National Renewable Energy Laboratory
Innovation for Our Energy Future

DOE Hydrogen Program Risk Analysis in Support of EERE's Portfolio Analysis
(project #ANP_02_Duffy)

2009 DOE Hydrogen Program Review

May 19, 2009
Arlington, VA

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Overview

Timeline

Start date: Oct 2008

Completion: June 2009

Percent complete: 75%

Budget

Total funding: $120K

- 100% DOE funded

Objectives

Near Term: Provide Risk Analysis methodologies and tools that are useful to Staff, Team Leaders, Program Managers, and Portfolio Managers in identifying, quantifying, evaluating, managing, monitoring, documenting, and communicating technology development risks and benefits

Long Term: Assist project, program, and portfolio decision-making that aligns and balances the portfolio with strategic goals.

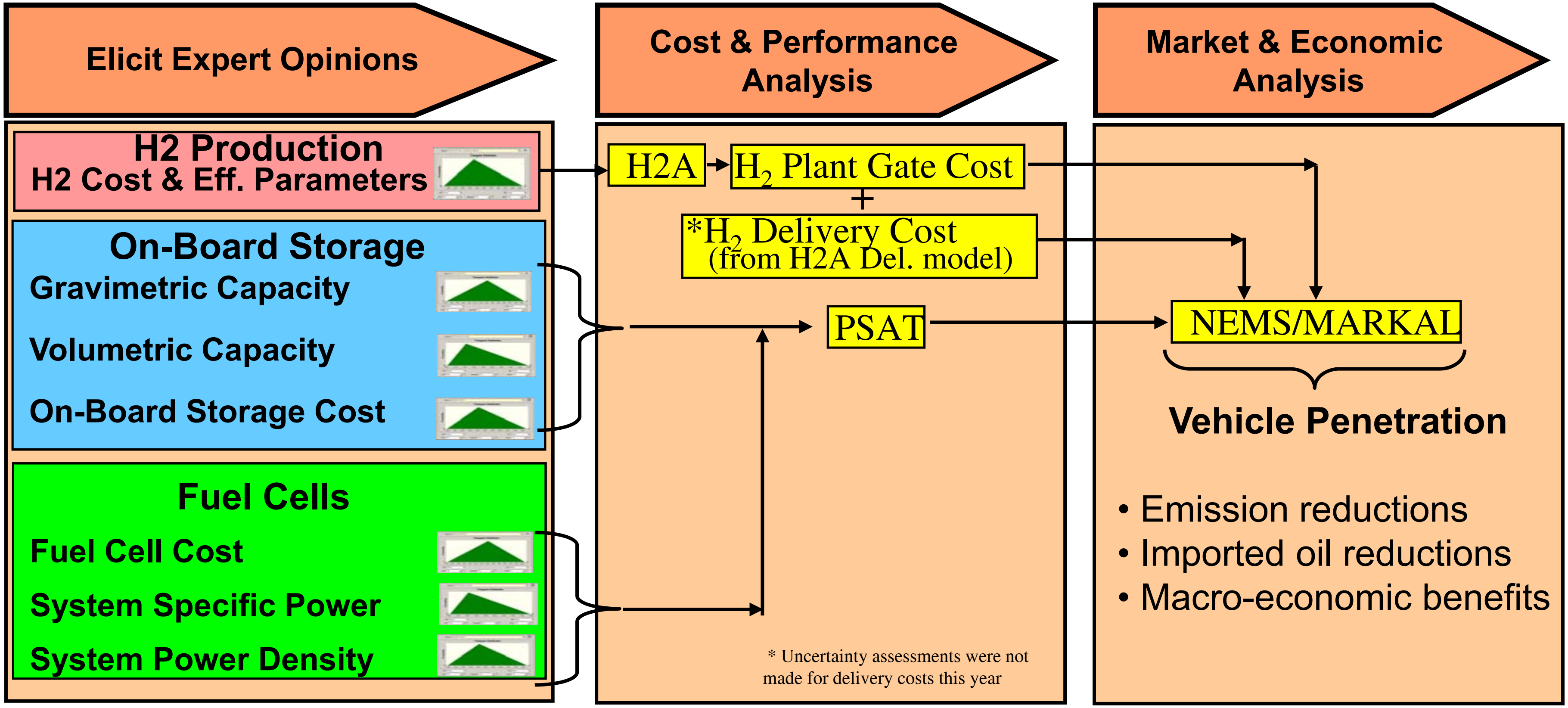
Approach: Analyzed Technical Risk

- **Analyzed technical risk**
  - Levels of performance, reliability, cost, etc. achieved by R&D
- **Given Budget and Schedule**
  - 3 budget levels involved (flat, zero, and double) and assuming that work can be completed as funded
- **Assuming other risks are overcome**
  - Market acceptance, organizations are capable of commercialization, safety / reliability / environmental risks are overcome, financial backing is available, and political / strategic support is available.

Approach

1. Identify Technology Improvement Opportunities (TIOs). These are research areas where success might improve technology performance (e.g., improved reactor design for production or cryo-compressed on-board storage)
2. Select and characterize Technology Performance Measures (TPMs). These are measurements of performance (e.g., yield or capital cost)
3. Select experts to participate
4. Expert's estimate TPM potential (stochastic estimation)
    a. Meeting to explain the process, discuss assumptions, and elicit feedback
    b. Aggregation of initial responses
    c. Present initial responses to experts and allow them to discuss their input
    d. Experts modify responses as desired
    e. Aggregation of final responses
5. Provide TPM potential results to additional models for use in EERE's portfolio analysis

Approach: Models Involved



Aggregated results for production and delivery are provided to NEMS & Markal modelers for the EERE Portfolio Decision Support (PDS) analysis.

Aggregated results for on-board storage and fuel cells are provided to PSAT modelers who generate vehicle cost and fuel economy data that are used by NEMS & Markal modelers

Hydrogen Production / Distribution

1. Technology Improvement Opportunities (TIOs)
   - Four were selected because the program is funding R&D in those potentially high-impact technologies
     1. Central biomass gasification
     2. Central electrolysis using electricity generated by wind turbines
     3. Distributed ethanol reformation
     4. Compression, storage, and dispensing (CSD)

Hydrogen Production / Distribution

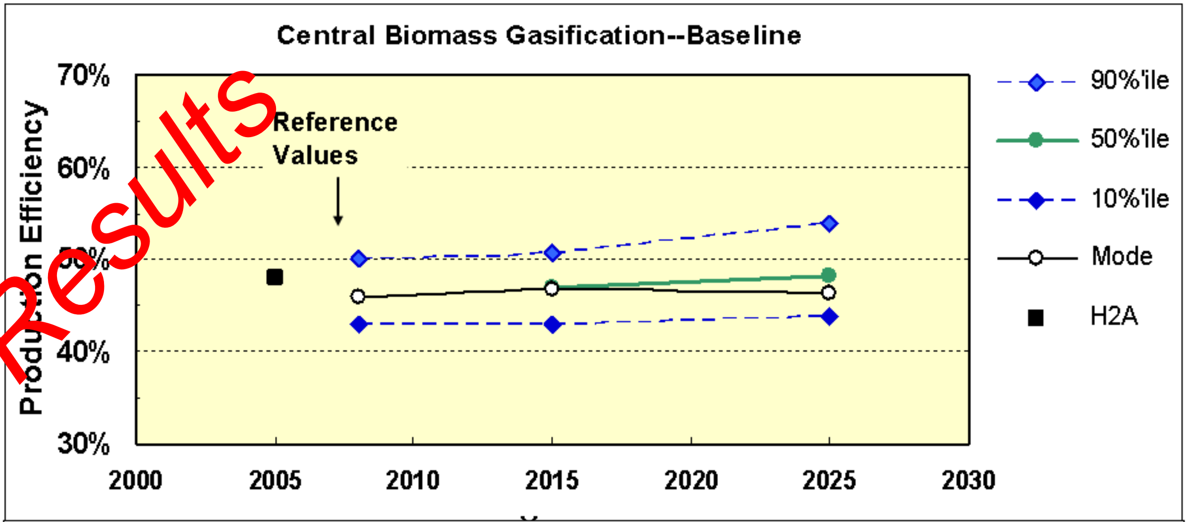
2. Technology Performance Measures (TPMs)
3. Select experts to participate

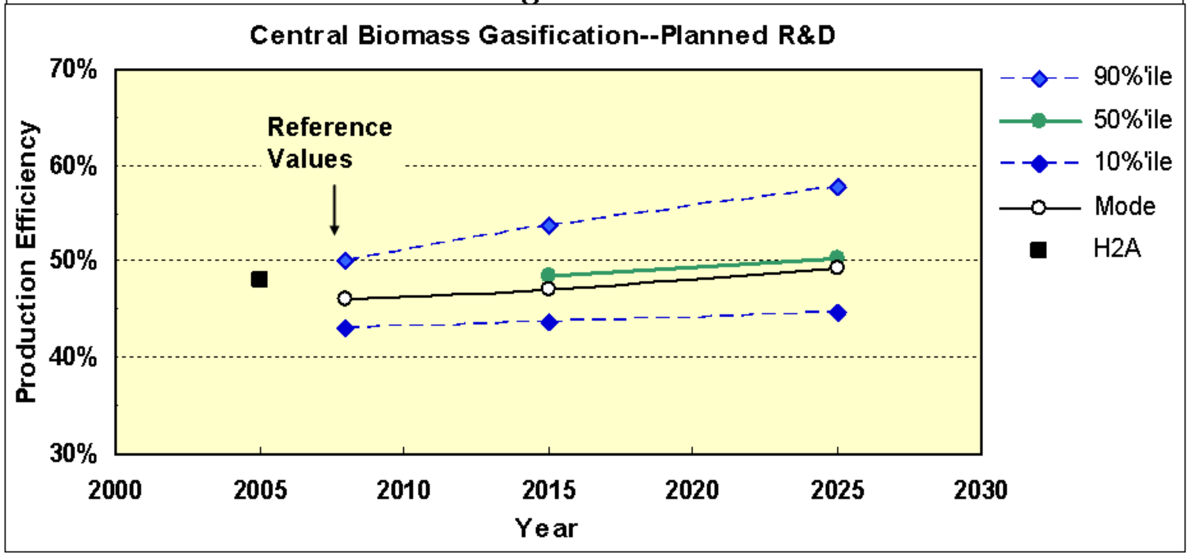
Below is a table showing the TPMs for each technology and the number of experts responding (responses as of April 8)

	Efficiency	Capital Cost	O&M Cost	Capacity Factor	Labor
Central Biomass Gasification	7	7	7	7	7
Central Wind Electrolysis	6	5	5		
Dist. Ethanol Reformation	8	7	7	6	
CSD	7	6			

Hydrogen Production / Distribution

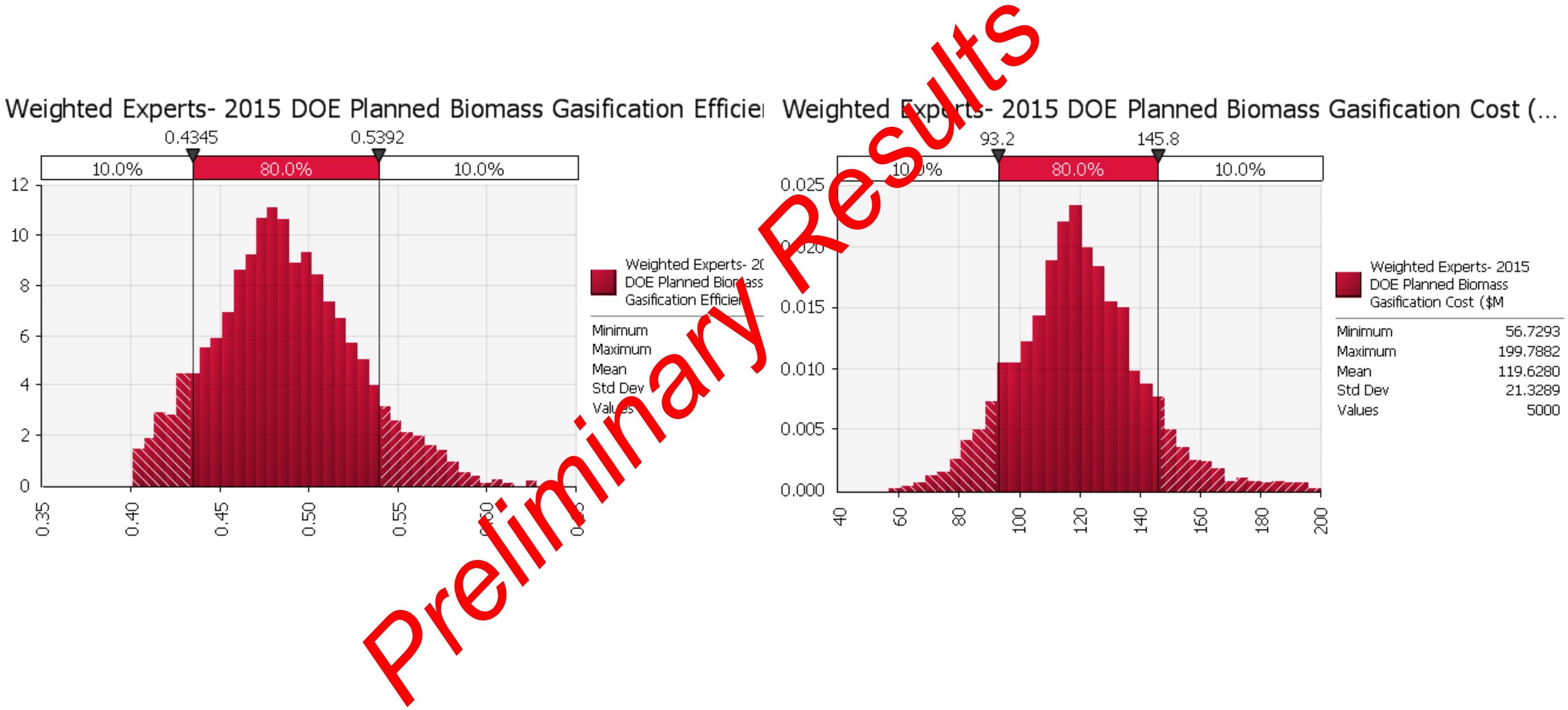
4. Experts estimate TPM potential





Hydrogen Production / Distribution

5. Provide TPM potential results for use in EERE's portfolio analysis
   - Based on the aggregated distribution functions, tabulated results will be provided to NEMS and Markal for energy sector modeling.



On-Board Storage

1. Technology Improvement Opportunities (TIOs)
   - Seven parallel technology options are considered
     1. 350 bar compressed gas
     2. 700 bar compressed gas
     3. Liquid
     4. Cryo-compressed
     5. Adsorbents
     6. Metal Hydrides
     7. Chemical Hydrides

On-Board Storage

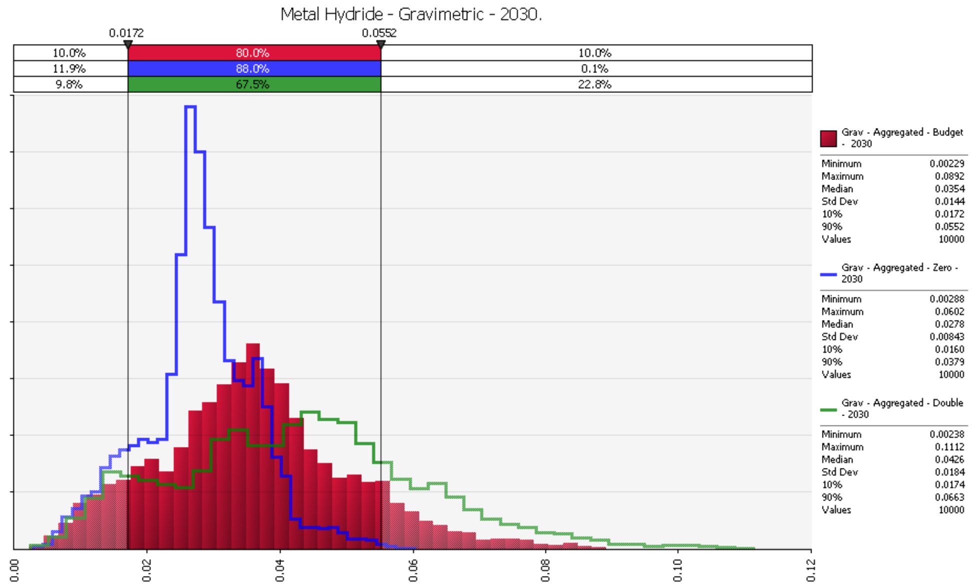
2. Technology Performance Measures (TPMs)
    - Gravimetric Capacity
    - Volumetric Capacity
    - Cost
3. Select experts to participate

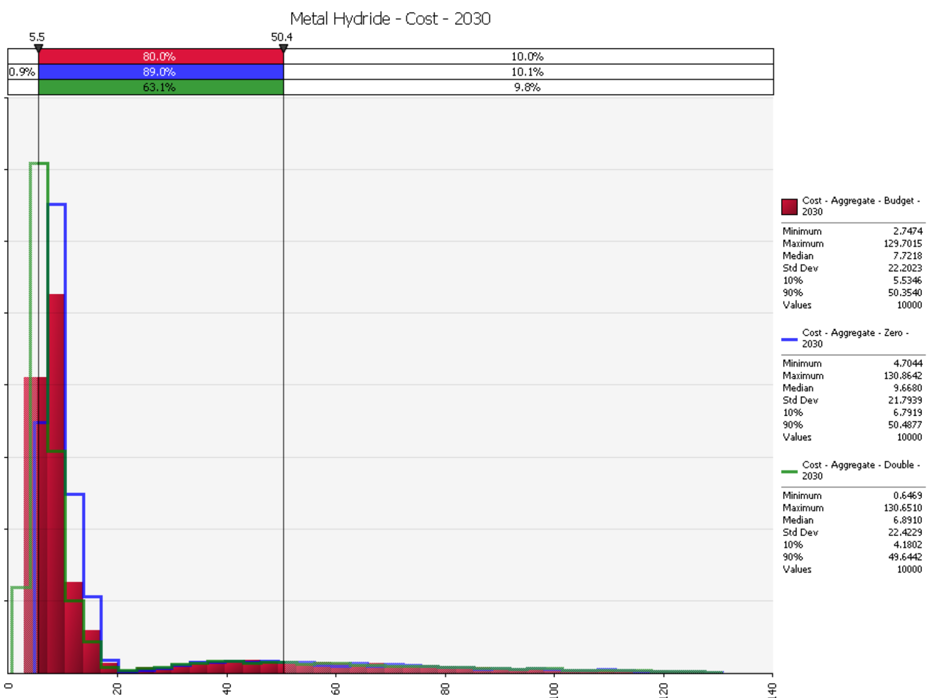
   13 experts from industry, national labs, and DOE contractors provided input. The number of experts providing input on each technology follows:

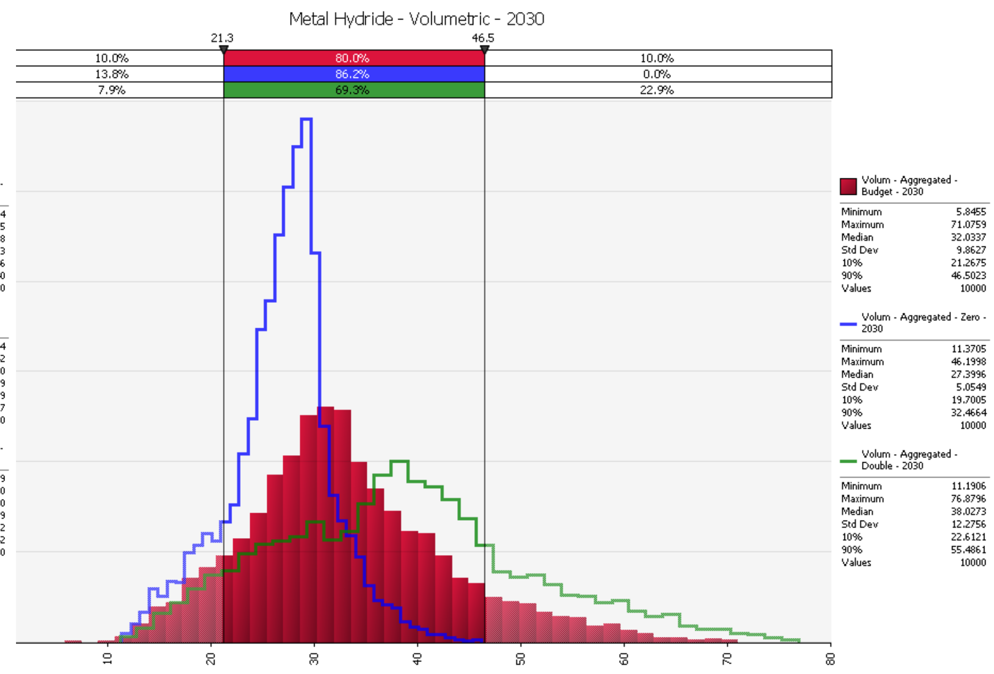
    - 350 bar compressed gas – 4 experts
    - 700 bar compressed gas – 4 experts
    - Liquid – 5 experts
    - Cryo-compressed – 5 experts
    - Adsorbents – 5 experts
    - Metal Hydrides – 8 experts
    - Chemical Hydrides – 7 experts

On-Board Storage

4. Experts estimate TPM potential
   - Shown are aggregated responses from 8 experts on Metal Hydride TPMs in 2030

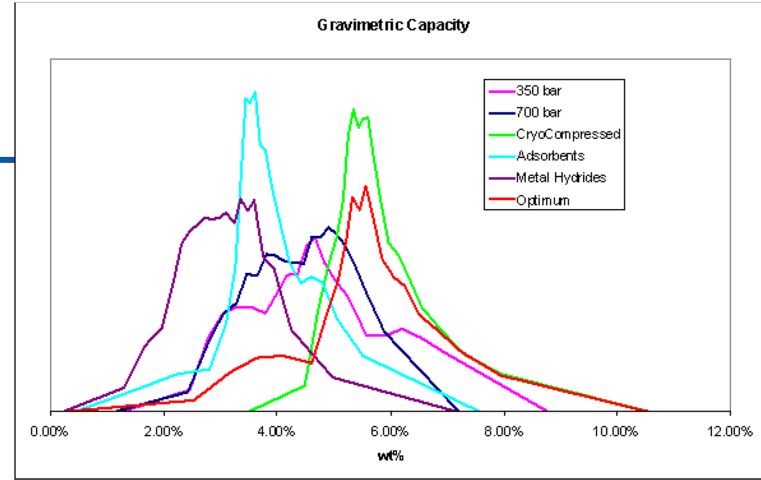


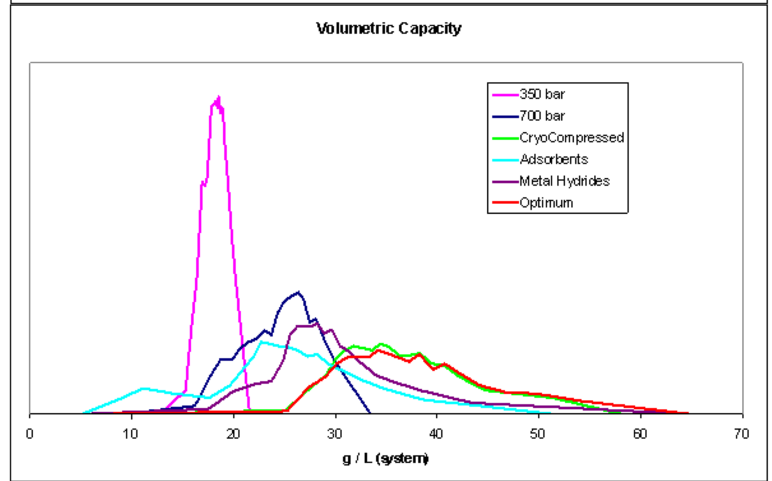


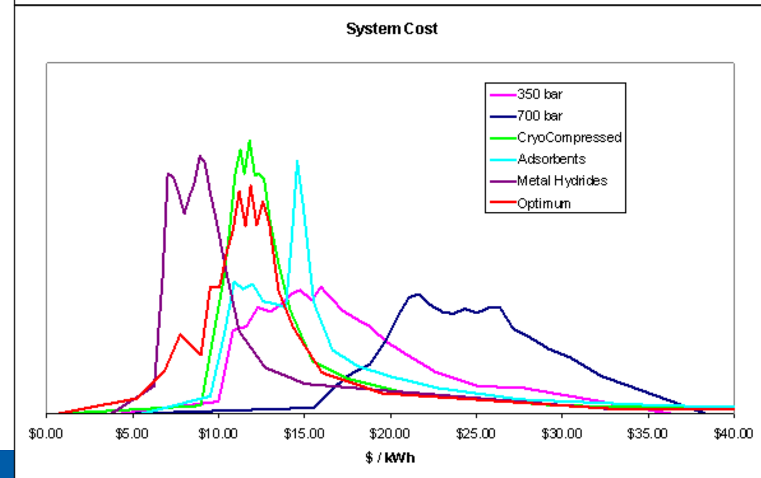


On-Board Storage

5. Provide TPM potential results for use in EERE's portfolio analysis
   - An objective function was developed to weigh tradeoffs between weight, volume, and cost assuming that the upstream (off-board costs) for those technologies are similar. Five of the technologies were optimized stochastically develop a best or optimum scenario -- a selection of best technologies based on distributions (i.e., no single winner)
   - Resulting PDFs for 2015 with a flat DOE budget are shown
   - The optimum results for each budget scenario and year were provided to the PSAT team.







PEM Fuel Cells

1. Technology Improvement Opportunities (TIOs) – PEM Fuel Cells
2. Technology Performance Measures (TPMs)
    - System Specific Power (W/kg)
    - System Power Density (W/L)
    - Total fuel cell system cost ($/kW)
        - 80kW stack cost ($/kW)
            - Power density (mW/cm^2)
            - Platinum loading (mg/cm^2)
            - Membrane cost ($\$/m^2$)
            - Gas diffusion layer cost ($\$/m^2$)
            - Gaskets ($/kW)
            - Bipolar Plate Stamping ($/kW)
        - Balance of Plant Costs ($/kW)
            - Mounting frames ($/kW)
            - Air loop ($/kW)
            - Humidifier & water recovery loop ($/kW)
            - Coolant loop ($/kW)
            - Fuel loop ($/kW)
            - System controller & sensors ($/kW)
            - Other ($/kW)

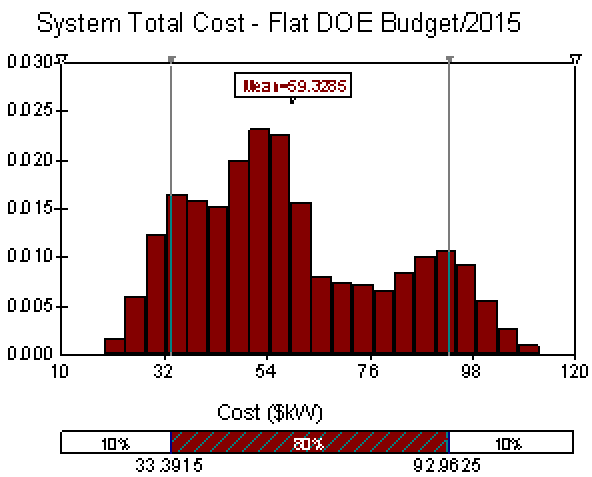
PEM Fuel Cells

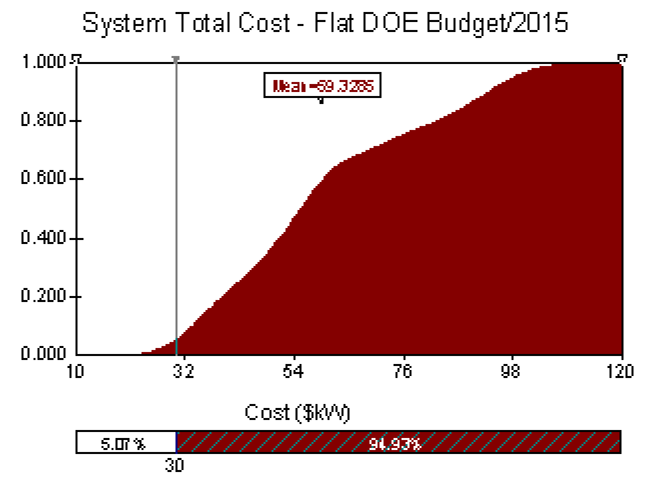
3. Select experts to participate

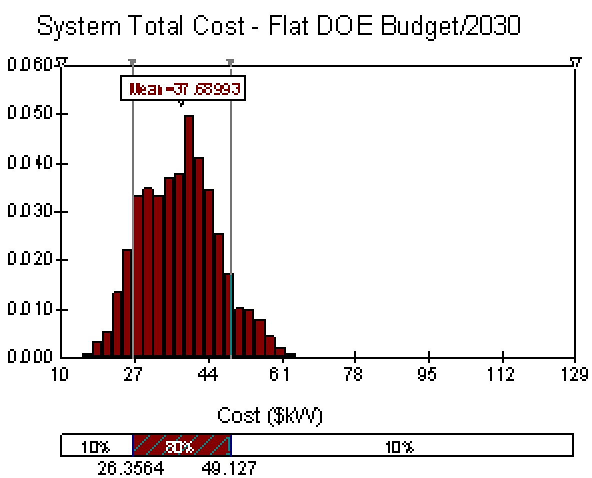
   8 experts provided input. That group included three experts involved in the independent review of the 2008 cost estimate for PEM fuel cells.

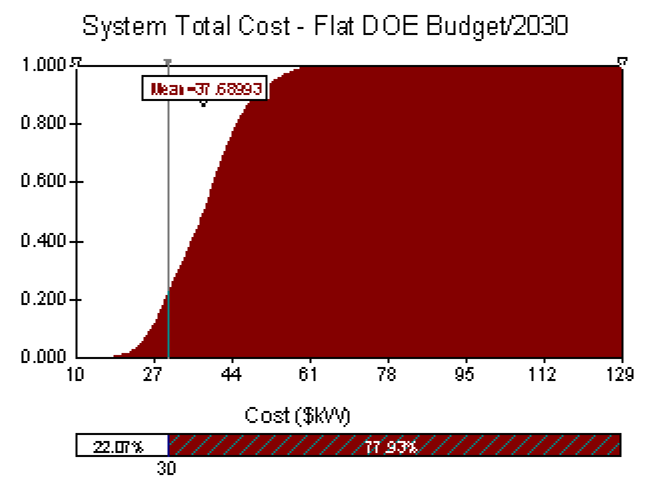
PEM Fuel Cells

4. Experts estimate TPM potential









PEM Fuel Cells

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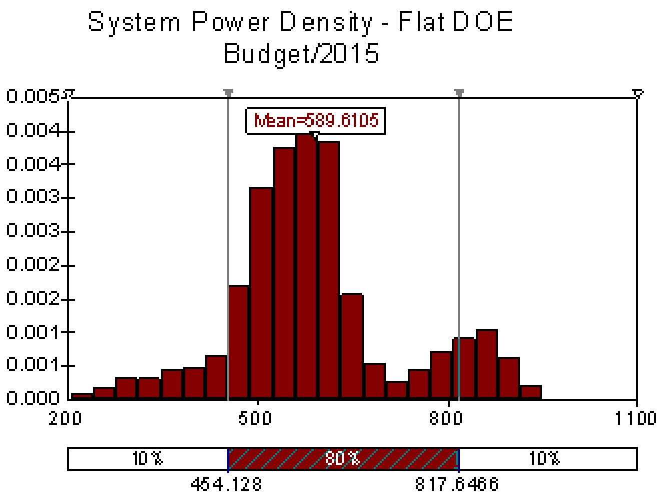

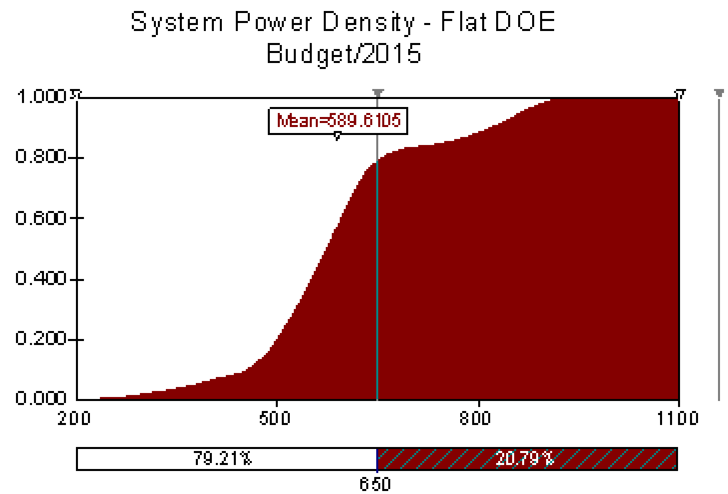

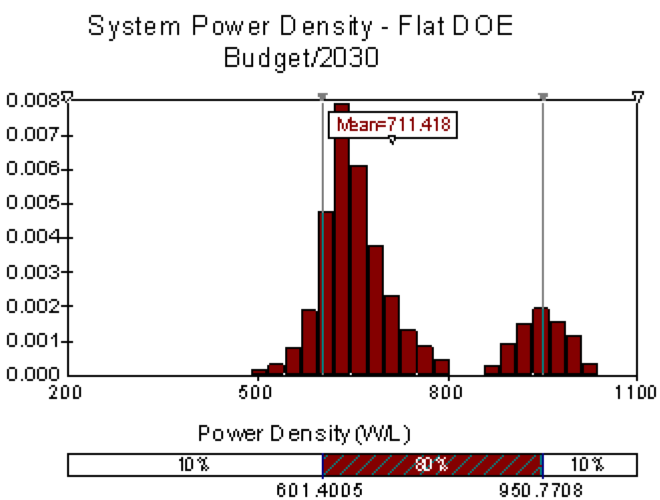

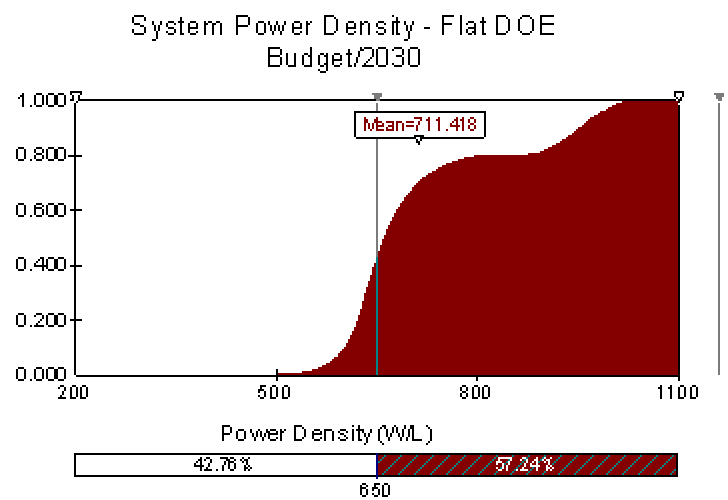

PEM Fuel Cells

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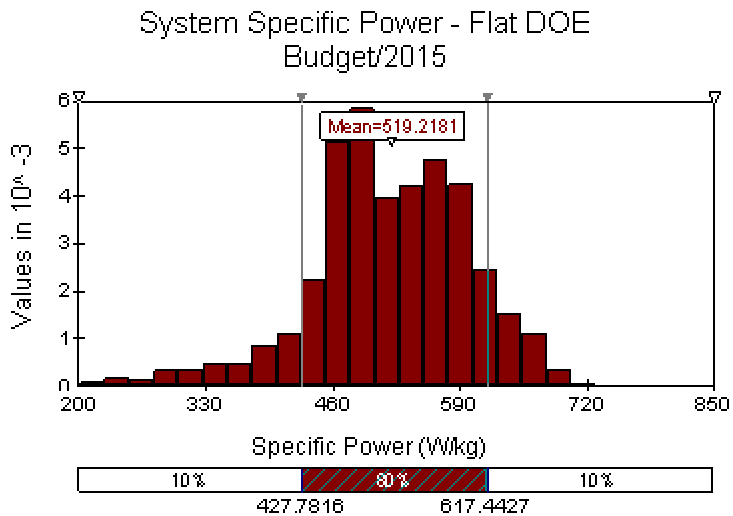

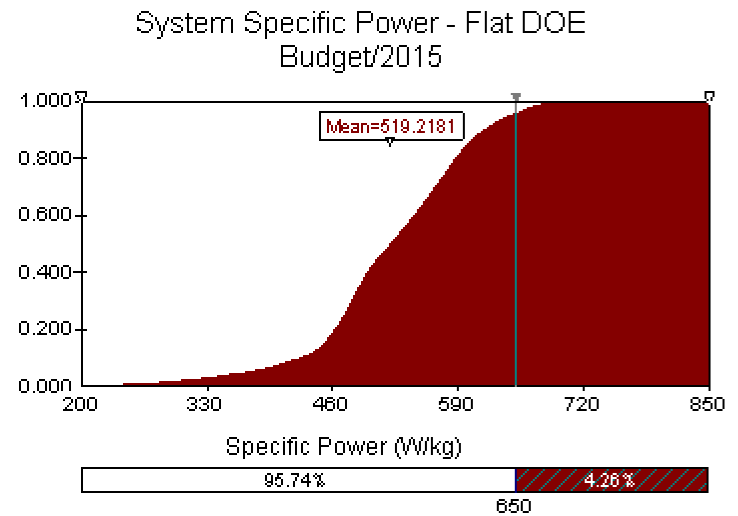

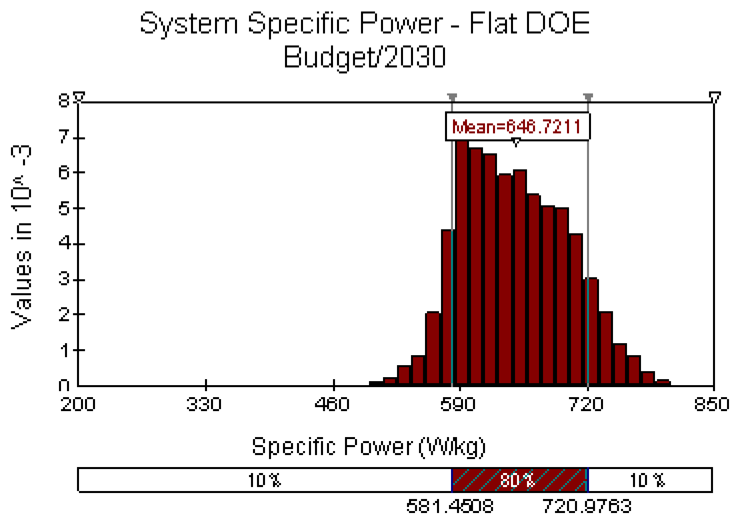

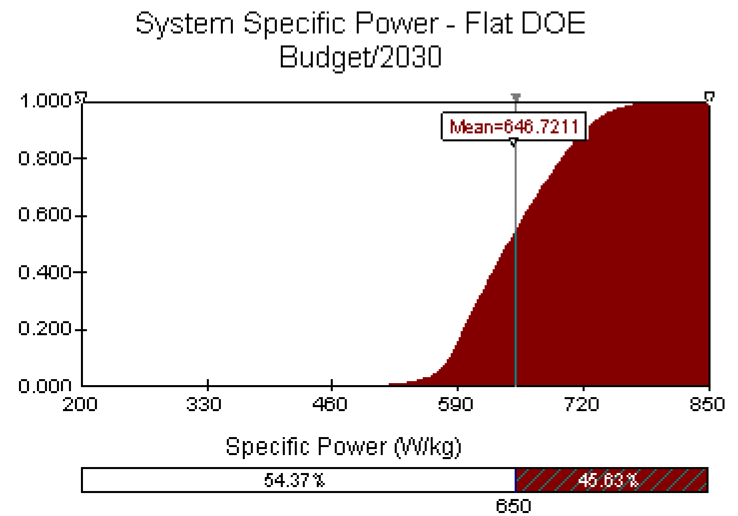

PEM Fuel Cells

5. Provide TPM potential results for use in EERE's portfolio analysis

Parameter	Current	2010			2015		
		Low	Med	High	Low	Med	High
Specific Power FC system (W/kg)	470 [2]	305	405	470	428	519	617
Power Density (W/L)	500 [2]	280	390	500	454	590	818
Peak Fuel Cell System Efficiency (%)							
Cost ($/kw)	72.63	80	70	60	92.96	59.33	33.39

[2] 2005 status as reported in the 2007 MYRDD Plan; based on corresponding stack values divided by 3 to account for ancillaries

Parameter	Current	2030			2045		
		Low	Med	High	Low	Med	High
Specific Power FC system (W/kg)	470 [2]	581	647	721	650	750	850
Power Density (W/L)	500 [2]	601	711	951	650	850	1150
Peak Fuel Cell System Efficiency (%)							
Cost ($/kw)	72.63	49.13	37.69	26.35	30	25	15

Summary

- Relevance
  - Supporting HFCIT's portion of EERE's portfolio analysis (all 11 programs are included)
- Approach
  - Estimated performance improvements based on expert opinions and used those estimates in stochastic analyses
- Technical Accomplishments and Progress
  - Completed a much smoother and more thorough analysis than done previously
- Future Work
  - Risk analyses for EERE are to be conducted biennially.
  - Future analyses may focus on subsystem-level TPMs to improve understanding of areas to focus research funding.