DOE Fuel Cell Technologies Office Record		
Record #: 12002	**Date:** February 22, 2012	
Title: H2 Production Status & Threshold Costs Plot 2006-2011		
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Approved by: R. Farmer, S. Satyapal	**Date:** January 7, 2013	

Item:

Plots of the projected high-volume untaxed cost of hydrogen from 2006 to 2011 are presented for several production pathways. Cost ranges for each pathway are shown in 2007 dollars (2007$) and are based on Hydrogen Analysis Model (H2A) analyses using the assumption of high volume (i.e., sufficiently high annual and cumulative volumes have been reached that all economies of scale for capital and unit costs have been achieved [1]). In addition, cost ranges shown reflect variability in major feedstock pricing and a bounded range for capital cost estimates. The H2A analysis model provides transparent reporting of process design assumptions and a consistent cost analysis methodology for hydrogen production at central and distributed facilities [2]. Cost ranges for dispensed hydrogen (Figure 1) and for hydrogen production alone (Figure 2) are included.

The following table summarizes the 2011 status cost ranges shown in Figures 1 and 2 for near-term hydrogen production pathways requiring additional research and development (R&D) to meet the cost threshold goal of $2-$4/gge for untaxed dispensed hydrogen by 2020 [3]. The H2A projections for these pathways were based on the latest technology advancements reviewed by the DOE-EERE Fuel Cell Technologies (FCT) Program as of 2011.

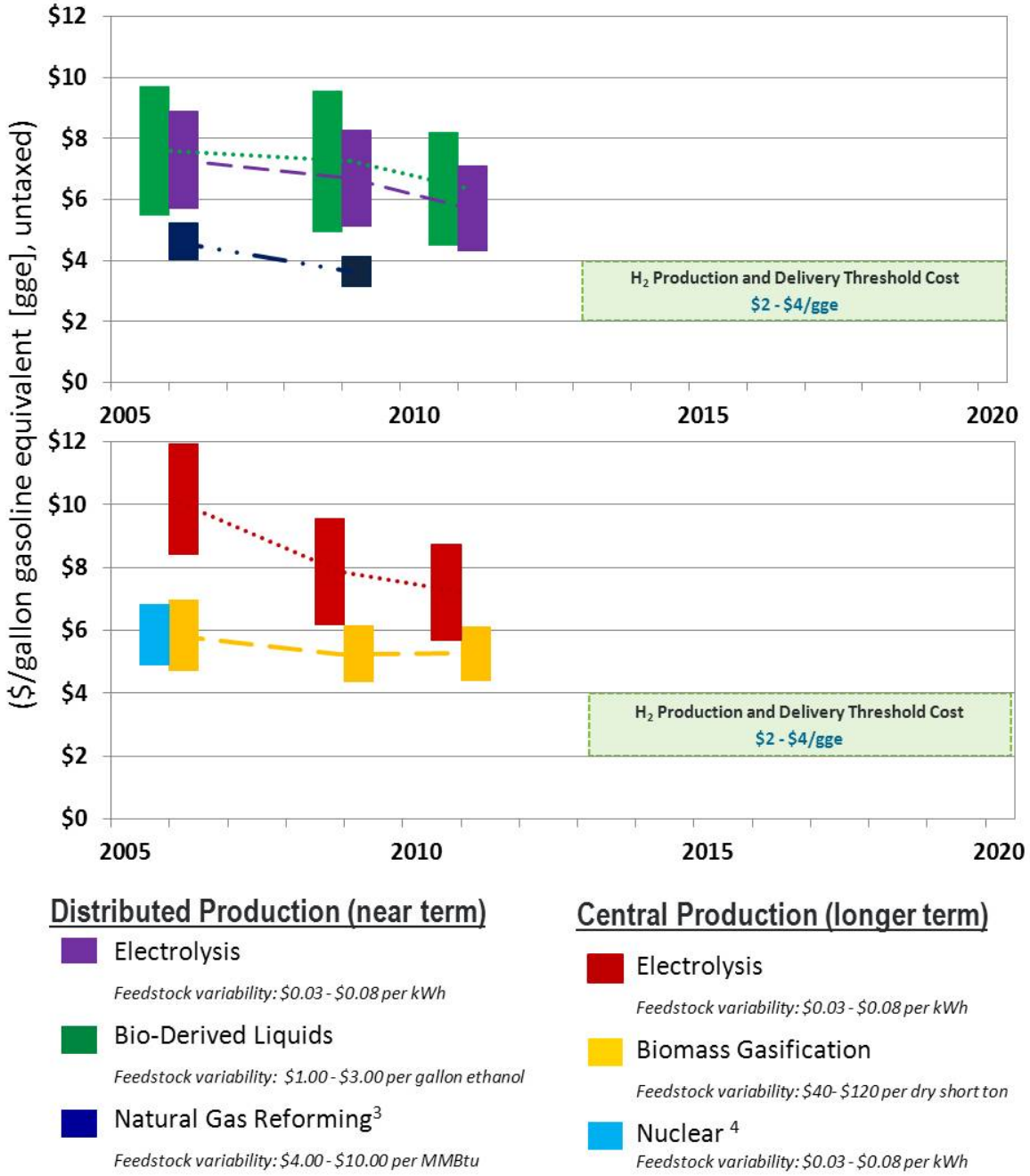
	Dispensed H_2 Cost Range[a]	H_2 Production Cost Alone[a]
Distributed Pathways	*H_2 dispensed at the point of use[b] (untaxed)*	
Distributed Electrolysis:	$4.30 - $7.10 /gge	$2.50 - $5.30 /gge
Distributed Bio-Derived Liquids:	$4.50 - $8.20 /gge	$2.70 - $6.40 /gge
Central Pathways	*H_2 delivered from plant gate to point of use[b] (untaxed)*	
Central Electrolysis:	$5.70 - $8.70 /gge	$3.10 - $6.10 /gge
Central Biomass:	$4.40 - $6.10 /gge	$1.80 - $3.50 /gge

[a] *Projected high-volume costs (2007$) per gallon gasoline equivalent (gge) rounded to the nearest $0.10 (given the range of assumptions and level of uncertainty)*

[b] *Consistent with previous H2A version 2 runs, forecourt compression, storage, and dispensing is estimated for 350 bar applications.*

A 2006 independent analysis of distributed hydrogen production from natural gas concluded that existing technologies could be used to produce hydrogen from natural gas at a cost competitive with gasoline [4]. In addition, a cost range of $3.10-$4.10/gge was reported in 2009 [5] and falls within the cost threshold goal of $2-$4/gge. As a result, FCT funding of Distributed Natural Gas Reforming was completed by 2009. The Office of Nuclear Energy (NE) funded Central Nuclear High-Temperature Electrolysis activities through 2008 as part of the Hydrogen Fuel Initiative and continued funding these activities under the Next Generation Nuclear Plant Program through 2011. The 2006 projected cost range for this pathway, based on an H2A analysis case study [6], was $4.90-$6.80/gge for delivered H_2.

Figure 1: High-Volume Cost of Hydrogen Production[1] (Dispensed[2])—Status



Notes:

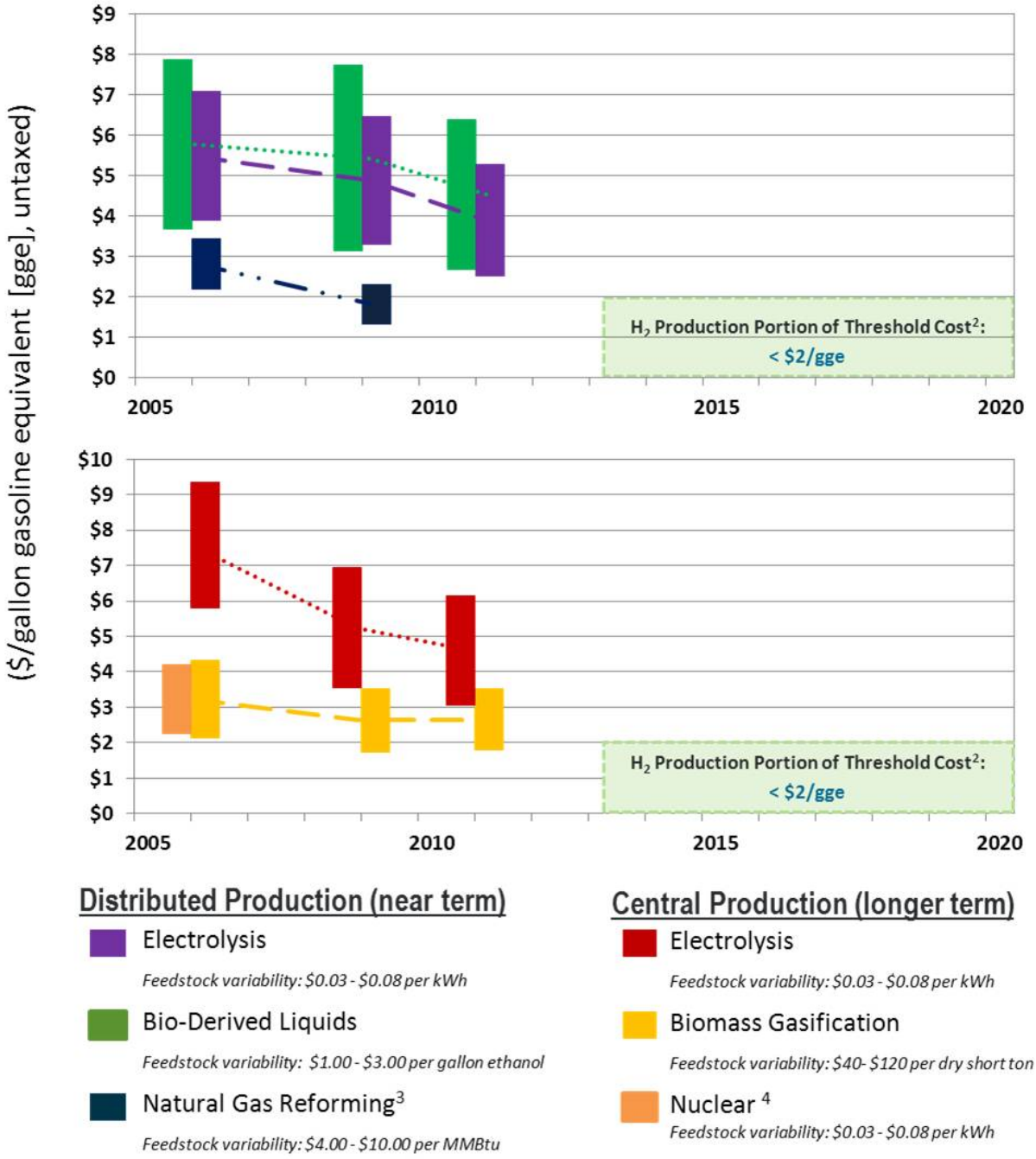
[1] *Costs shown include all delivery and dispensing costs, but do not include taxes. A cost of $1.82 for forecourt compression, storage, and dispensing is included for distributed technologies, and $2.61 is included as the total cost of delivery (including transportation, compression, storage, and dispensing) for centralized technologies. All delivery costs are based on the Hydrogen Pathways Technical Report (NREL/TP-6A1-46612, September 2009). Cost ranges for each pathway are shown in 2007 dollars, based on projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates. Projections of costs assume N^{th}-plant construction, distributed station capacities of 1,500 kg/day, and centralized station capacities of ≥50,000 kg/day.*

[2] Cost threshold at which hydrogen fuel cell vehicles are projected to become competitive with hybrid-electric vehicles .Record 11002, Hydrogen Threshold Cost Calculation, 2011, http://www.hydrogen.energy.gov/pdfs/11007_h2_threshold_costs.pdf .

[3] DOE funding of distributed natural gas reforming projects was completed in 2009 due to achievement of the threshold cost if projected at high volumes. Incremental improvements will continue to be made by industry.

[4] High-temperature electrolysis activities were funded through the Office of Nuclear Energy through FY2011.

Figure 2: Projected High-Volume Cost of Hydrogen Production[1]—Status



Notes:

[1] Cost ranges for each pathway are shown in 2007 dollars, based on projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates. Costs shown do not include delivery and dispensing costs. Projections of costs assume N^{th}-plant construction, distributed station capacities of 1,500 kg/day, and centralized station capacities of ≥50,000 kg/day.

[2] The Hydrogen Production Threshold Cost of <$2/gge reflects the Production apportionment (Record 12001, in preparation) of the 2010-revised Hydrogen Production and Delivery Cost Threshold of $2-4/gge (Record 11002, Hydrogen Threshold Cost Calculation, 2011, http://www.hydrogen.energy.gov/pdfs/11007_h2_threshold_costs.pdf).

[3] DOE funding of distributed natural gas reforming projects was completed in 2009 due to achievement of the threshold cost if projected at high volumes. Incremental improvements will continue to be made by industry.

[4] High-temperature electrolysis activities were funded through the Office of Nuclear Energy through FY2011.

General Description:

The plots shown in Figures 1 and 2 track the hydrogen cost ranges based on reported high-volume H2A projections of different distributed and central production pathways from 2006, 2009 and 2011. Figure 1 shows projected costs of dispensed hydrogen, while Figure 2 shows projected costs for hydrogen production only (without dispensing). Key features of the plots in both figures include:

- Distributed pathways of steam methane reforming (SMR), electrolysis, and bio-derived liquids (ethanol reforming) are represented.
- Central pathways of electrolysis from renewable power, biomass gasification, and nuclear high temperature electrolysis are represented.
- Data in the plots are shown as vertical bars representing cost spreads due to variability in the major feedstock costs and uncertainties in estimated capital costs.
- The hydrogen cost threshold of $2-$4/gge (in 2007$) reported in the 2011 *Hydrogen Threshold Cost Calculation* [3] is included in Figure 1 for reference. Figure 2 includes a production-only cost threshold of <$2/gge (2007$).

Analytical Basis for Data in Plots:

The data shown in the plots are based on H2A analysis, which projects the untaxed high-volume cost of hydrogen production and dispensing using capital, feedstock, and operation and maintenance (O&M) cost contributions. Important details of the analytical basis for the data reported in the plots include:

- A cost basis of 2007 dollars (2007$) was used to be consistent with EERE-wide analysis based on projections from the *Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2009 Report* [7] which uses 2007$ as its standard cost basis.
- The 2011 cases shown in the plots were based on analyses using the 2011 published H2A v3 tool [8] which projects costs in 2007$ as a standard default.
- The 2006 and 2009 cases were based on analyses using the older H2A v2, which projected costs in 2005$. To adjust data to 2007$ in these cases, the capital costs were inflated by a factor of 1.2 [1].
- Feedstock price ranges consistent with independent publications are reflected in the cost spreads (pathway-specific feedstock price ranges are included in the following section).
- Capital cost uncertainties in H2A [1] reflected in the cost spreads are modeled as a 30% uncertainty factor over the base capital cost estimate for most pathways, though a higher percentage is used in specific cases, as addressed in the following section
- In the cost spread for each pathway, the low-end cost projection uses the low-end feedstock price and the base capital cost estimate. The high-end cost projection uses the high-end feedstock price and the escalated capital cost including the uncertainty factor.
- For the distributed pathways in Figure 1, $1.82/gge is used as the projected cost of forecourt compression, storage, and dispensing for 350 bar applications. For the central pathways, $2.61/gge is used as the projected cost of pipeline delivery from central facilities. These values are consistent with the 2009 Hydrogen Production Pathways Report [5] based on H2A v2 analysis.
- All cost projections prepared after 2011 will use H2A v3 exclusively and will address 700 bar dispensing (rather than 350 bar) to meet current transportation market requirements. Nominally higher projected costs for hydrogen dispensing are expected compared with numbers from the 2009 Hydrogen Production Pathways Report [5].

Pathway Specific Data Points in Plots:

The following tables provide additional information detailing the assumptions and calculations used for the analysis of cost ranges for each of the production pathways represented in the plots.

Distributed Natural Gas:

Year	Low End Cost Contributions ($/gge in 2007$)					High End Cost Contributions ($/gge in 2007$)				
	Capital[c]	O&M[d]	Feedstock: low end @ $4/MMBTU[e]	**Production Total**	**Dispensed Total[f]**	Capital[g]	O&M[d]	Feedstock: high end @ $10/MMBTU[e]	**Production Total**	**Dispensed Total[f]**
2006[a]	$0.66	$0.85	$0.69	**$2.20**	**$4.02**	$0.86	$0.85	$1.72	**$3.43**	**$5.25**
2009[b]	$0.54	$0.26	$0.53	**$1.33**	**$3.15**	$0.70	$0.26	$1.34	**$2.30**	**$4.12**

[a] Based on H2A v2 analysis cited in the 2007 Multi-Year Program Plan (MYPP), page 3.1-11 [9].
[b] Based on H2A v2 analysis cited in the Hydrogen Production Pathways report, p. 75 [5].
[c] Capital cost factor of 1.2 used to convert capital costs from the 2005$ used in H2A v2 to 2007$.
[d] Operations and maintenance(O&M) costs include fixed and variable costs from original analysis.
[e] Feedstock cost range of $4.00-$10.00 per million British Thermal Unit (MMBTU) is consistent with the 2009 DOE Annual Energy Outlook [7] and the 2006 independent panel review of Distributed Hydrogen from Natural Gas [4].
[f] $1.82 is added in the plot as the projected cost of forecourt compression, storage and dispensing for 350 bar applications.
[g] High-end includes a further capital cost escalation factor of 1.3, used based on error bars in H2A analysis.

Distributed Electrolysis:

Year	Low End Cost Contributions ($/gge in 2007$)					High End Cost Contributions ($/gge in 2007$)				
	Capital	O&M[e]	Feedstock: low end @ 3¢/kWh[f]	**Production Total**	**Dispensed Total[g]**	Capital[h]	O&M[e]	Feedstock high end @ 8¢/kWh[f]	**Production Total**	**Dispensed Total[g]**
2006[a]	$1.44[d]	$0.80	$1.65	**$3.89**	**$5.71**	$1.87	$0.80	$4.40	**$7.07**	**$8.89**
2009[b]	$1.18[d]	$0.45	$1.68	**$3.31**	**$5.13**	$1.53	$0.45	$4.48	**$6.46**	**$8.28**
2011[c]	$0.76	$0.22	$1.53	**$2.51**	**$4.33**	$0.99	$0.22	$4.06	**$5.27**	**$7.09**

[a] Based on H2A v2 analysis cited in the 2007 Multi-Year Program Plan (MYPP), page 3.1-14 [9].
[b] Based on H2A v2 analysis cited in the Hydrogen Production Pathways report, p. 86 [5].
[c] Based on new National Renewable Energy Labs (NREL) case using H2A v3 [8].
[d] Capital cost factor of 1.2 used to convert capital costs from the 2005$ used in H2A v2 to 2007$.
[e] Operations and maintenance (O&M) costs include fixed and variable costs from original analysis.
[f] Feedstock cost range of $0.03-$0.08 per kilowatt hour (kWh) for industrial electricity costs consistent with the 2009 Independent Panel Review on water electrolysis [10].
[g] $1.82 is added as the projected cost of forecourt compression, storage and dispensing for 350 bar applications.
[h] High-end includes a further capital cost escalation factor of 1.3, used based on error bars in H2A analysis.

Distributed Bio-Derived Liquids:

Year	Low End Cost Contributions ($/gge in 2007$)					High End Cost Contributions ($/gge in 2007$)				
	Capital	O&M[e]	Feedstock: low end @ $1/gal of ethanol[f]	**Production Total**	**Dispensed Total[g]**	Capital[h]	O&M[e]	Feedstock: high end @ $3/gal of ethanol[f]	**Production Total**	**Dispensed Total[g]**
2006[a]	$0.90[d]	$0.80	$1.96	**$3.66**	**$5.48**	$1.17	$0.80	$5.89	**$7.86**	**$9.68**
2009[b]	$0.70[d]	$0.25	$2.18	**$3.13**	**$4.95**	$0.90	$0.25	$6.57	**$7.72**	**$9.54**
2011[c]	$0.65	$0.29	$1.74	**$2.68**	**$4.50**	$0.85	$0.29	$5.23	**$6.37**	**$8.19**

[a] Based on H2A v2 analysis cited in the 2007 Multi-Year Program Plan (MYPP), page 3.1-12 [9].
[b] Based on 2008 DTI H2A v2 run "Ethanol Steam Reformer (SR) at Forecourt 1500kg/day" [13].
[c] Based on new National Renewable Energy Labs (NREL) case using H2A v3 [8].
[d] Capital cost factor of 1.2 used to convert capital costs from the 2005$ used in H2A v2 to 2007$.
[e] Operations and maintenance(O&M) costs include fixed and variable costs from original analysis.
[f] Feedstock cost range of $1.00-$3.00 per gallon of ethanol consistent with the 2009 NAS report on liquid transportation fuels [12].
[g] $1.82 is added in the plot as the projected cost of forecourt compression, storage and dispensing for 350 bar applications.
[h] High-end includes a further capital cost escalation factor of 1.3, used based on error bars in H2A analysis.

Central Electrolysis:

Year	Low End Cost Contributions ($/gge in 2007$)					High End Cost Contributions ($/gge in 2007$)				
	Capital	O&M[e]	Feedstock: low end @ 3¢/kWh[f]	**Production Total**	**Dispensed Total[g]**	Capital[h]	O&M[e]	Feedstock: high end @ 8¢/kWh[f]	**Production Total**	**Dispensed Total[g]**
2006[a]	$2.64[d]	$1.50	$1.65	**$5.79**	**$8.40**	$3.43	$1.50	$4.40	**$9.33**	**$11.94**
2009[b]	$1.39[d]	$0.38	$1.78	**$3.55**	**$6.16**	$1.81	$0.38	$4.74	**$6.93**	**$9.54**
2011[c]	$1.07	$0.36	$1.64	**$3.07**	**$5.68**	$1.39	$0.36	$4.37	**$6.12**	**$8.73**

[a] Based on H2A v2 analysis cited in the 2007 Multi-Year Program Plan (MYPP), page 3.1-15 [9].
[b] Based on H2A v2 analysis cited in the Hydrogen Production Pathways report, p. 139 [5].
[c] Based on new National Renewable Energy Labs (NREL) case using H2A v3 [8].
[d] Capital cost factor of 1.2 used to convert capital costs from the 2005$ used in H2A v2 to 2007$.
[e] Operations and maintenance(O&M) costs include fixed and variable costs from original analysis.
[f] Feedstock cost range of $0.03-$0.08 per kilowatt hour (kWh) for industrial electricity costs consistent with the 2009 Independent Panel Review on water electrolysis [10].
[g] $2.61 is added as the projected cost of pipeline delivery from central facilities.
[h] High-end includes a further capital cost escalation factor of 1.3, used based on error bars in H2A analysis.

Central Biomass Gasification:

Year	Low End Cost Contributions ($/gge in 2007$)					High End Cost Contributions ($/gge in 2007$)				
	Capital	O&M[e]	Feedstock: low end @ $40/dry short[f]	**Production Total**	**Dispensed Total[g]**	Capital[h]	O&M[e]	Feedstock: high end @ $120/dry short[f]	**Production Total**	**Dispensed Total[g]**
2006[a]	$0.84[d]	$0.60	$0.68	**$2.12**	**$4.73**	$1.68	$0.60	$2.05	**$4.33**	**$6.94**
2009[b]	$0.64[d]	$0.52	$0.58	**$1.74**	**$4.35**	$1.27	$0.52	$1.74	**$3.53**	**$6.14**
2011[c]	$0.64	$0.61	$0.53	**$1.78**	**$4.39**	$1.28	$0.61	$1.62	**$3.51**	**$6.12**

[a] Based on H2A v2 analysis cited in the 2007 Multi-Year Program Plan (MYPP), page 3.1-19 [9].
[b] Based on H2A v2 analysis cited in the Hydrogen Production Pathways report, p. 115 [5].
[c] Based on new National Renewable Energy Labs (NREL) case using H2A v3 [8].
[d] Capital cost factor of 1.2 used to convert capital costs from the 2005$ used in H2A v2 to 2007$.
[e] Operations and maintenance(O&M) costs include fixed and variable costs from original analysis.
[f] Feedstock cost range of $40-$120 per dry short ton consistent with the 2011 independent panel review of biomass gasification [11].
[g] $2.61 is added in the plot as the projected cost of pipeline delivery from central facilities.
[h] High-end includes a further capital cost escalation factor of 2.0, used based on error bars in H2A analysis specific to biomass gasification.

Central Nuclear:

Year	Low End Cost Contributions ($/gge in 2007$)					High End Cost Contributions ($/gge in 2007$)				
	Capital[b]	O&M[c]	Feedstock: low end @ 3¢/kWh [d,e]	**Production Total**	**Dispensed Total[f]**	Capital[g]	O&M[c]	Feedstock: high end @ 8¢/kWh [d,e]	**Production Total**	**Dispensed Total[f]**
2006[a]	$0.91	$0.37	$0.99	**$2.27**	**$4.88**	$1.19	$0.37	$2.63	**$4.19**	**$6.80**

[a] Based on H2A v2 analysis for future nuclear high temperature electrolysis published in 2008 [6].
[b] Capital cost factor of 1.2 used to convert 2006 case capital costs from the 2005$ used in H2A v2 to 2007$.
[c] Operations and maintenance(O&M) costs include fixed and variable costs from original analysis[6].
[d] The feedstock cost range was applied to the electrical energy portion of the feedstock costs from the original analysis. The thermal energy portion of the feedstock costs, supplied by the nuclear plant itself, was treated similarly to the O&M costs.
[e] Feedstock cost range of $0.03-$0.08 per kilowatt hour (kWh) for industrial electricity costs consistent with the 2009 Independent Panel Review on water electrolysis [10].
[f] $2.61 is added in the plot as the projected cost of pipeline delivery from central facilities.
[g] High-end includes a further capital cost escalation factor of 1.3, used based on error bars in H2A analysis.

References

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[11], *Hydrogen Production Cost Estimate Using Biomass Gasification*, NREL/BK-6A10-51726, October, 2011, http://www.hydrogen.energy.gov/pdfs/51726.pdf, p. i and Table ES-2, p. V.

[12] *Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts*, NAS, 2009, (http://www.nap.edu/openbook.php?record_id=12620) Page 137, Table 3.3.

[13] 01D_Current_Forecourt_Hydrogen_Production_from_Ethanol_(1,500_kg_per_day)_version_2.1.3.xls, http://www.hydrogen.energy.gov/h2a_production_archive.html