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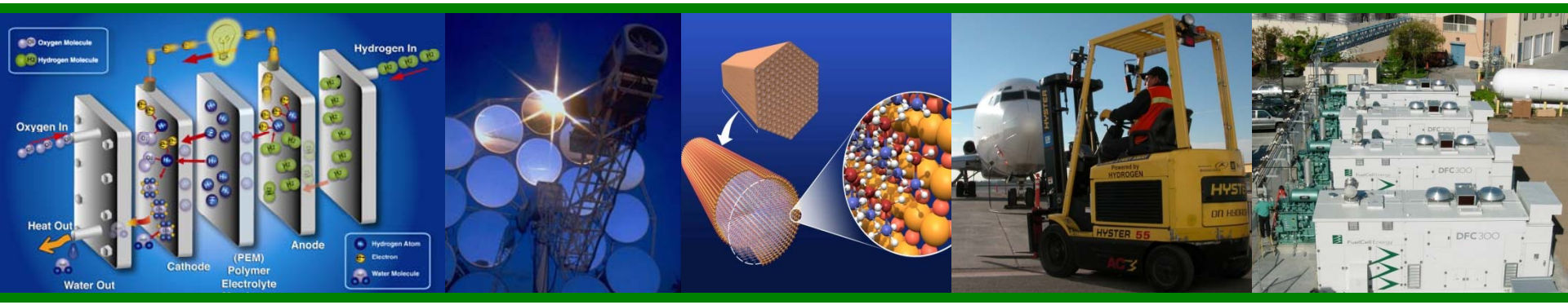

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Hydrogen Threshold Cost Analysis

Fuel Cell Technologies Program

Fred Joseck

Technology Analyst

U.S. DOE Fuel Cell Technologies Program

Mark Ruth

Systems Integration Office, NREL

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Outline

- Analysis Summary
- Background
  - Reason to Update Hydrogen Cost Target/Threshold Cost
  - Principles for Top-Down Hydrogen Threshold Cost
- Methodology and Results
- Next Steps and Conclusions

Analysis Summary

Summary: The cost threshold at which hydrogen is projected to become competitive with gasoline in HEVs in 2020 is $2.00 - $4.00/gge.

- Range captures gasoline cost volatility and range of vehicle cost and performance assumptions.
- Gasoline hybrid electric vehicle (HEV) used as the comparative / competing technology. (Sensitivity analyses comparing fuel cell vehicles (FCV) to other vehicle platforms were included.)
- Range includes incremental FCV ownership costs compared to gasoline HEVs.

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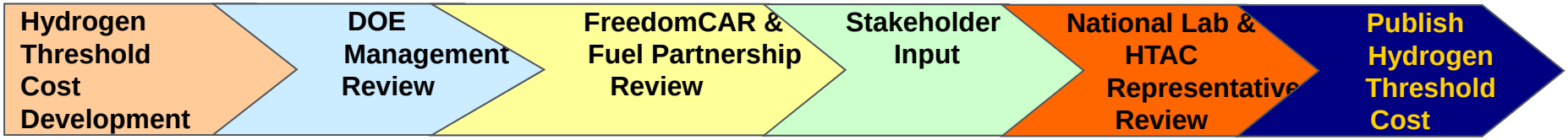
Peer Review Process



Feedback for Hydrogen Threshold Cost included Multiple Stakeholders

- Review with DOE management
- Review with tech team members and directors of FreedomCar & Fuel Partnership
- Webinar review with multiple entities such as industrial gas companies, energy companies, automobile companies, electrical companies, national laboratories, and academia.
- Input from international stakeholders
- Review with national laboratory analysts and Hydrogen Technical Advisory Committee representatives

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Reasons to Update Hydrogen Cost Target/Threshold Cost

- DOE reassesses program targets periodically

- Gasoline cost and competing technology options have changed.
  - EIA projections of gasoline prices have increased.
    - Previous projection (2005 AEO): $1.29/gal in 2015 – Hi Oil Case*
    - 2009 AEO projections for 2020
      - $3.13/gal. Reference Case*
      - $4.57/gal. Hi Oil Case*

- Threshold cost includes the incremental fuel cell vehicle ownership cost range of $0.00/mile to $0.04/mile over gasoline HEVs.

* Projections do not include gasoline tax or sales tax.

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Principles for Top-Down Hydrogen Threshold Cost Analysis

- Consumer fueling costs with hydrogen must be equivalent to or less than those of the competing technology on a fuel cost per mile basis.
- Threshold cost provides a measure for assessing technology performance.
- Guides R&D programs by focusing options and enabling prioritization.
- Threshold cost is pathway independent.
- Projected improvements to vehicle technologies are implicitly included in the calculation of the threshold cost through the fuel economies used.

Hydrogen Threshold Cost developed through a well defined, transparent process.

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Hydrogen Threshold Cost Analysis
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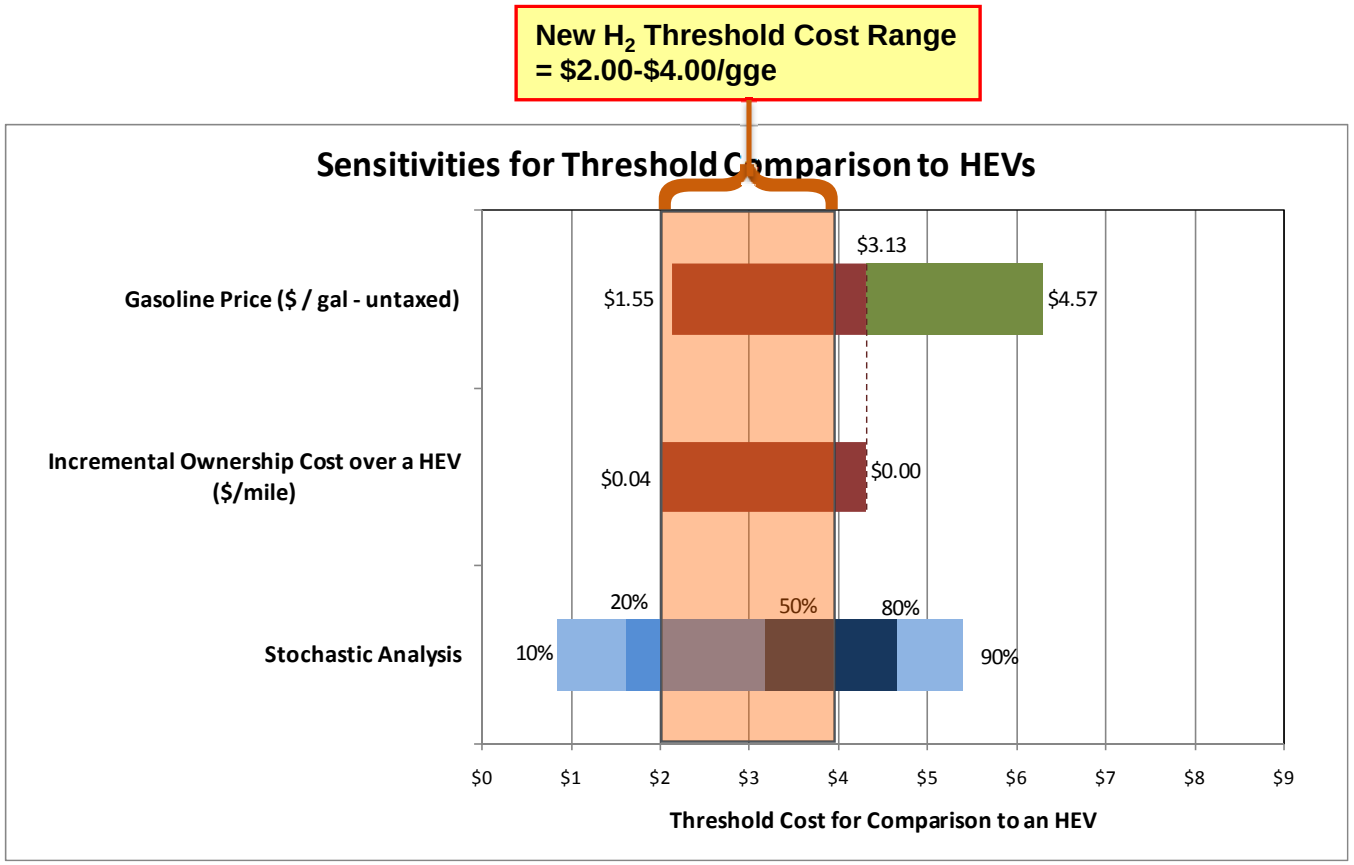

- The cost necessary for hydrogen to be competitive depends upon the gasoline cost, and vehicle fuel economies and incremental cost.

$4.57 / gal gasoline (untaxed) is the AEO 2009 High Energy Price case
$3.13 / gal gasoline (untaxed) is the AEO 2009 Reference (including effects of ARRA).
Baseline FCV/HEV fuel economy ratio is 1.4.

Stochastic Analysis Details

-$2.37	$0.24	$0.84	$1.29	$1.62	$1.93	$2.22	$2.47	$2.72	$2.95	$3.18	$3.41	$3.63	$3.87	$4.12	$4.35	$4.66	$4.95	$5.38	$5.91	$7.80
0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%

Hydrogen Threshold Cost Analysis

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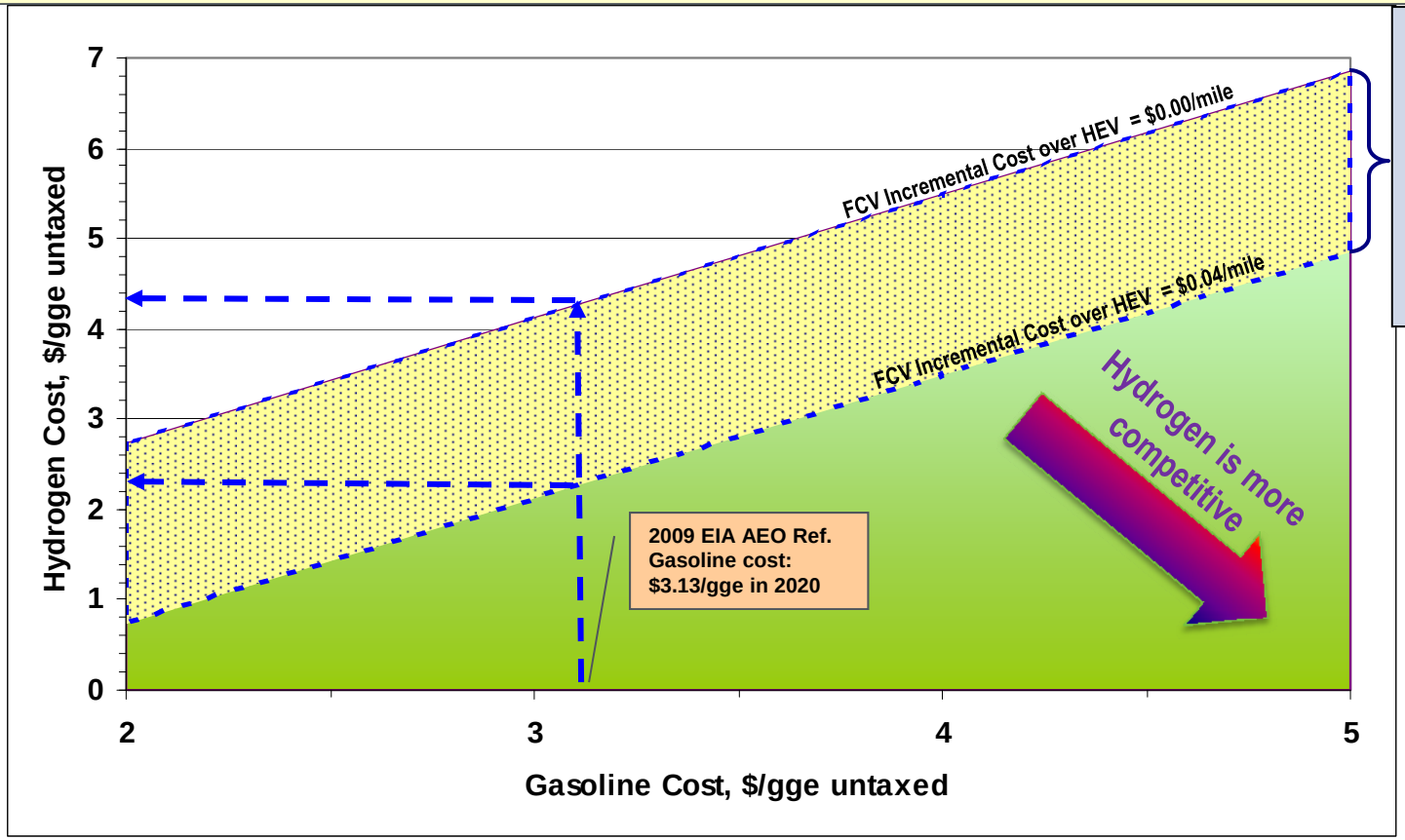
Competitive cost of Hydrogen compared to gasoline HEV is ~$2.00 - $4.00/gge



Range includes diverse technologies, fuel economies and incremental vehicle cost assumptions.

- The fuel cost per mile for a hydrogen fuel cell vehicle is set equivalent to the price of the competing vehicle on a "per mile" basis.

$$\$/\text{gge H2} = \left[\left(\frac{\text{Gasoline HEV cost, \$/gge}}{\text{HEV fuel economy, miles/gge}}\right) - \text{FCV incremental vehicle cost, \$/mile}\right] \times \text{FCV fuel economy, miles/gge}$$

Next Steps

- This process leads to a top-down threshold cost. Analyses and discussions are necessary to develop bottom-up targets for each production and delivery technology. Updates to those will lead to updates to the Multi Year Program Plan (MYPP).

- H2A (**H_2 A**nalysis) (Hydrogen Production Model) & HDSAM (**H**ydrogen **D**elivery **S**cenario **A**nalysis **M**odel) need to be updated with AEO 2009 energy cost projections; capital cost estimates need to be updated to 2007$. The updated models will then need to be run through the Macro-System Model (MSM) to determine pathway costs.

- The scale of distributed production technologies and distribution stations should be considered before identifying the status of the technology (i.e., estimate cost with a demand of 100-400 kg/day instead of over 1000 kg/day).

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Conclusions

- The cost range at which hydrogen is projected to become competitive with gasoline HEVs in 2020 is $2.00 - 4.00/gge.

- Threshold cost is expressed as a range to include uncertainty of several parameters of the threshold cost.

- The new cost range will require a review of the hydrogen production technology suite and a rationalization of technology R&D priorities.

- Revised hydrogen threshold cost will guide MYPP updates for Production and Delivery.

Supporting Slides

Assumptions

	Previous Case	New Case (Base case)[1]
Reference Yr.	2015	2020
EIA AEO source yr./ case	2005/ Hi Oil Case	2009 EIA AEO Reference and Hi Oil Cases
Reference year dollars	2005	2007
Comparative vehicles	Gasoline ICE/HEV	Gasoline HEV
Gasoline Cost (untaxed), $/gal.	$1.30/gal	$3.13/gal (untaxed, $2007)
Electricity Cost, $/kWh	Not applicable	$0.085/kWh
Source of vehicle performance projections	NAS Report (2005)	PSAT Simulations
H_2 FCV to ICE fuel economy ratio	2.40	Not used
H_2 FCV to gasoline HEV fuel economy ratio	1.67	1.4[2]
Incremental cost of financing, maintenance, tires, repairs, insurance, registration, taxes, and fees, the following table shows the incremental vehicle costs	Not applicable	$0
Assumed lifetime mileage of all vehicles	150,000 miles	150,000 miles
Incremental cost of vehicle ownership (not including fuel) for an FCV over an HEV	Not applicable	$0.00 / mile

Notes:

[1] Sensitivity analysis conducted to a broader range of parameters.

[2] Fuel economy ratio is based on FCV fuel economy of 59 miles/gge and gasoline HEV fuel economy of 42 miles/gge.

Vehicle Ownership Costs

- Vehicle ownership costs include the following
  - Vehicle depreciation, financing, maintenance, tires, repairs, insurance, registration, taxes, fees, tax credits
- The primary difference between vehicles on two different platforms is vehicle depreciation
- Assuming no financing cost, no time value of money, full depreciation over 150,000 miles, and negligible differences in the cost of maintenance, tires, repairs, insurance, registration, taxes, and fees, the following table shows the incremental vehicle costs.

Platform comparison	Incremental vehicle cost between gasoline vehicle and FCV	Incremental cost ($/mile)
HEV → FCV	$6000 / vehicle	$0.04 / mile

Hydrogen Threshold Cost Methodology

- The fuel cost per mile for a hydrogen vehicle is set equivalent to the cost of the competing vehicle (gasoline HEV) on a "per mile" basis using the following methodology:

$$\frac{\text{H}_2\text{ Threshold Cost, \$/gge}}{\text{Fuel Economy H}_2\text{ FCV, miles/gge}} + \text{Incremental vehicle cost, \$/mile} = \frac{\text{EIA Gasoline Cost in 2020, \$/gge}}{\text{Fuel Economy Gasoline HEV, miles/gge}}$$

- Current projections of fuel economy ratios
  - FCV to HEV ratio of 1.4
  - With the AEO 2009 Reference Case energy price projections and the price of gasoline in 2020 is $3.13/gal.
- Vehicle ownership costs are set to a per mile basis include:
  - Vehicle depreciation, financing, maintenance, tires, repairs, insurance, registration, taxes, fees, tax credits

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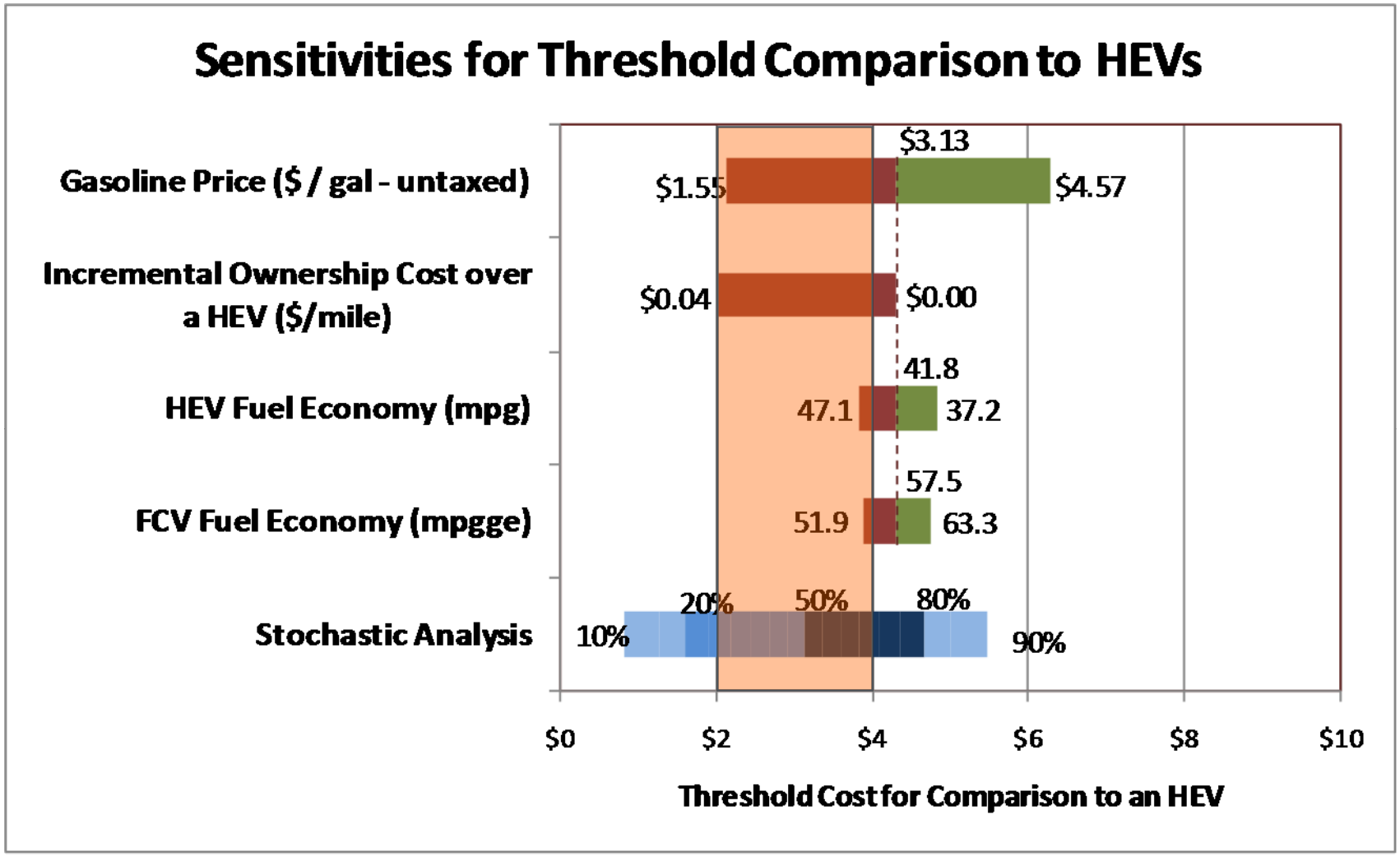
Hydrogen Threshold Cost Analysis – *DRAFT*
Fuel Economy Ratio Allowed to Vary



-$2.33	$0.21	$0.81	$1.25	$1.61	$1.92	$2.19	$2.43	$2.68	$2.91	$3.14	$3.36	$3.61	$3.84	$4.09	$4.37	$4.66	$5.01	$5.48	$6.07	$9.26
0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%

Hydrogen Threshold Cost Analysis
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Revising the hydrogen threshold cost will result in an assessment of Hydrogen Production and Delivery R&D priorities. Projections of high-volume / nth plant production and delivery of hydrogen meet the targets for most technologies.

Projected High-Volume Cost of Hydrogen (Dispensed)—Status

($/gallon gasoline equivalent [gge], untaxed)

NEAR TERM:

Distributed Production

- Natural Gas Reforming
- Ethanol Reforming
- Electrolysis

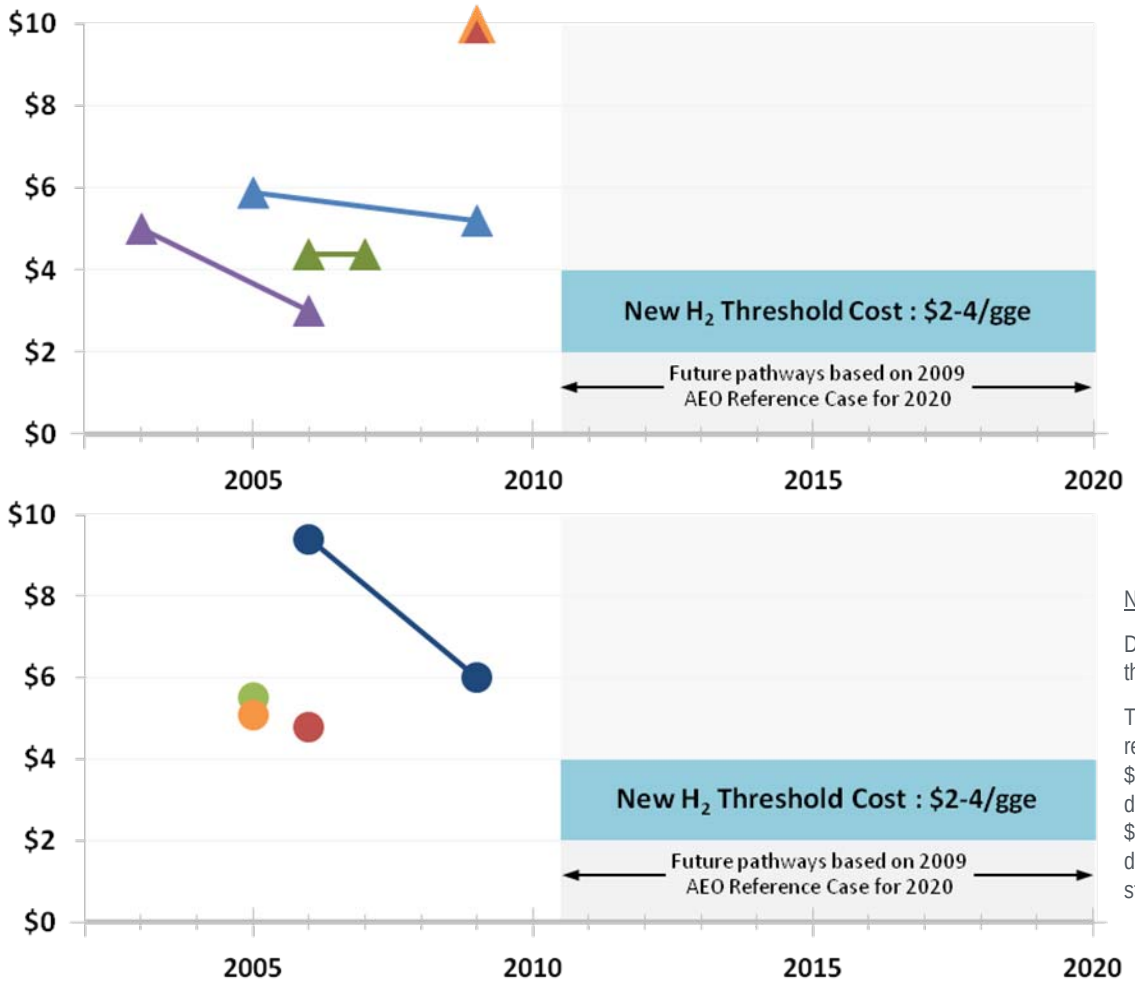
Low-volume (200 kg/day)

- Steam Methane Reforming
- H_2 from Combined Heat, Hydrogen, and Power Fuel Cell

LONGER TERM:

Centralized Production

- Biomass Gasification
- Central Wind Electrolysis
- Coal Gasification with Sequestration
- Nuclear



Notes:

Data points are being updated to the 2009 AEO reference case.

The 2010 Technology Validation results show a cost range of $8-$10/gge for a 1,500 kg/day distributed natural gas and $10-$13/gge for a 1,500 kg/day distributed electrolysis hydrogen station.

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Potential Issues

Projected high volume costs for some hydrogen production technologies can meet new hydrogen threshold cost but R&D is still required for initial, low-volume production.

Market entry risks were not included.

- By setting the hydrogen cost (on a per-mile basis) at a lower level than the gasoline cost (either a percentage or a constant reduction) market entry/penetration could be accelerated.

The AEO 2009 energy price projections of the reference and high oil cases were used for setting this threshold cost.

Stochastic Analysis Parameters and Results

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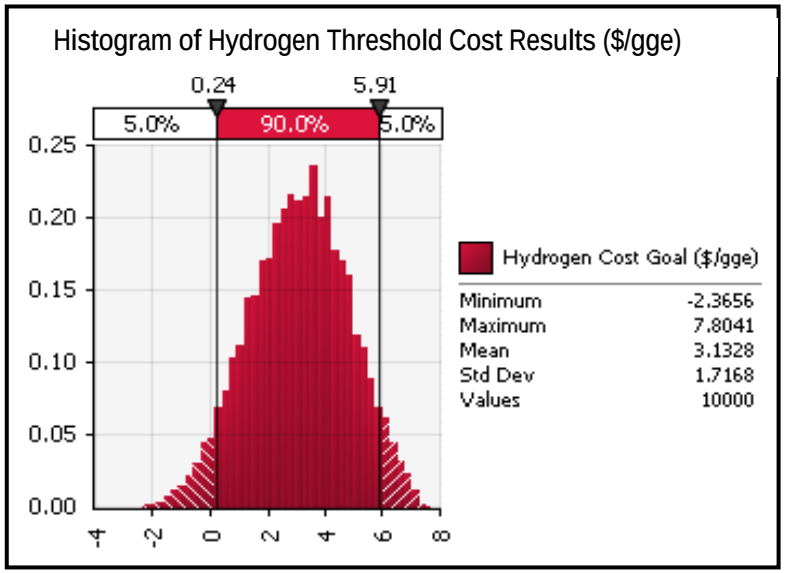
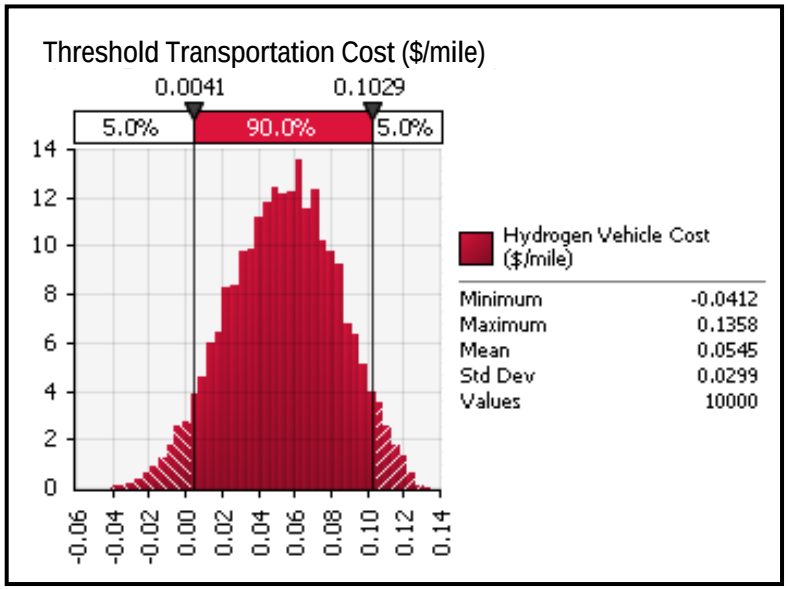
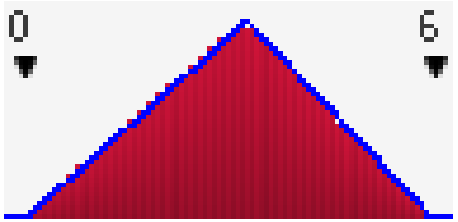


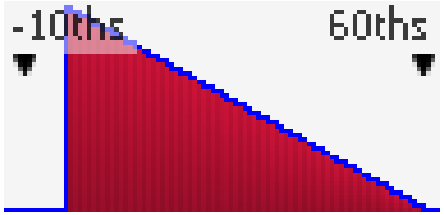


Input Distribution: Gasoline Cost ($/gal without taxes)



Min	Mean	Max	5%	95%
$0.31	$3.09	$5.70	$1.18	$4.91

Input Distribution: Incremental Ownership Cost over a HEV ($/mile)



Min	Mean	Max	5%	95%
$0.0000	$0.0195	$0.0580	$0.0015	$0.0454

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