal and regional incentives currently in place as well as the gasoline market prices in the regions analyzed.

Gasoline Market Price

FCEVs will need to compete with ICEVs, but in early markets, such as U.S. regions that plan or require low to zero-emission vehicles (ZEVs), higher hydrogen prices (compared to the U.S. average gasoline price) may be commercially viable for a short period. The regions selected for this analysis are California and New York.

[1] The most likely value is the value most commonly returned by the stochastic analysis, and in this case, is also the mean of the distribution.

California Executive Order B-16-2012 targets 1.5 million ZEVs, which include hydrogen fuel cell electric vehicles, on the road by 2025.[2] New York and other states have signed a Memorandum of Understanding (MOU) to have 3.3 million ZEVs on the road by 2025.[3] The gasoline prices over a one year period from these regions, illustrated in Table 1, were obtained from the Energy Information Administration (EIA) and used in the calculations to determine the competitive hydrogen costs for the FCEVs. During each trial of the Monte Carlo simulation one of the two early market states was selected with equal probability and then a gasoline price was selected from the data set associated with the state, again with equal probability. A statistical summary of the untaxed gasoline prices from these regions is shown in Table 1. The full data set can be accessed at the link provided.

Table 1: Summary of Gasoline Price Distributions by State from July 2013 to July 2014

	New York Gasoline prices, $/gal. (untaxed)	California Gasoline prices, $/gal. (untaxed)
Minimum	**$3.10**	**$2.90**
Average	**$3.29**	**$3.29**
Maximum	**$3.47**	**$3.65**

Source: U.S. Energy Information Administration, Weekly Retail and Gasoline prices, http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sny_w.htm, August 19, 2014 and http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sca_w.htm, August 19, 2014

Note: $0.60 per gallon was subtracted from the California gasoline prices and $0.45 per gallon was subtracted from the New York gasoline prices reported by EIA to account for the federal and state taxes.

Vehicle Cost of Ownership

The FCEV differential cost of ownership (FCEV ΔCO) to the ICEV was obtained by adding the differential purchase cost (ΔPC) and the differential yearly costs (ΔYC) associated with ownership. The differential purchase cost was calculated by using the differential vehicle sales price for an FCEV vs an equivalent ICEV, subtracting the state and federal incentives available in the region and dividing over the vehicle life time to determine the incremental purchase cost in $/mile for the region. The yearly differential cost of ownership in $/mile was calculated by adding the yearly maintenance cost savings and the yearly high occupancy vehicle (HOV) lane incentives and dividing by the miles driven per year.

$$FCEV\ \Delta CO\left(\frac{\$}{mile}\right) = \Delta PC\left(\frac{\$}{mile}\right) + \Delta YC\left(\frac{\$}{mile}\right)$$

$$\Delta PC\left(\frac{\$}{mile}\right) = \frac{\big(FCEV\ price\ (\$) - ICEV\ price\ (\$)\big) - Fed.Incentive\ (\$) - State\ Incentive(\$)}{Lifetime\ (miles)}$$

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[2] California ZEV Action Plan: http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf
[3] http://www.arb.ca.gov/newsrel/newsrelease.php?id=520

$$\Delta YC\left(\frac{\$}{mile}\right) = \frac{FCEV\ maintanence\ savings\left(\frac{\$}{yr}\right) - HOV\ lane\ savings\left(\frac{\$}{yr}\right)}{miles\ driven\ \left(\frac{miles}{yr}\right)}$$

The FCEV ΔCO was independently calculated for California and New York based on the incentives available in the region during the timeframe considered and applied to the analysis based on the state selected. See Table 2 for the values used in the calculation.

Calculation Methodology and Results

The consumer's cost per mile for hydrogen used in FCEVs is set to be equivalent to the cost per mile for gasoline used in an ICEV using the following equation:

$$\frac{H_2\ cost\ \left(\frac{\$}{gge}\right)}{FCEV\ fuel\ economy\ \left(\frac{miles}{gge}\right)} + FCEV\ \Delta CO\left(\frac{\$}{mile}\right) = \frac{Gasoline\ cost\ \left(\frac{\$}{gal}\right)}{ICEV\ fuel\ economy\left(\frac{miles}{gal}\right)}$$

To be consistent with prior DOE analyses and because the value of taxes may vary, the early market hydrogen cost and gasoline cost do not include sales taxes in the analysis below.

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

$$H_2\ cost\ \left(\frac{\$}{gge}\right) = \left[\frac{Gasoline\ cost\ \left(\frac{\$}{gal}\right)}{ICEV\ fuel\ economy\left(\frac{miles}{gal}\right)} - FCEV\ \Delta CO\left(\frac{\$}{mile}\right)\right] * FCEV\ fuel\ economy\ \left(\frac{miles}{gge}\right)$$

A base set of assumptions was chosen using the best available projections for market and technology status in the 2015-2020 timeframe. The FCEV fuel economy is given in miles per gallon of gasoline equivalent (mpgge). The assumptions used in the calculation of the required hydrogen cost for FCEVs to be competitive in the early market with gasoline ICEVs are shown in Table 2.

Table 2: Early Market Hydrogen Cost Calculation Parameters

Parameter	Current Analysis Assumptions
Reference year	**2014**
Competing vehicles	**Gasoline ICEV**
Gasoline cost (untaxed), $/gal.	**See Table 1**
Gasoline ICEV fuel economy range	**26 mpg**[4] **29 mpg**[5]

[4] Fuel economies (as measured in the laboratory on standard test cycles) for all fuel/vehicle systems were determined using ANL's Autonomie modeling system, a vehicle simulation system used to assess the fuel consumption and performance of advanced vehicles. For information on Autonomie, see: http://www.transportation.anl.gov/modeling_simulation/PSAT/autonomie.html

[5] Environmental Protection Agency Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2013, http://www.epa.gov/fueleconomy/fetrends/1975-2013/420s13002.pdf

FCEV fuel economy range	**50 mpgge**[4] **68 mpgge**[6]
Assumed lifetime mileage of all vehicles	**150,000 miles**
Assumed miles driven per year	**15,000 miles**
FCEV sales price	**$68,000**[7]
ICEV sales price	**$48,625**[8]
Federal incentive for FCEVs	**$4,000**[9]
California state incentive for FCEVs	**$5,000**[10]
New York state incentive	**$0**
Yearly maintenance cost savings	**$388** **-$388**[11]
Yearly HOV incentive savings	**$1,350**[12]

Explanation of the values reported in Table 2 follow:

- The ICEVS were chosen as the competing technology for light-duty vehicles since they make up the majority of the vehicle fleet on the road today.
- The regional gasoline prices from California and New York were used since these fuel markets are expected to be the first to introduce hydrogen FCEVs.

Since each of the parameters used in the early market hydrogen cost calculation are not known definitively, a probability range for each was included in the calculations.

Figure 1 shows the effect of a range of gasoline prices on the competitive hydrogen cost in the early market for a FCEV with a fuel economy range of 50-68 mpgge compared to a gasoline

[6] Wipke, K., Anton, D., & Sprik, S. (2009, August). Evaluation of Range Estimates for Toyota FCHV Under Open Road Driving Conditions, Technical Report SRNS-STI-2009-00446. Aiken, SC: Savannah River National Laboratory.

[7] Toyota, "Toyota Hydrogen Fuel Cell Electric Vehicle Will be Shown at 2014 Aspen Ideas Festival." June, 25, 2014, http://corporatenews.pressroom.toyota.com/releases/toyota+hydrogen+fuel+cell+electric+vehicle+at+2014+aspen+ideas+festival.htm Accessed: September 2014.

[8] Kelly Blue Book reported MSRP for a 2014 Lexus GS 350 with standard options as a comparable vehicle to the Toyota FCEV. http://www.kbb.com/lexus/gs/2014-lexus-gs/gs-350/?vehicleid=392570&intent=buy-new,Accessed Sept 2014.

[9] Internal Revenue Service, Credit for New Qualified Alternative Motor Vehicles, Notice 2008-33, http://www.irs.gov/pub/irs-drop/n-08-33.pdf.

[10] California Air Resources Board, 2014-15 GRANT SOLICITATION, Air Quality Improvement Program (AQIP), CLEAN VEHICLE REBATE PROJECT, http://www.arb.ca.gov/msprog/aqip/solicitations/msc1410solicit.pdf.

[11] A triangular distribution was created which assumes FCEVs most likely have a maintenance cost equivalent to ICEVs and tails of +/- 50% of the average maintenance value reported by the U.S. Department of Transportation scaled to 2014$. Research and Innovative Technology Administrative, Bureau of Transportation Statistics, Average Cost of Owning and Operating an Automobile(a) (Assuming 15,000 Vehicle-Miles per Year) http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_03_17.html, Accessed: September, 2014.

[12] Average of congestion cost per commuter reported for California and New York metropolitan areas of $1,282 scaled from 2011$ to 2014$. Schrank, David. "TTI's 2012 URBAN MOBILITY REPORT." Texas A&M Transportation Institute, http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012.pdf.

ICEV with a fuel economy of 26 mpg. The range of gasoline costs exhibited in this figure was selected to represent the variation of gasoline costs across regions due to supply and demand issues.

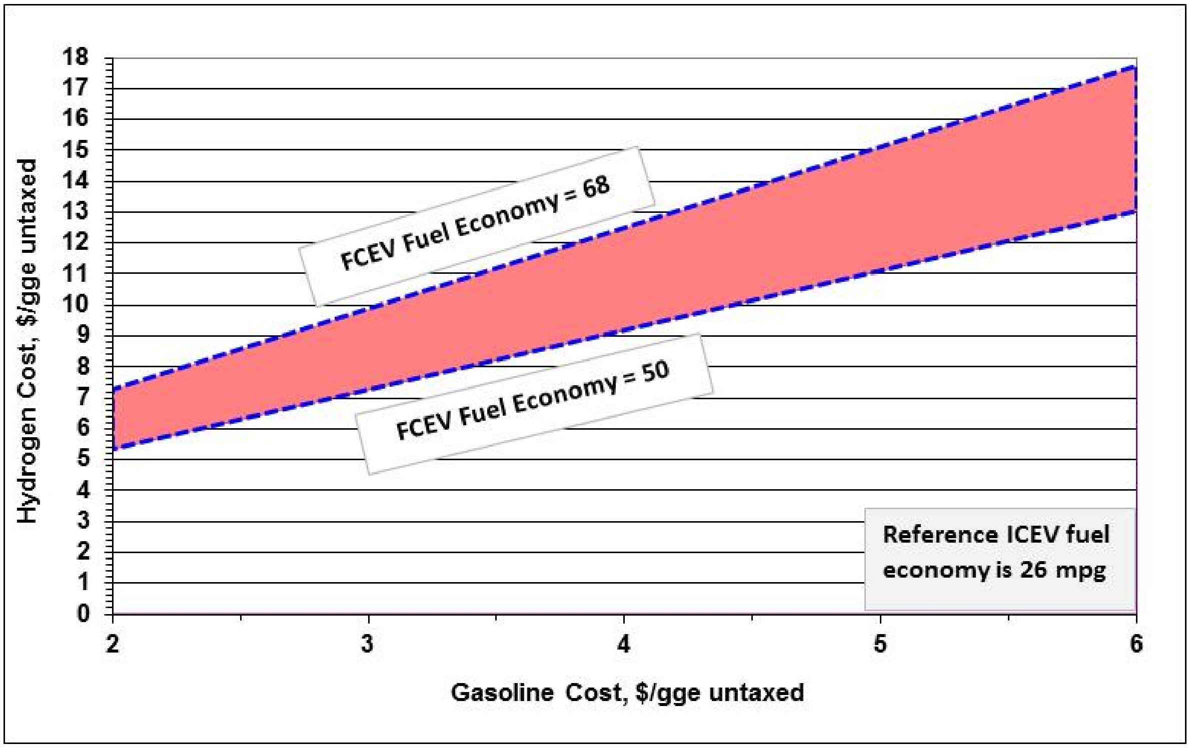

Figure 1: Effect of Variable Gasoline Costs on Hydrogen Cost

Stochastic and sensitivity analyses were performed in order to vary the following parameters simultaneously: gasoline cost, ICEV fuel economy, vehicle ownership cost differential and FCEV fuel economy. The bottom four bars in Figure 2 show the effect of varying these parameters individually while keeping all others constant. The top bar shows the results of varying these three parameters simultaneously using Monte Carlo techniques. To generate the top bar, triangular probability density functions (PDFs) were defined for the parameters in the Monte Carlo analysis.

The resulting cost probability distribution based on the Monte Carlo analysis is shown in Figure 3. A hydrogen cost of up to $9/gge may be competitive with gasoline in the 2014-2020 timeframe based on the 90th percentile of the distribution. The cost target of $7/gge is based on the most likely value rounded to the nearest whole number. Based on the results of the stochastic analysis this is the most likely hydrogen cost at which FCEVs will be competitive with ICEVs.

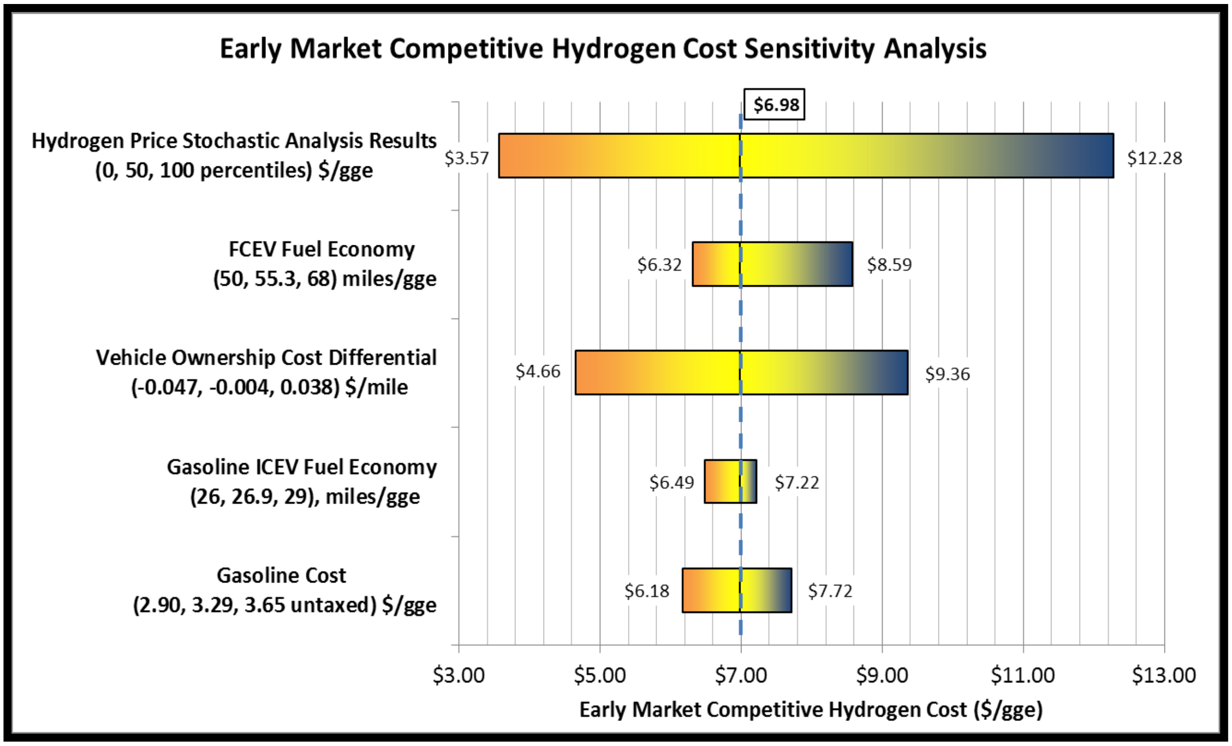

Figure 2: Sensitivity of the Early Market Hydrogen Cost (untaxed) to Gasoline Cost, Vehicle Ownership Cost Differential, and Vehicle Fuel Economy.

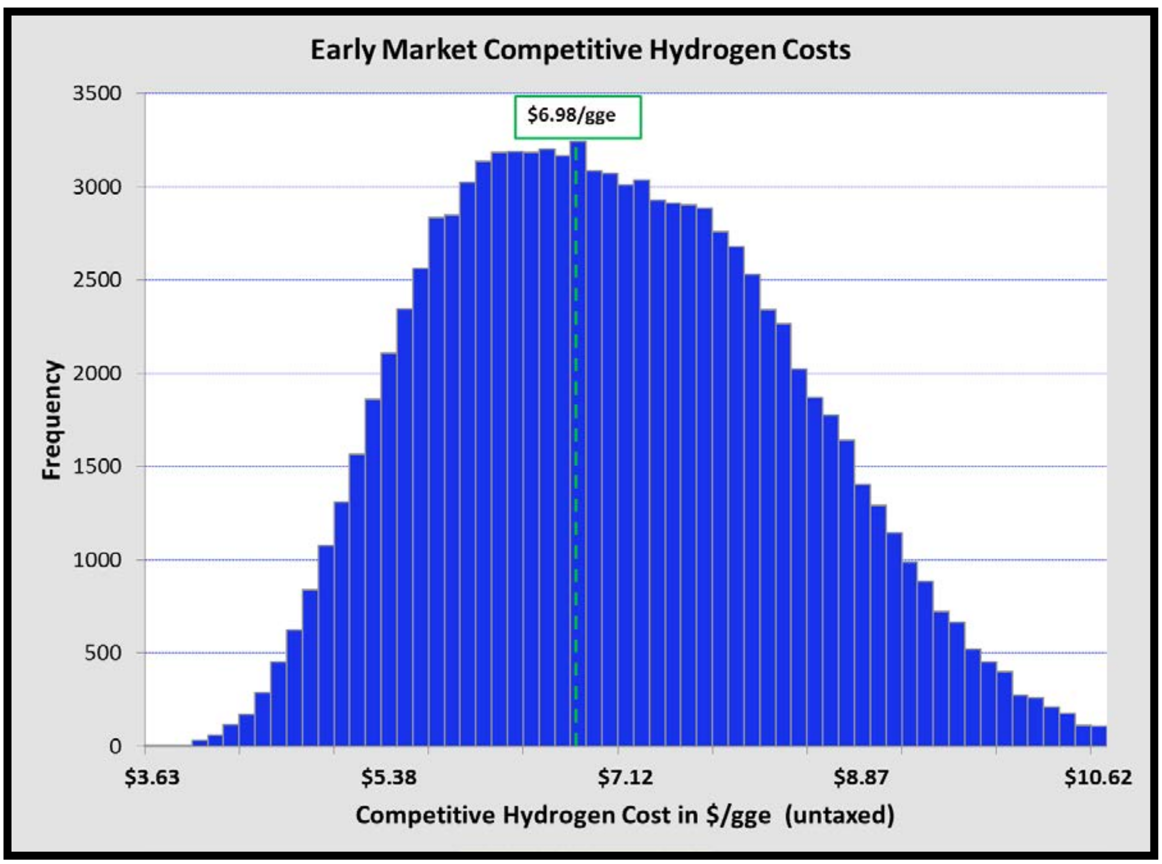

Figure 3: Histogram of Stochastic Analysis Results for Competitive Hydrogen Costs

Triangular distributions were also used in the analysis to quantify the uncertainty associated with the fuel economy projections, as shown in Table 3. The fuel economy values used for the ICEV and FCEV most likely values were based on analysis conducted using the Argonne National Laboratory Autonomie model. The maximum percentile fuel economy for the ICEV was based on EPA fuel economy distribution information. The maximum percentile fuel economy for the FCEV was based on the Toyota Highlander test data.[6]

Table 3: Percentile values the triangular PDFs used in the stochastic analysis and the resulting 10th and 90th percentile cost of hydrogen to be competitive with gasoline ICEVs

Parameter	Minimum	Most Likely	Maximum
ICEV Fuel Economy (mile / gal)	**26**[4]	**26**[4]	**29**[5]
FCEV Fuel Economy (mile / gge)	**50**[4]	**50**[4]	**68**[6]
FCEV Maintenance Cost Differential ($/yr)	**-$388**	**$0**	**$388**
Analysis Results	**10th percentile**	**Most Likely**	**90th percentile**
Hydrogen Cost, $/gge	**$5.41**	**$6.98**	**$8.80**

Conclusion

Based on the results of the stochastic analysis, the hydrogen cost needed for FCEVs to be competitive with ICEVs in the early market ranges from $5.40/gge to $8.80/gge with a most likely value of $6.98, rounding this to the nearest dollar results in a hydrogen cost target of <$7 per gallon of gasoline equivalent for hydrogen in the early market time frame of 2015-2020, based on the current vehicle prices and incentives.

This record was peer-reviewed by the U.S. DRIVE Fuel Pathways Integration, Hydrogen Delivery, and Hydrogen Production Technical Teams, as well as industry stakeholders including hydrogen suppliers.