DOE Hydrogen Program Risk Analysis in Support of EERE's Portfolio Analysis

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Project ID # ANP3

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Overview

Timeline

- Project start date: November 29, 2007
- Project end date: Continuing

Targets Addressed: 2010 & 2015

- Production
  - Total H2 Cost
    - Total direct capital investment
    - O&M Cost
    - Capacity factor
  - Efficiency
- Storage
  - System gravimetric capacity
  - System volumetric capacity
  - On-board system cost
- Fuel Cells
  - System Cost
    - Power Density
    - Platinum Cost
    - Platinum Loading
    - Membrane Cost
    - Graphite Material Cost
    - Gas Diffusion Layer Cost
    - Balance of Plant Cost
  - System Specific Power
  - System Power Density

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

1. Prepare for the TYCHE analysis.
2. Identify Technology Improvement Opportunities (TIOs)
   - **11 Production Pathways**
   - **7 Storage Pathways**
   - **1 Fuel Cell Pathway**
3. Select and characterize Technology Performance Measures (TPMs)
   - **Production**
     - Total H2 Cost
       - Total direct capital investment
       - O&M Cost
       - Capacity factor
     - Efficiency
   - **Storage**
     - System gravimetric capacity
     - System volumetric capacity
     - On-board system cost
   - **Fuel Cells**
     - System Cost
       - Power Density
       - Platinum Cost
       - Platinum Loading
       - Membrane Cost
       - Graphite Material Cost
       - Gas Diffusion Layer Cost
       - Balance of Plant Cost
     - System Specific Power
     - System Power Density

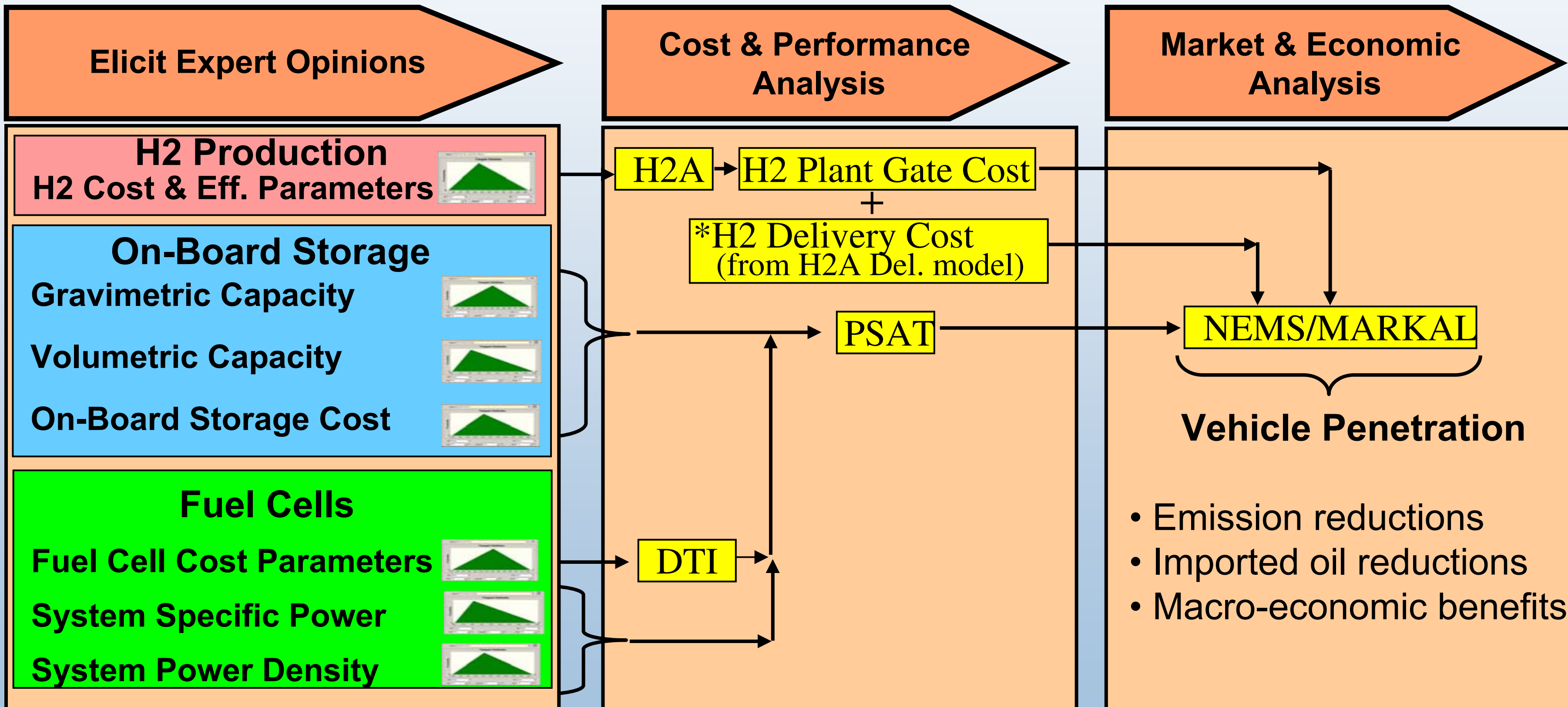
Approach (continued)

4. Develop an Engineering-Economics Model for the energy system
   - **Production – H2A Model**
   - **Storage**
   - **Fuel Cells – DTI Cost Model**
5. Form the expert team
   - **Production – Private industry, National Labs, Academia, DOE contractors**
   - **Storage – TT members, National Labs, Academia, DOE contractors**
   - **Fuel Cells – Initially Private Industry; then National Lab staff**
6. Estimate the TIO potential
   - **Storage & Fuel Cells**
     - **Requested Budget (2010, 2015)**
     - **50% over Requested Budget (2010, 2015)**
   - **Production**
     - **2005, 2015, 2025**
7. Define the inter-relationships among TIOs.
8. Run the Systems Model with the TIOs.
9. Develop/Run a risk-adjusted benefits Logit model for the system.
10. Document the TYCHE analysis and write the Risk Report.

HFCIT Program Element	Technology Pathways	TIOs & TPMs Assessed
Hydrogen Production	• **Central Biomass Gasification** • Central Electrolysis • **Central Natural Gas Reforming** • Reforming & CCS • Central Coal Gasification • Central Coal Gasification & CCS • CO_2 Transport & Sequestration • **Forecourt Natural Gas Reforming** • Forecourt Electrolysis • Forecourt Ethanol Reforming • Forecourt Storage & Dispensing	• Plant efficiency, % LHV • Labor requirement, # FTE's • Total capital investment, 2005 $ • O&M cost (excluding fuel), % capital cost • Capacity factor, % maximum capacity • Production unit efficiency, % LHV • Direct capital cost, 2005 $
On-Board Storage	• **700 bar compressed hydrogen;** • **350 bar compressed hydrogen;** • **Liquid hydrogen;** • **Cryo-compressed hydrogen;** • **Adsorbents;** • **Metal hydrides; and,** • **Chemical hydrides.**	• System gravimetric capacity (net useful hydrogen mass / max system mass – weight %) • System volumetric capacity (net useful hydrogen mass / maximum system volume – g H_2/L system) • On-board system cost ($/kWh).
Fuel Cells	• **PEM Fuel Cells for Vehicles**	• Total Fuel Cell System Cost ($/kW$_e$) • 80 kW Stack cost ($/kW) • **Power Density (mW/cm^2)** • **Platinum Loading (mg/cm^2)** • **Membrane Cost ($/m^2)** • **Gas Diffusion Layer Cost ($/m^2)** • **Gaskets (Materials and Formation/Application costs) ($/kW)** • **Flow Plates (Stamping) ($/kW)** • **Balance of Plant Cost ($/kW)** • Mounting Frames ($/kW) • Air Loop ($/kW) • Humidifier and Water Recovery Loop ($/kW) • Coolant Loop (High & Low Temp) ($/kW) • Fuel Loop ($/kW) • System Controller/Sensors ($/kW) • Miscellaneous/BOP ($/kW) • System Specific Power (W/kg) • System Power Density (W/L)

Risk Analysis Approach

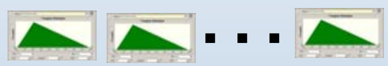
Our approach is based on the subjective opinions of subject matter experts and the use of several detailed technical models …



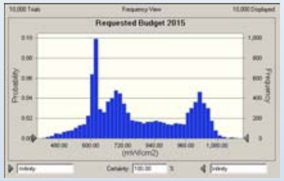
Linkage Between HFCIT Performance Parameters & Vehicle Penetration

Identify program element performance parameters

→ Experts estimate median, high, and low values for performance parameters



→ Estimates are aggregated



→ Experts review aggregated and individual estimates and modify, if desired

→ Combined estimates are used for cost & performance analysis

PSAT ← DTI

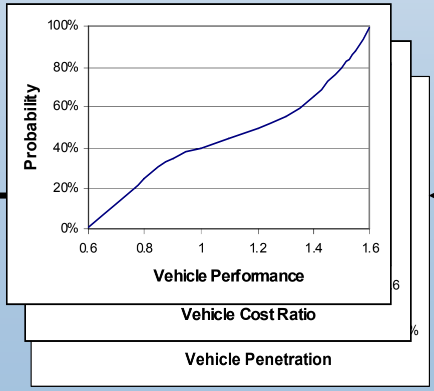
H2A

→ **On-Board Storage**
- System Gravimetric Capacity
- System Volumetric Capacity
- Cost

Fuel Cells
- System Specific Power
- System Power Density
- Cost

Production
- H2 Cost

→



→ **Benefits**
- Emission reduction
- Reduction of oil imports
- Macro-economic benefits

Fuel Cell Results

Expert Elicitations for Fuel Cells

- 1st Questionnaire
  - Sent to 19 experts from private industry
  - Only two relevant responses for a few TPMs
    - Unwilling to share proprietary information
    - Not an expert
    - No time
- 2nd Questionnaire
  - Sent to 20 experts from National Labs
  - PTS removed (i.e., assumed to be 100%)
  - 14 experts responded (4 as a group from one Lab)
  - Very few responses on Balance of Plant
  - Webcon cleared up some but not all of the confusion

Table FC 1. Fuel Cell Round One Questionnaire
Scenario 1: DOE H2 Fuel Cell Budget Equal to Requested Budget

Entries in the Min, Median, Max columns indicate the number of responses received

Fuel Cell Cost Elements	Current 2007 Status	Advanced (2010)				Long Term (2015)			
		Target	Min	Median	Max	Target	Min	Median	Max
Total Fuel Cell System Cost ($/kW$_e$)	93.58	45	**2**	**2**	**2**	30	**2**	**2**	**2**
1. 80 kW$_e$ Stack Cost ($/kW$_e$)	49.74	25	**4**	**4**	**4**	15	**4**	**4**	**4**
1.1. Power Density (mW/cm^2)	583		**7**	**7**	**7**		**7**	**7**	**7**
1.2. Platinum Loading (mg/cm^2)	0.35		**7**	**7**	**7**		**7**	**7**	**7**
1.3. Membrane Cost ($/m^2)	16.62	20	**5**	**5**	**5**	20	**6**	**6**	**6**
1.4. Gas Diffusion Layer Cost ($/m^2)	12.31		**4**	**4**	**4**		**4**	**4**	**4**
1.5. Gaskets (Materials and Formation/Application costs) ($/kW)	3.03		**4**	**4**	**4**		**4**	**4**	**4**
1.6. Bipolar Plates (Stamping) ($/kW)	4.58	5	**2**	**2**	**2**	3	**2**	**2**	**2**
2. Balance of Plant Cost ($/kW)	41.99		**1**	**1**	**1**		**1**	**1**	**1**
2.1. Mounting Frames ($/kW)	0.38								
2.2. Air Loop ($/kW)	9.86								
2.3. Humidifier and Water Recovery Loop ($/kW)	3.75		**2**	**2**	**2**		**2**	**2**	**2**
2.4. Coolant Loop (High & Low Temp) ($/kW)	6.30		**1**	**1**	**1**		**1**	**1**	**1**
2.5. Fuel Loop ($/kW)	5.72								
2.6. System Controller/Sensors ($/kW)	8.75								
2.7. Miscellaneous/BOP ($/kW)	7.24								
3. System Specific power (W/kg)	470		**4**	**4**	**4**		**4**	**4**	**4**
4. System Power Density (W/L)	500		**4**	**4**	**4**		**4**	**4**	**4**

Power Density (mW/cm^2)

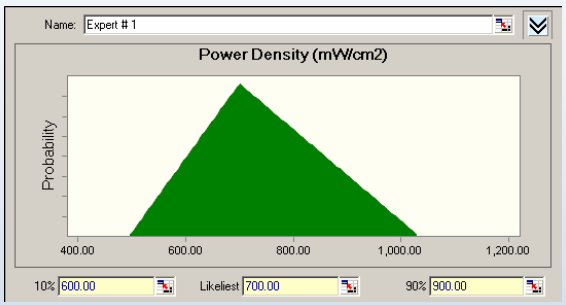
Requested Budget

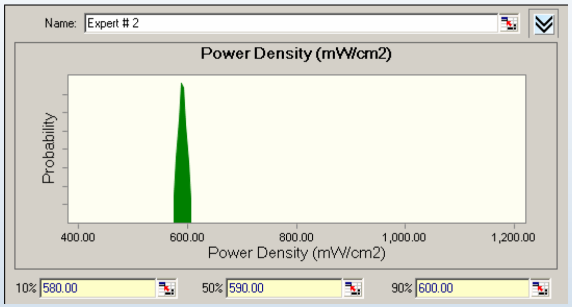
Expert #	2007 Status	Target	2010 Min	2010 Median/ Mode	2010 Max	2015 Min	2015 Median/ Mode	2015 Max
1	583		600	700	900	600	750	1000
2	583		580	590	600	600	615	625
3	583		500	600	750	500	625	800
5	583		700	800	1000	700	1000	1100
4	583		600	650	800	600	700	900
6	583		800	870	940	950	1015	1080
7	583		625	650	700	650	700	725

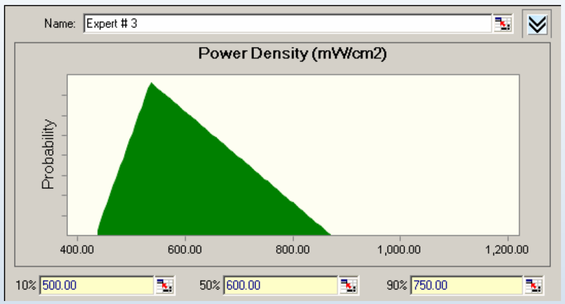
+ 50% Budget

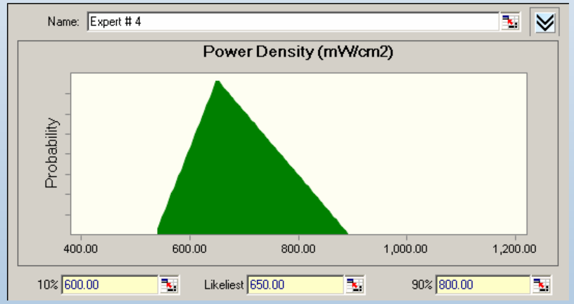
Expert #	2007 Status	Target	2010 Min	2010 Median/ Mode	2010 Max	2015 Min	2015 Median/ Mode	2015 Max
1	583		600	700	900	600	800	1200
2	583		600	615	630	650	725	800
5	583		700	800	1000	600	800	1200
4	583		600	700	900	700	1100	1200
6	583		1000	1050	1100	1150	1225	1300
7	583		625	700	750	650	750	800

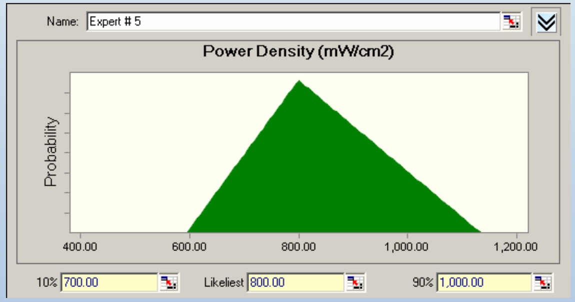
Power Density (mW/cm^2) Requested Budget – 2010
Expert Triangular pdf's

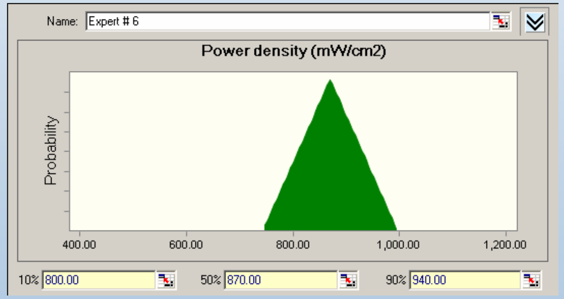


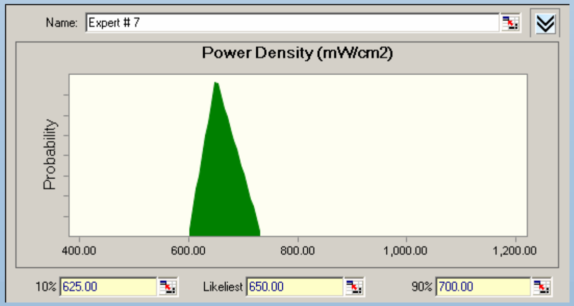






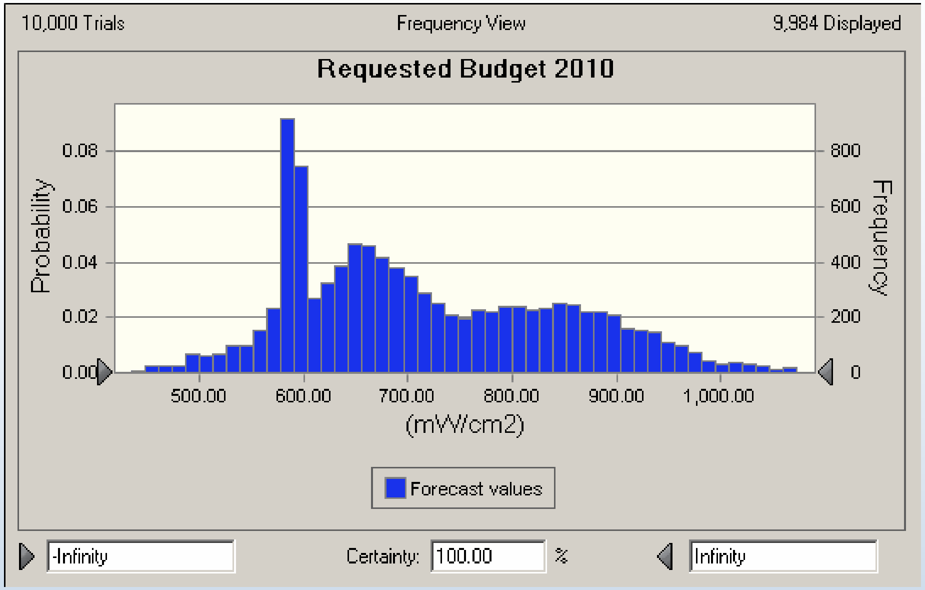


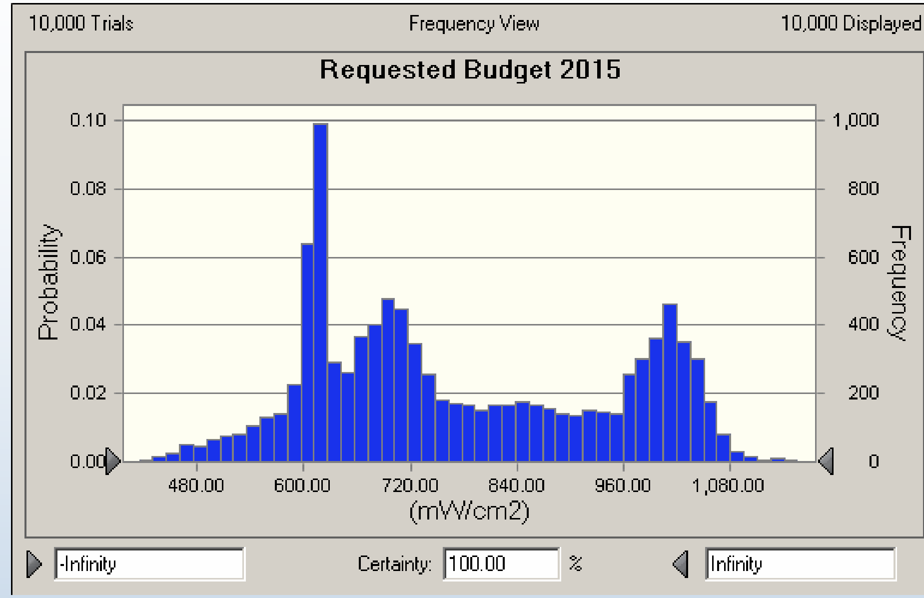


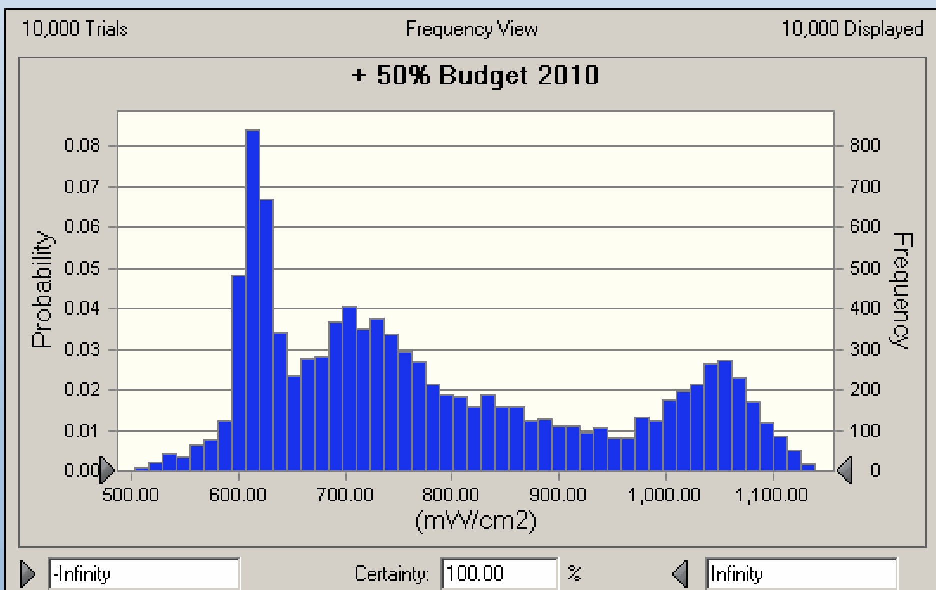


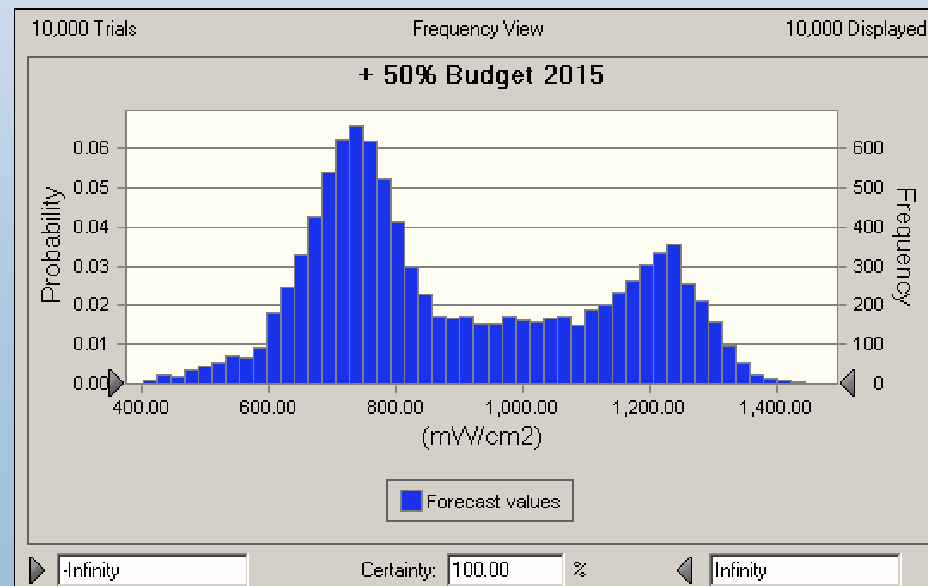
Power Density (mW/cm^2) Aggregated Results

- 7 experts Requested Budget Cases
- 6 experts + 50% Budget Cases
- 10,000 trials









Monte Carlo Analysis Using the Sensitive Variables As Input to the DTI Cost Model

Sensitive Variables
J = 1,7

- Power density
- Platinum loading
- Membrane cost
- Gas diffusion layer
- Gaskets
- Bipolar plates
- Balance of plant

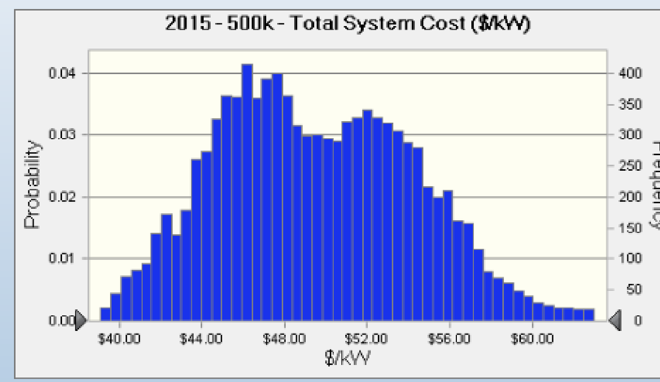
Aggregated distributions for Sensitive Variables (sv)

i = 10,000 trials

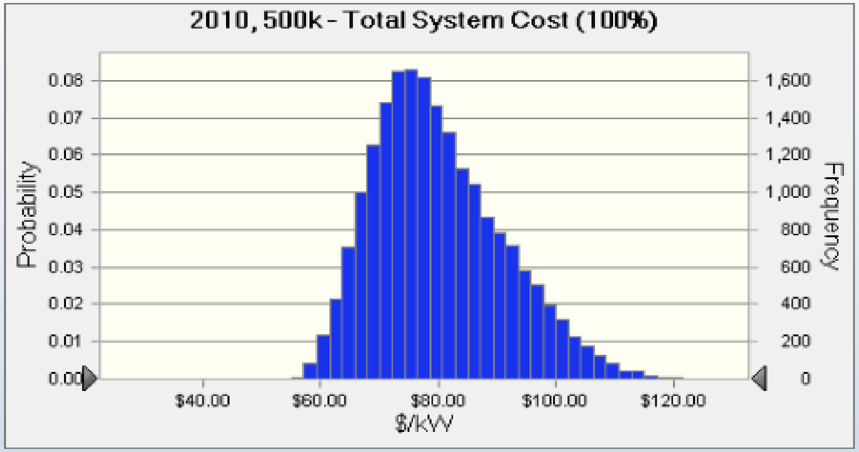
FC Price$_i$ = DTI($\int_j$sv(i,j))

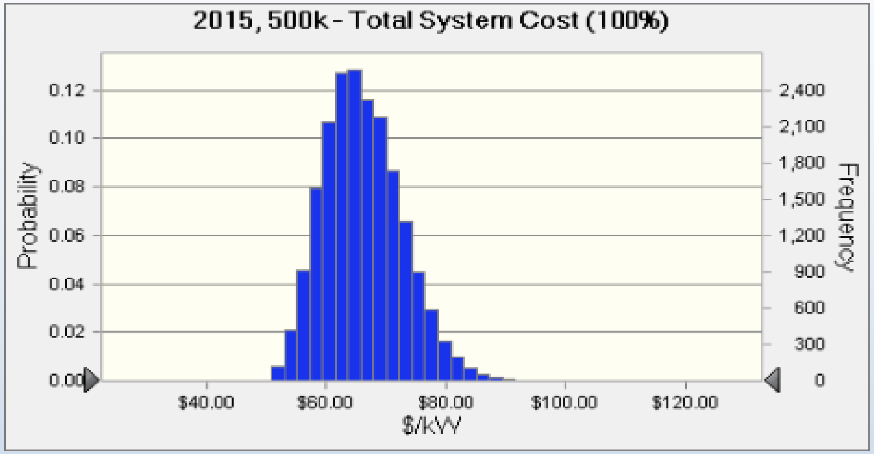
Each sensitive variable needs to be input into the DTI Cost Model as a probability distribution and the set of variables randomly selected 10,000 times

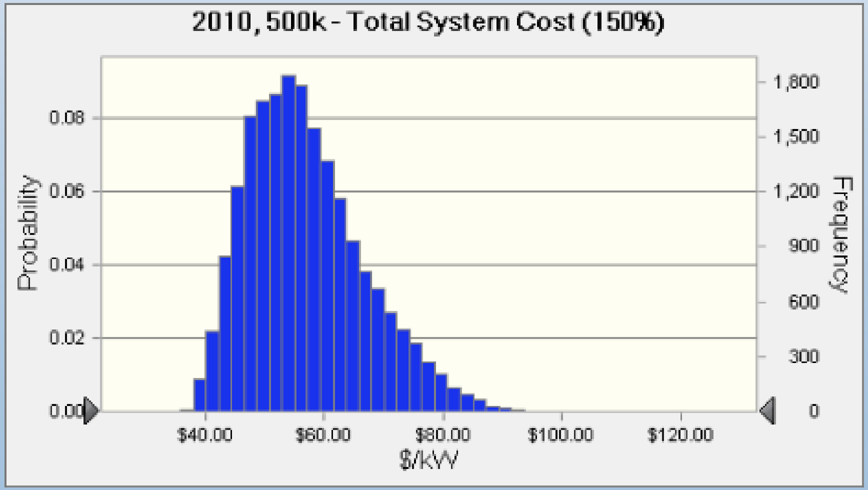
Fuel Cell Price Distribution for 10,000 trials

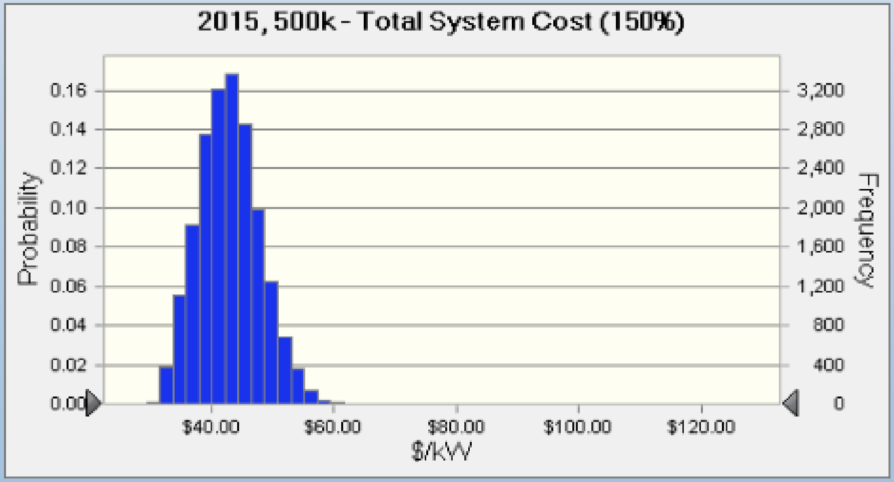


Total Fuel Cell System Cost ($/kw)

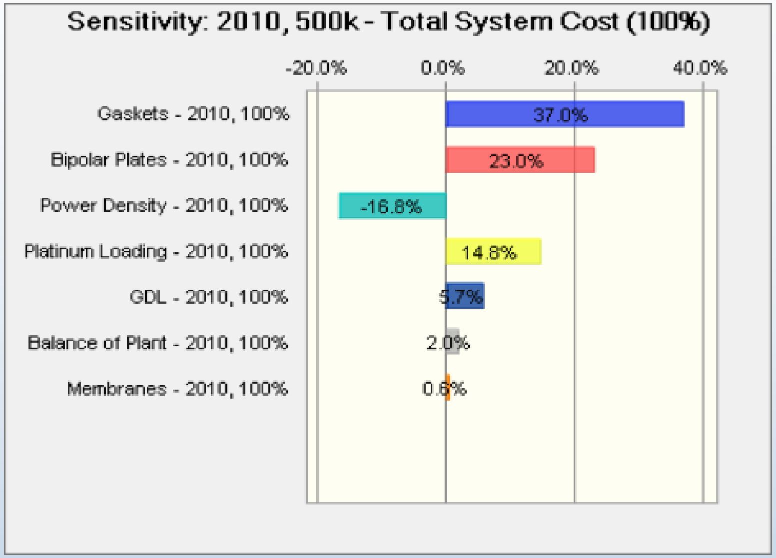


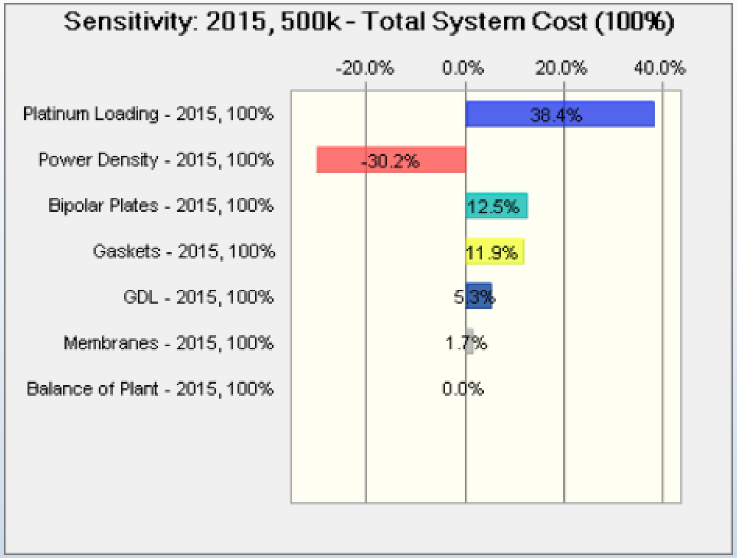


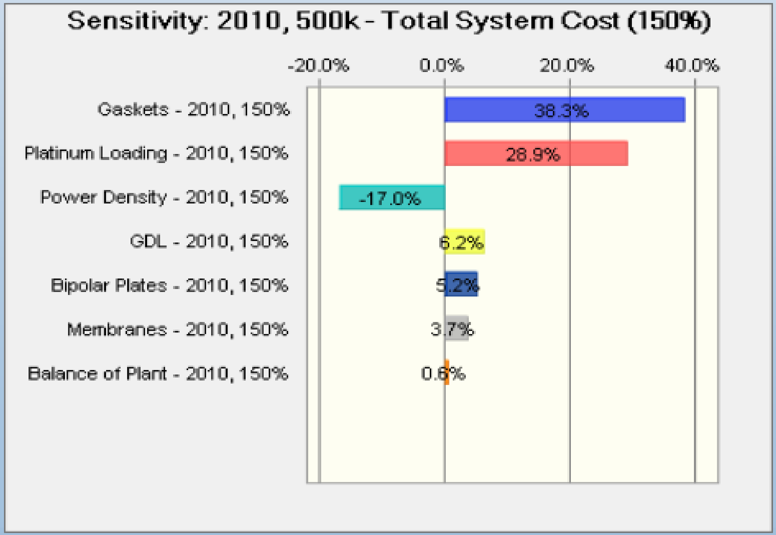


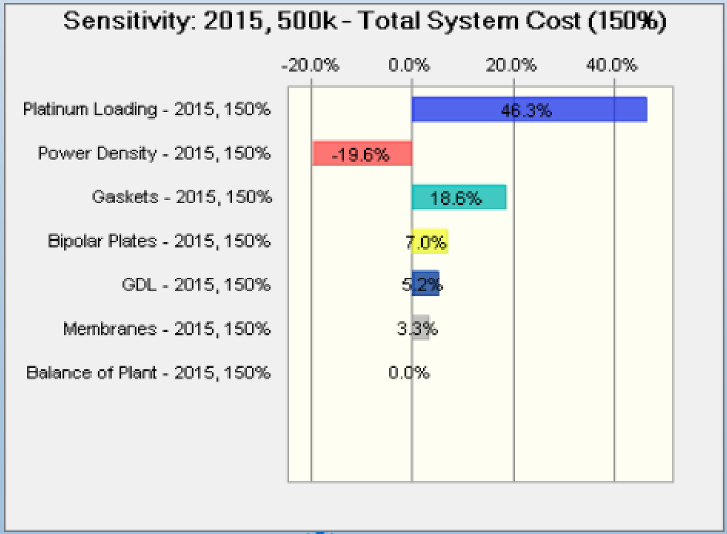


Sensitivity Charts for Total Fuel Cell System Cost

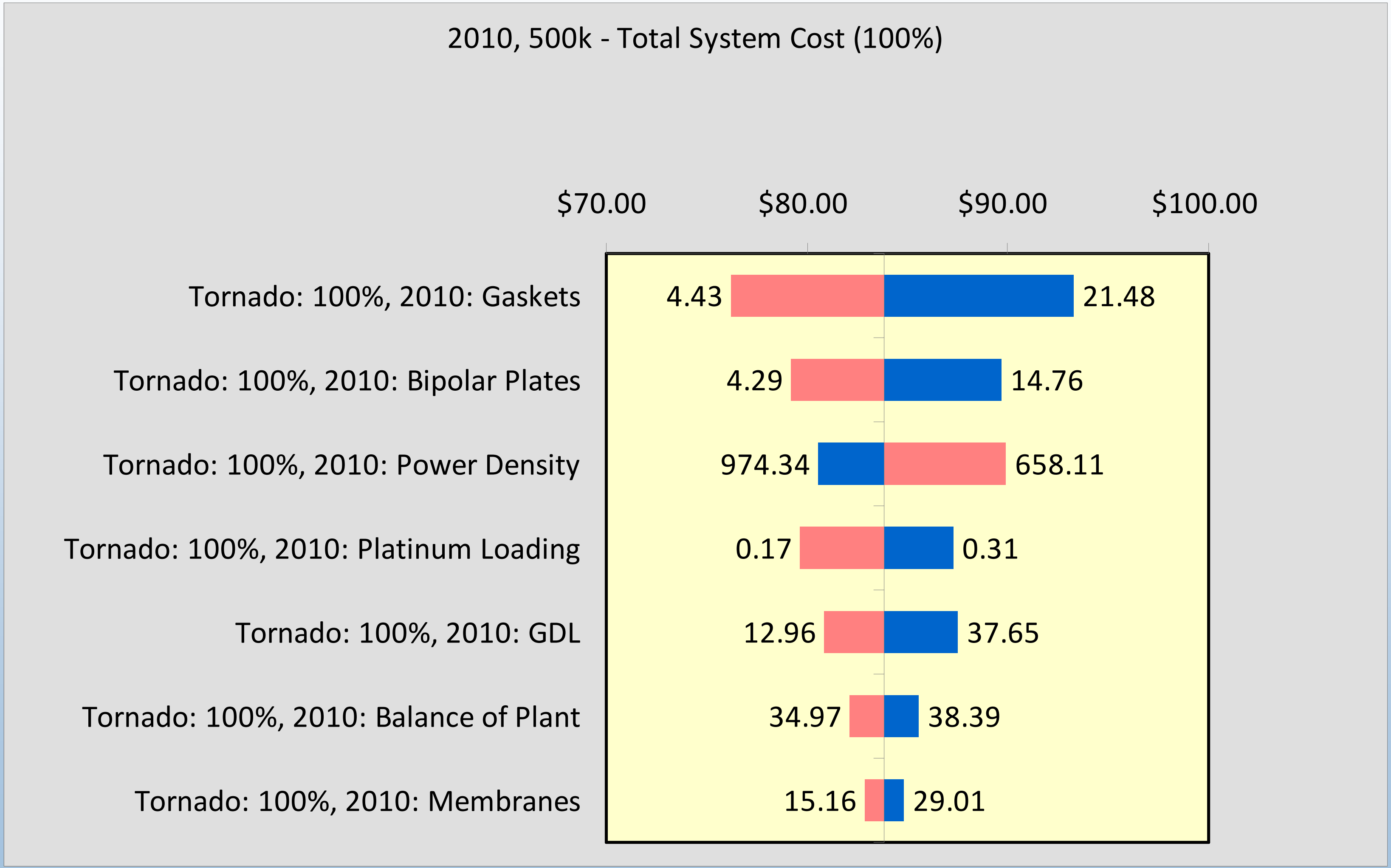








Tornado Charts for Total Fuel Cell System Cost



System Specific Power (W/kg) Aggregated Results

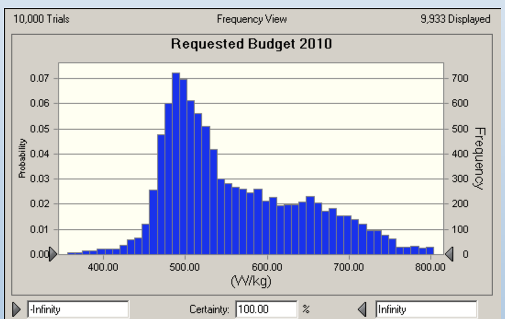
- **4 experts**
- **10,000 trials**

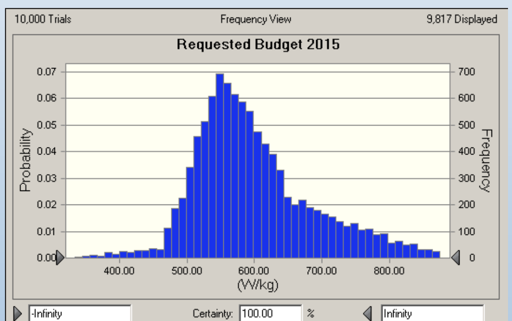
Requested Budget

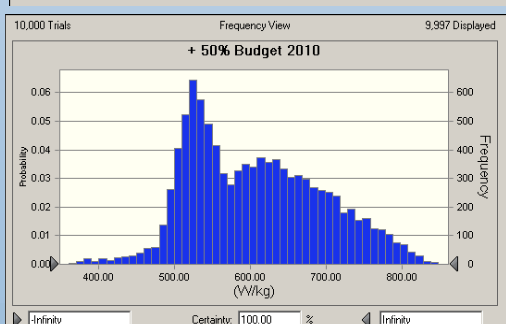
Expert #	2007 Status	Target	2010 Min	2010 Median/ Mode	2010 Max	2015 Min	2015 Median/ Mode	2015 Max
1	470		470	650	750	470	650	850
2	470		470	485	520	500	550	600
9	470		475	522	574	503	553	608
7	470		500	650	700	575	650	750

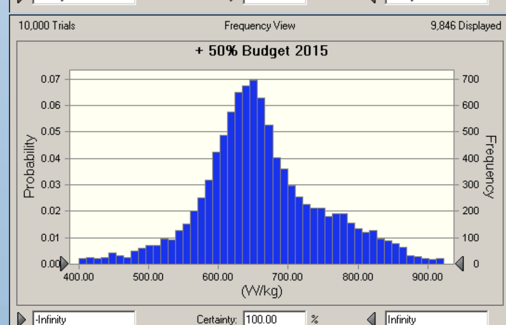
+ 50% Budget

Expert #	2007 Status	Target	2010 Min	2010 Median/ Mode	2010 Max	2015 Min	2015 Median/ Mode	2015 Max
1	470		470	650	750	470	650	850
2	470		500	525	550	600	650	675
9	470		522	614	737	553	651	781
7	470		575	650	750	600	650	800









System Specific Density (W/L) Aggregated Results

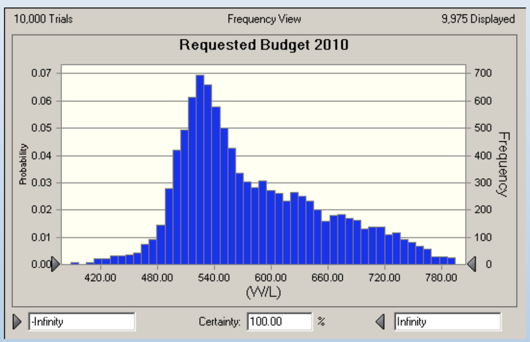
- 4 experts
- 10,000 trials

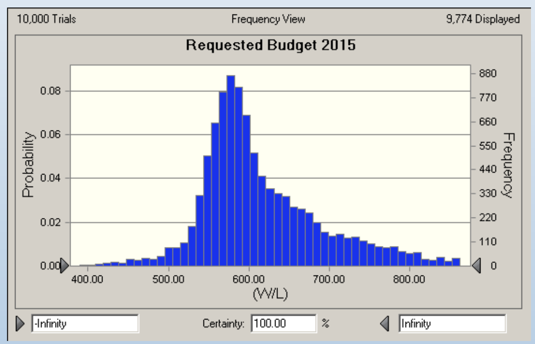
Requested Budget

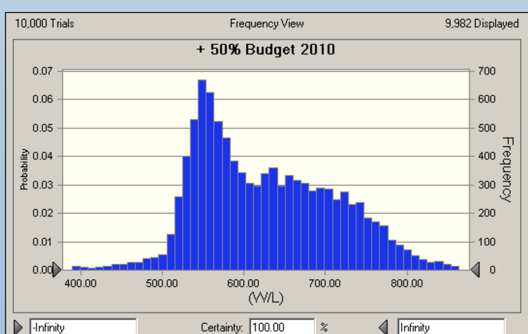
	2010					2015		
Expert #	2007 Status	Target	Min	Median	Max	Min	Median	Max
1	500		500	650	750	500	650	850
2	500		500	525	550	550	575	600
9	500		505	556	611	535	588	647
7	500		500	650	700	575	650	750

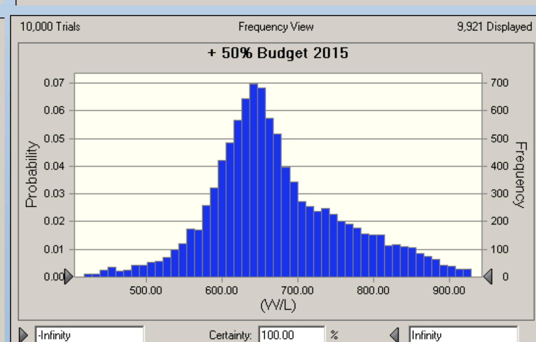
+ 50% Budget

	2010					2015		
Expert #	2007 Status	Target	Min	Median	Max	Min	Median	Max
1	500		500	650	750	500	650	850
2	500		525	550	575	600	650	675
9	500		556	654	784	588	692	830
7	500		575	650	750	600	650	800









Fuel Cell Inputs to PSAT

Fuel Cell Parameter	Requested Budget 2010			Requested Budget 2015			Requested Budget 2030			Requested Budget 2045		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
Total Fuel Cell System Cost ($/kW$_e$)	66.85	78.35	95.23	57.93	65.37	74.50	30.00	30.00	30.00	30.00	30.00	30.00
System Specific Power (W/kg)	472	533	690	507	583	743	650	650	650	650	650	650
System Power Density (W/L)	500	559	696	543	597	741	650	650	650	650	650	650

Fuel Cell Parameter	+ 50% Budget 2010			+ 50% Budget 2015			+ 50% Budget 2030			+ 50% Budget 2045		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
Total Fuel Cell System Cost ($/kW$_e$)	45.25	55.31	70.88	36.44	42.55	49.32	30.00	30.00	30.00	30.00	30.00	30.00
System Specific Power (W/kg)	507	598	733	560	651	788	650	650	650	650	650	650
System Power Density (W/L)	532	614	745	575	657	805	650	650	650	650	650	650

Production Results

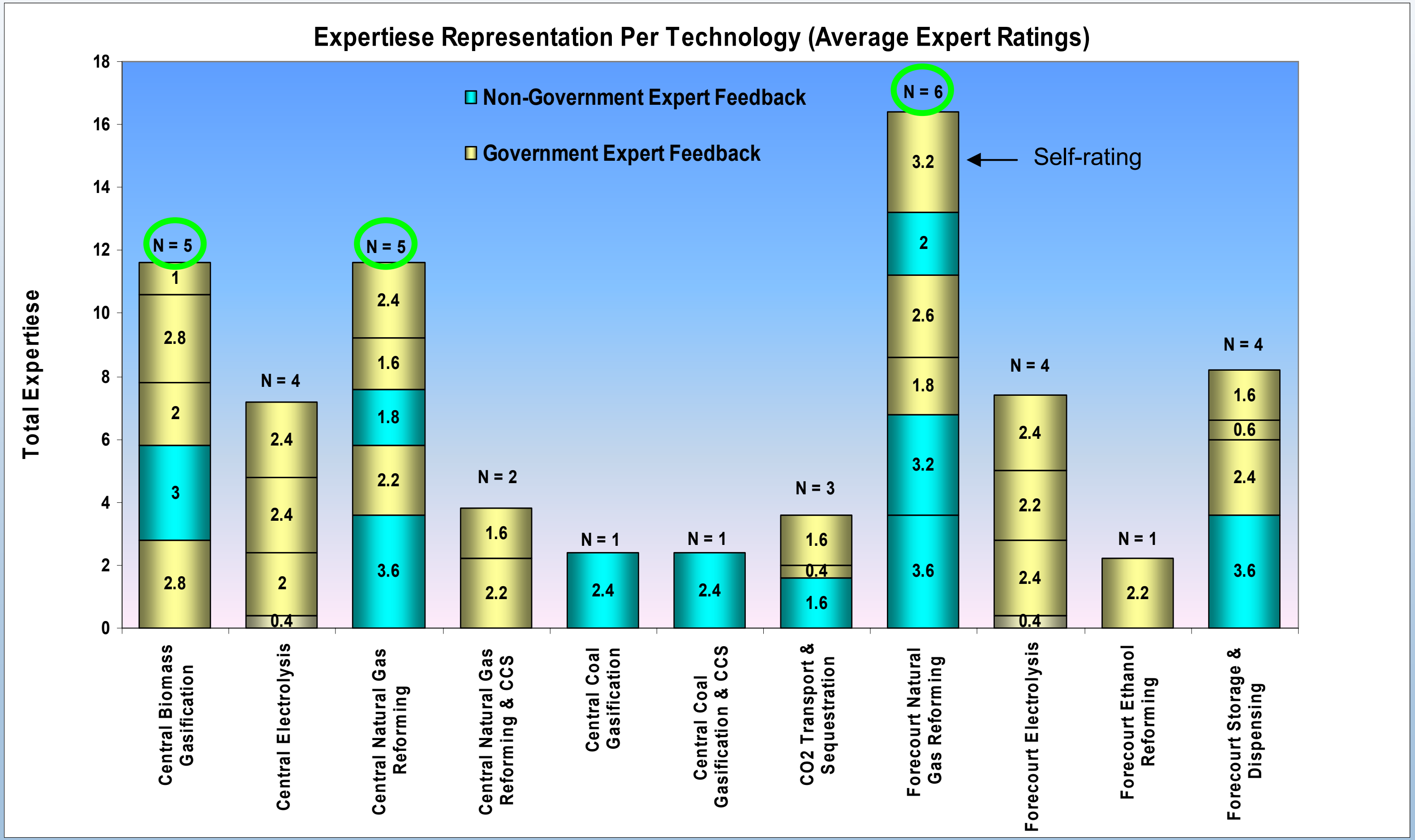
Expert Elicitations for Production

- **Pre-Questionnaire (2/26/08)**
  - Self-identification & help request
- **Questionnaire (3/9/08)**
  - All technology feedback requests
  - Deadline 3/18/08
  - 8 expert responses total
- **Tutorial (anonymous web-cast) (3/11/08)**
  - Attendees 5
  - Individual contacts ~3/11/08-3/30/08
- **Aggregation (anonymous web-cast) (3/25/08)**
  - Attendees 7
- **Final + Late inputs**
  - 0 revisions after aggregation
  - 15 expert responses total

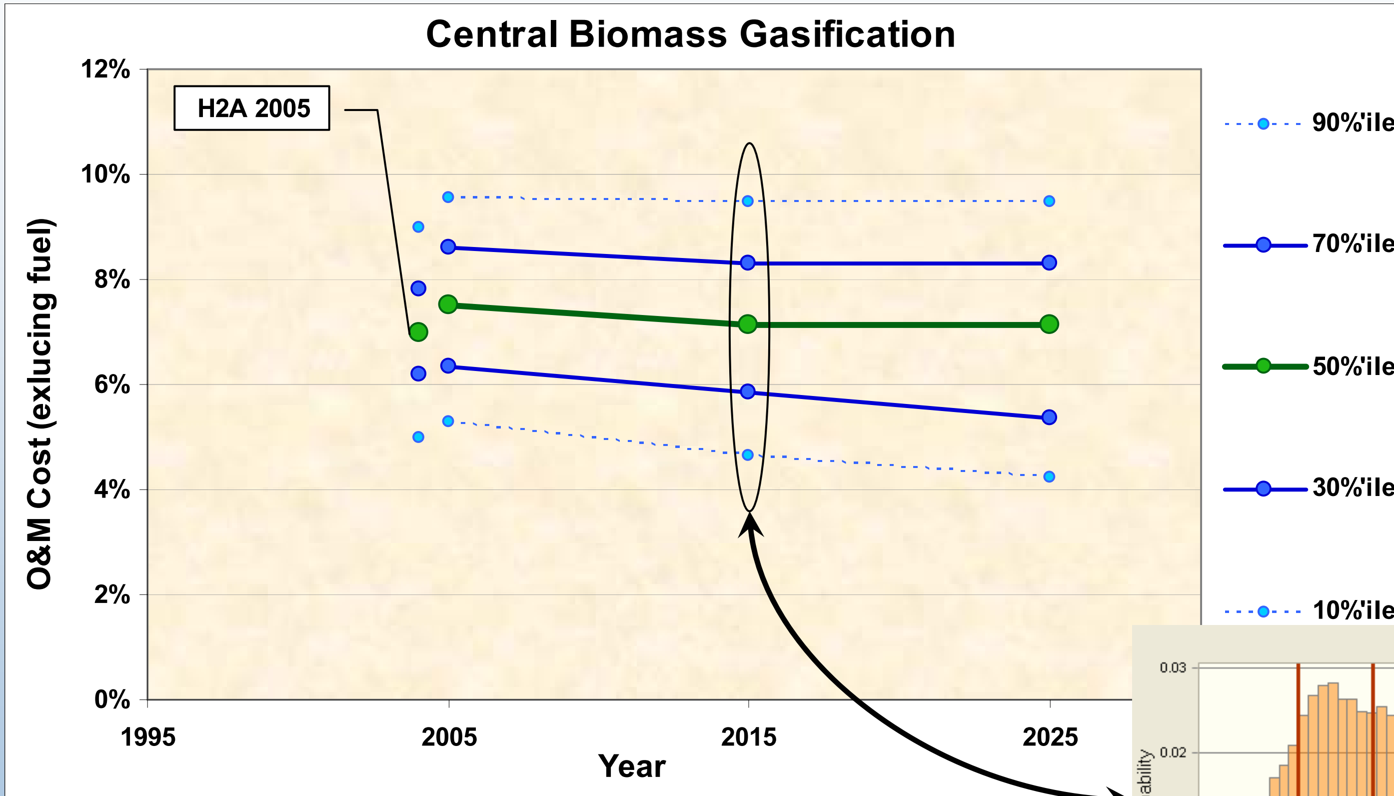
Pre-Questionnaire	Sent	Positive	Decline	No Resp.
Industry	46	9 (20%)	9	28
Government	36	4 (11%)	7	25
Subcontractors	8	1 (13%)	1	6
Total	90	14 (16%)		

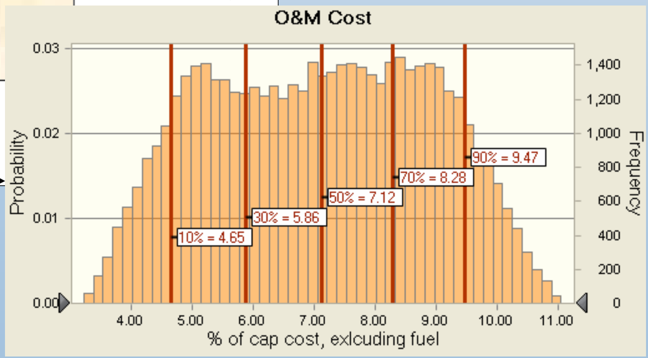
Questionnaire	Sent	Positive	Decline	No Resp.
Industry	60	9 (15%)	12	39
Government	37	5 (14%)	13	19
Subcontractors	9	1 (11%)	2	6
Total	106	15 (14%)		

Expert Responses - Hydrogen Production



Central Biomass Gasification

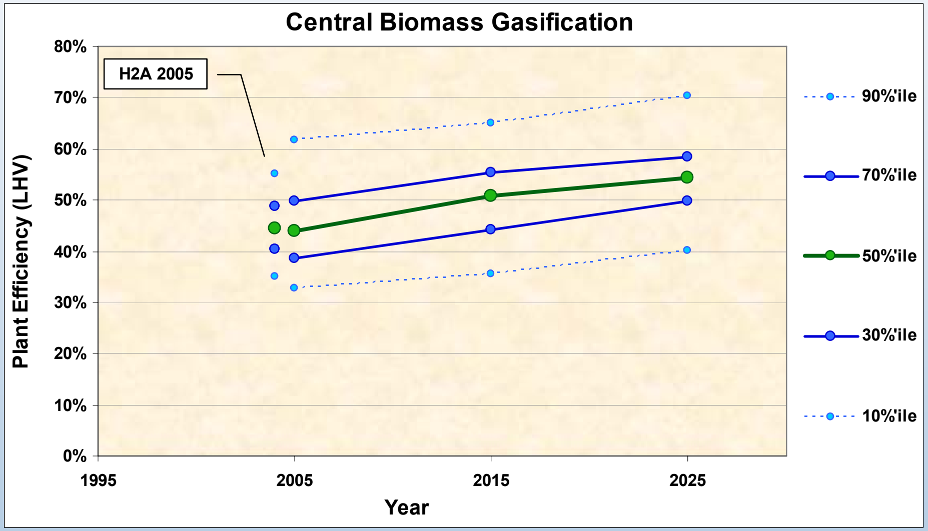


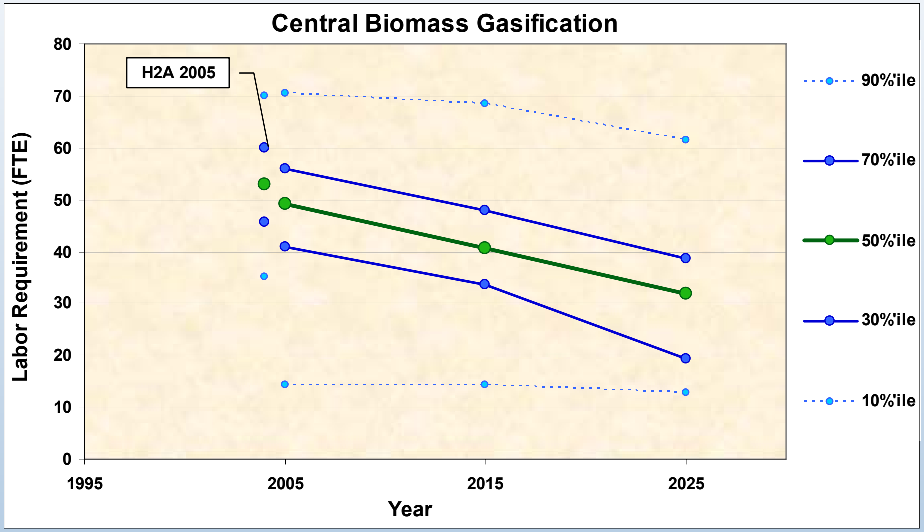


Year	2005	2015	2025
Aggregate PTS:	98%	96%	93%

Central biomass O&M costs (excluding fuel), % cap cost

Central Biomass Gasification (continued)





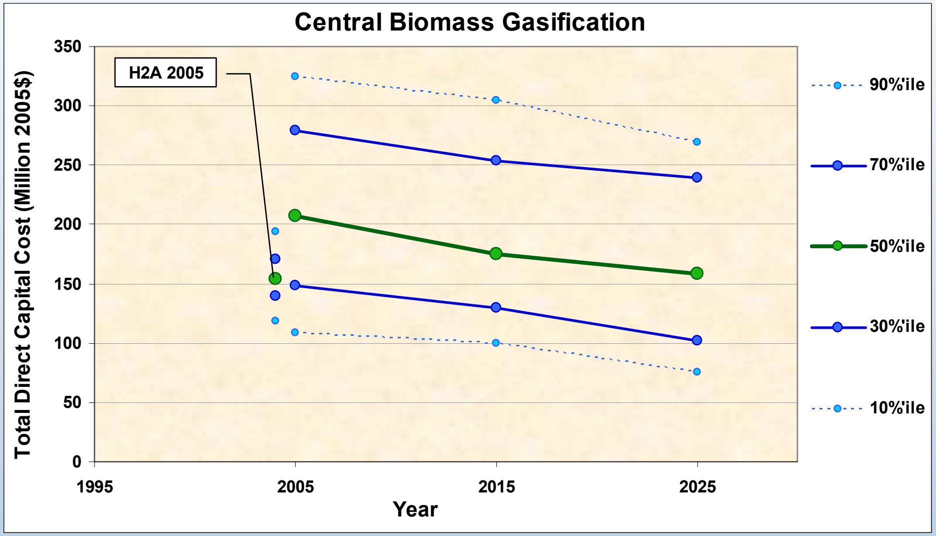
Year	2005	2015	2025
Aggregate PTS:	99%	97%	96%

Year	2005	2015	2025
Aggregate PTS:	98%	96%	94%

Central biomass Plant Efficiency (LHV)

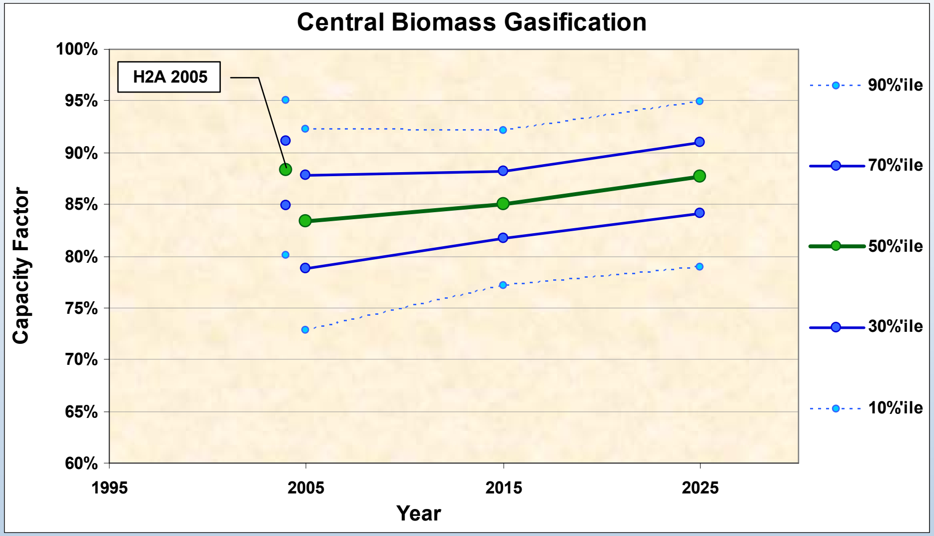
Central biomass labor requirements

Central Biomass Gasification (continued)



Year	2005	2015	2025
Aggregate PTS:	98%	96%	95%

Central biomass total capital investment (2005 dollars, millions)



Year	2005	2015	2025
Aggregate PTS:	98%	97%	95%

Central biomass capacity factor

GPRA numbers for Central Biomass Gasification for 2005, 2015 and 2025.

Biomass Gasification Percentiles for 2005:	10%	20%	30%	40%	50%	60%	70%	80%	90%	GPRA 2006
Capital Cost ($/kg day)	912	1,054	1,214	1,425	1,661	1,923	2,242	2,420	2,601	1,250
Fixed O&M ($/kg)	0.149	0.181	0.201	0.220	0.238	0.258	0.279	0.304	0.338	0.274
Variable O&M ($/kg)	0.156	0.194	0.230	0.269	0.313	0.362	0.416	0.484	0.572	0.171
Feedstock Required (BTU/kg; HHV basis)	196,173	225,536	242,610	257,110	273,923	291,909	310,814	333,882	366,336	320,280
Feedstock Required N.Gas (BTU/kg; HHV basis)	5,408	6,217	6,688	7,088	7,551	8,047	8,568	9,204	10,099	
Electricity required (kWh/kg)	1.28	1.47	1.58	1.68	1.79	1.91	2.03	2.18	2.39	1.58
Standard plant size (kg/day)	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236
Scaling factor	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	
Capacity Factor	0.730	0.760	0.790	0.810	0.830	0.860	0.880	0.900	0.920	0.900
Plant life (yrs)	40	40	40	40	40	40	40	40	40	

Biomass Gasification Percentiles for 2015:	10%	20%	30%	40%	50%	60%	70%	80%	90%	GPRA 2012
Capital Cost ($/kg day)	840	954	1,078	1,221	1,416	1,663	2,061	2,284	2,454	962
Fixed O&M ($/kg)	0.134	0.157	0.174	0.189	0.206	0.225	0.245	0.267	0.301	0.211
Variable O&M ($/kg)	0.127	0.158	0.186	0.217	0.251	0.291	0.340	0.409	0.502	0.171
Feedstock Required (BTU/kg; HHV basis)	187,729	209,675	218,497	227,158	238,138	253,445	274,912	300,180	338,618	260,390
Feedstock Required N.Gas (BTU/kg; HHV basis)	5,175	5,780	6,023	6,262	6,565	6,987	7,578	8,275	9,335	
Electricity required (kWh/kg)	1.23	1.37	1.43	1.48	1.56	1.66	1.8	1.96	2.21	1.58
Standard plant size (kg/day)	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236
Scaling factor	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	
Capacity Factor	0.770	0.800	0.820	0.830	0.850	0.870	0.880	0.900	0.920	0.900
Plant life (yrs)	40	40	40	40	40	40	40	40	40	

Biomass Gasification Percentiles for 2025:	10%	20%	30%	40%	50%	60%	70%	80%	90%	GPRA 2017
Capital Cost ($/kg day)	653	748	868	1,078	1,303	1,577	1,940	2,074	2,172	551
Fixed O&M ($/kg)	0.095	0.119	0.136	0.153	0.169	0.186	0.206	0.227	0.263	0.152
Variable O&M ($/kg)	0.091	0.119	0.145	0.175	0.210	0.247	0.296	0.365	0.441	0.106
Feedstock Required (BTU/kg; HHV basis)	173,582	194,431	207,900	215,248	222,476	231,658	244,415	266,092	304,465	192,116
Feedstock Required N.Gas (BTU/kg; HHV basis)	4,785	5,360	5,731	5,934	6,133	6,386	6,738	7,335	8,393	
Electricity required (kWh/kg)	1.13	1.27	1.36	1.41	1.45	1.51	1.6	1.74	1.99	0.948
Standard plant size (kg/day)	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236	155,236	194,144
Scaling factor	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	
Capacity Factor	0.790	0.820	0.840	0.860	0.880	0.890	0.910	0.930	0.950	0.900
Plant life (yrs)	40	40	40	40	40	40	40	40	40	

On-Board Storage Results

Expert Elicitations for Storage

- 1st Questionnaire
  - Sent to 21 experts from private industry, academia, national labs, and contractors
    - Most were members of the Storage Tech Team
- 1st response & Aggregation meeting
  - 9 responses (2 from multiple experts)
  - PTS confusion
  - Experts decide to start over
- 2nd Response & Aggregation meeting
  - Webcon to review aggregated responses
- 3rd Response
  - Still some confusion with PTS

700 bar Compressed Hydrogen On-Board Storage – Flat Budget

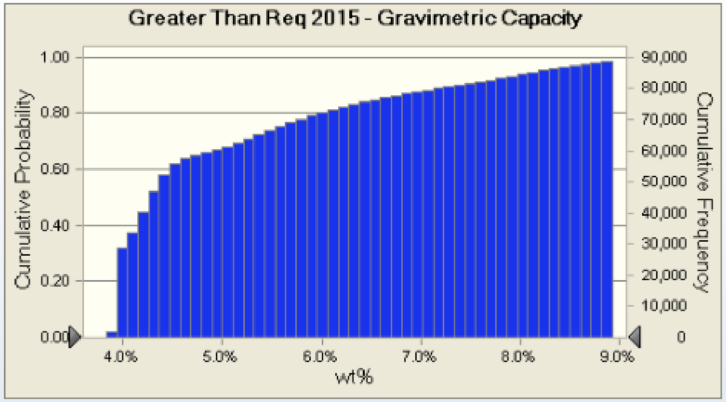
Requested Budget

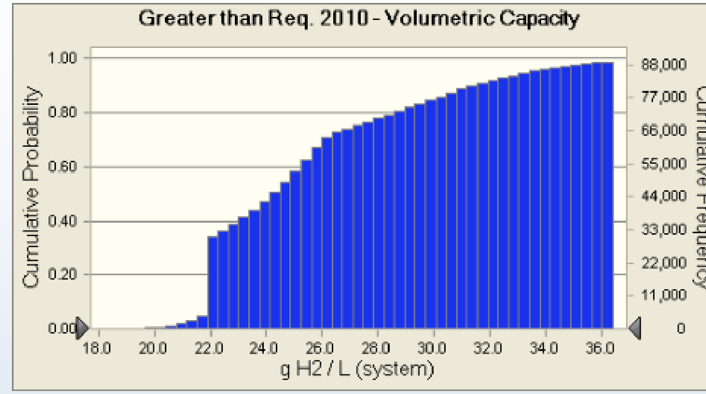
		Status	PTS	Low	High	10%	50%	90%	#
2010	Gravimetric Cap.	4%	75%	30%	100%	4.2%	4.6%	6.4%	6
2010	Volumetric Cap.	22	51%	20%	100%	23.9	25.8	28.5	6
2010	System Cost	18	30%	10%	100%	10.2	14.7	17.2	5
2015	Gravimetric Cap.	4%	68%	20%	100%	4.2%	4.6%	7.0%	5
2015	Volumetric Cap.	22	58%	1%	100%	23.9	26.2	31.6	5
2015	System Cost	18	45%	20%	100%	6.4	12.3	16.6	4

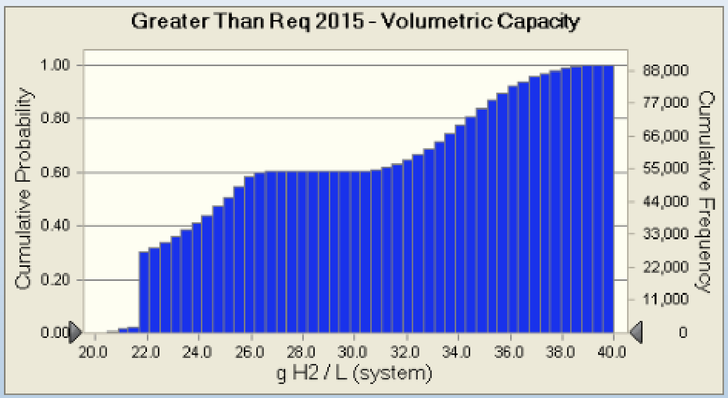
Above Budget Request

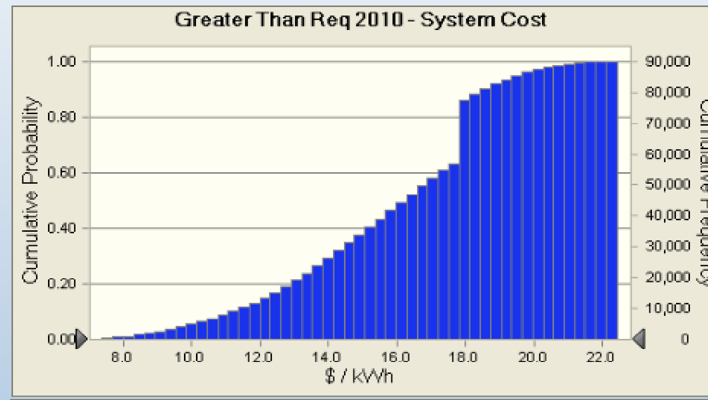
		Status	PTS	Low	High	10%	50%	90%	#
2010	Gravimetric Cap.	4%	66%	40%	100%	4.1%	4.5%	6.1%	3
2010	Volumetric Cap.	22	67%	40%	100%	23.2	25.9	32.9	3
2010	System Cost	18	65%	60%	100%	10.5	14.5	17.2	2
2015	Gravimetric Cap.	4%	70%	40%	100%	4.1%	4.8%	8.0%	3
2015	Volumetric Cap.	22	70%	40%	100%	23.5	32.4	36.5	3
2015	System Cost	18	91%	85%	100%	6.4	12.2	16.1	2

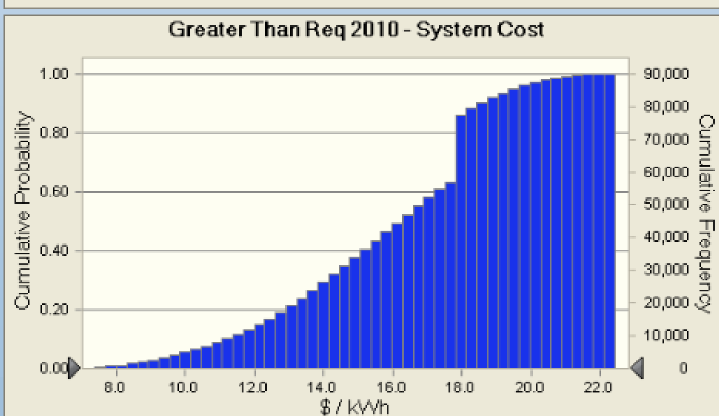
Aggregated cdf's for 700 bar Compressed Hydrogen On-Board Storage – Flat Budget

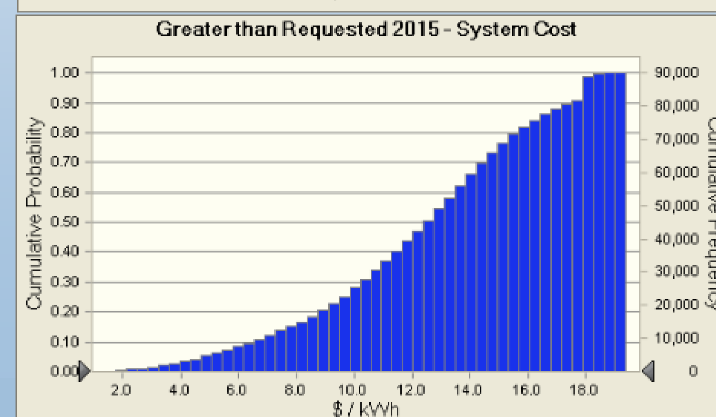












On-Board Storage using Chemical Hydrides – 50% Above Flat Budget

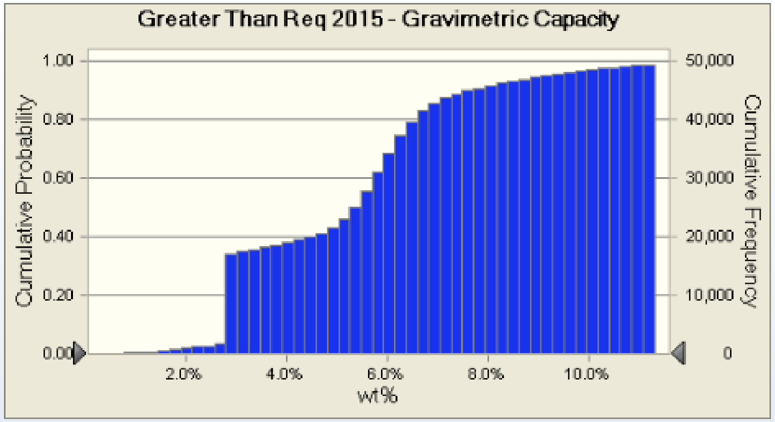
Requested Budget

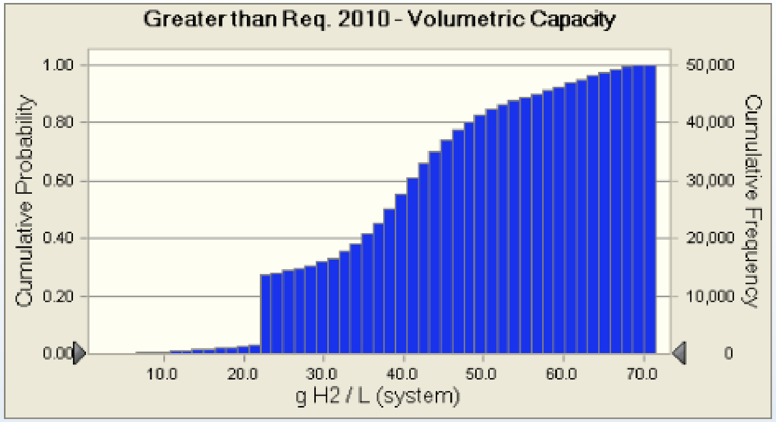
		Status	PTS	Low	High	10%	50%	90%	#
2010	Gravimetric Cap.	2.3%	61%	50%	100%	2.6%	4.1%	7.6%	6
2010	Volumetric Cap.	24	66%	50%	100%	26.2	35.7	65.6	6
2010	System Cost	11	34%	20%	100%	4.9	8.8	10.5	5
2015	Gravimetric Cap.	2.3%	55%	10%	100%	3.6%	5.6%	10.7%	5
2015	Volumetric Cap.	24	62%	30%	100%	36.3	57.8	88.6	5
2015	System Cost	11	41%	10%	100%	3.3	7.2	10.0	4

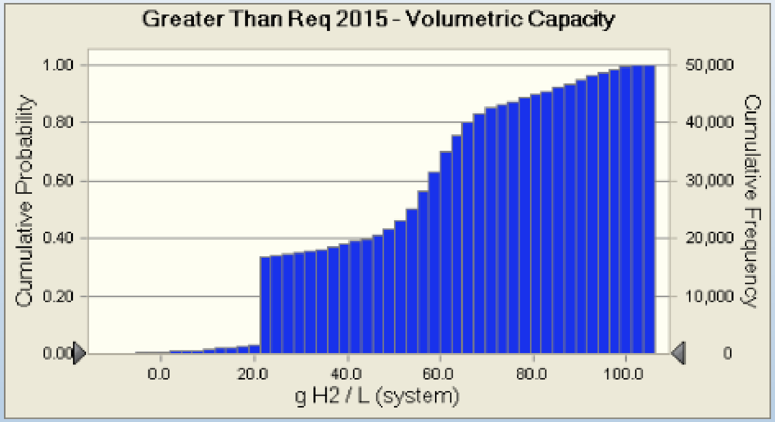
Above Budget Request

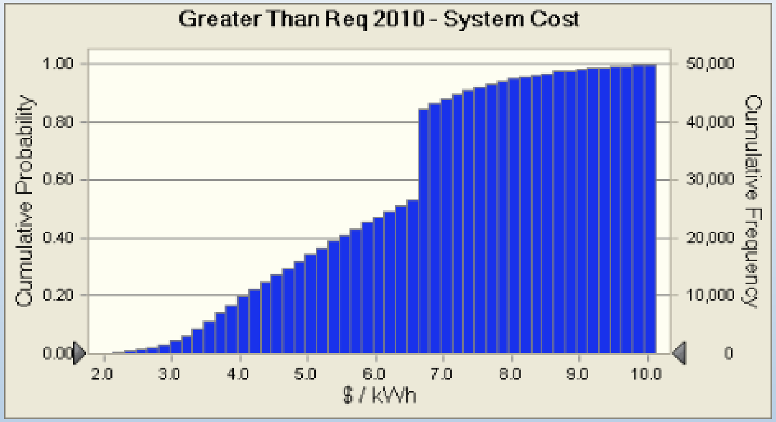
		Status	PTS	Low	High	10%	50%	90%	#
2010	Gravimetric Cap.	2.3%	73%	60%	100%	3.4%	4.6%	6.5%	3
2010	Volumetric Cap.	24	73%	60%	100%	33.9	44.8	77.3	3
2010	System Cost	11	72%	60%	100%	3.6	7.1	9.9	2
2015	Gravimetric Cap.	2.3%	68%	40%	100%	4.4%	6.1%	9.3%	3
2015	Volumetric Cap.	24	75%	60%	100%	50.1	68.7	90.1	3
2015	System Cost	11	86%	90%	100%	2.8	6.6	9.8	2

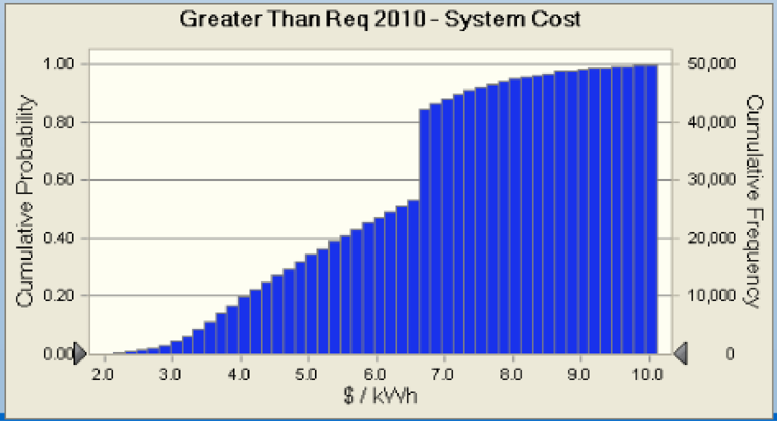
Aggregated cdf's for Hydrogen On-Board Storage using Chemical Hydrides – 50% Above Flat Budget

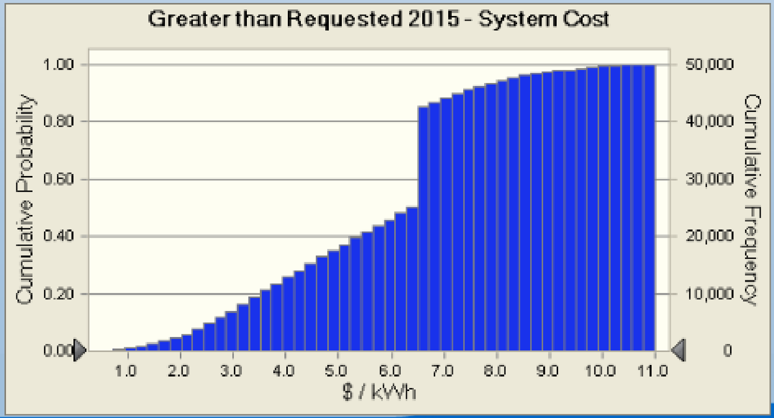












Storage parameters provided for PSAT runs

Parameter	Units	Current	2010				2015			
			Low	Med	High	Target	Low	Med	High	Target
System Gravimetric Capacity	kWh/kg	1.6	1.4	1.5	2.1	2	1.4	1.5	2.3	3
	kgH2/kg	0.048	0.042	0.046	0.064	0.060	0.042	0.046	0.070	0.090
System Volumetric Capacity	kWh/L	0.8	0.80	0.86	0.95	1.5	0.80	0.87	1.05	2.7
	kgH2/L	0.024	0.0239	0.0258	0.0285	0.045	0.024	0.026	0.032	0.081
Cost (Note must multiply by 1.5 to get RPE)	$/kWh	15	17.2	14.7	10.2	4	16.6	12.3	6.4	2

Parameter	Units	Current	2030			2045		
			Low	Med	High	Low	Med	High
System Gravimetric Capacity	kWh/kg	1.6	1.2	1.9	3.6	1.2	1.9	3.6
	kgH2/kg	0.048	0.036	0.056	0.107	0.036	0.056	0.107
System Volumetric Capacity	kWh/L	0.8	1.21	1.93	2.95	1.67	2.29	3.00
	kgH2/L	0.024	0.036	0.058	0.089	0.050	0.069	0.090
Cost (Note must multiply by 1.5 to get RPE)	$/kWh	15	10	7.2	3.3	9.8	6.6	2.8

Findings

1. Planning
   - Schedule was too compressed
   - Questionnaires were not adequately peer-reviewed before sending out
   - Did not explain benefits of participating well enough
   - A group meeting would have been preferred
2. Process
   - Response rate from private industry was very poor; some companies not willing to share proprietary information
   - Much better response rate from National Labs
   - Some experts just didn’t want to participate; time commitment
   - Some experts seemed to have a difficult time understanding our requests without a one-on-one conversation
   - Some experts disagreed with the 2007 status and provided estimates that were worse than our current status
   - Some experts provided inconsistent estimates

Findings

3. Analysis
   - Analytical tools developed late in the process
   - Concept of Probability of Technical Success (PTS) difficult to understand and not explained well
   - Aggregation of expert opinions with and without PTS presented some difficulties

4. Results
   - Few or no expert responses for some performance parameters
   - Some median responses were not consistent with a triangular distribution
   - Some inconsistent results
   - Some biased results

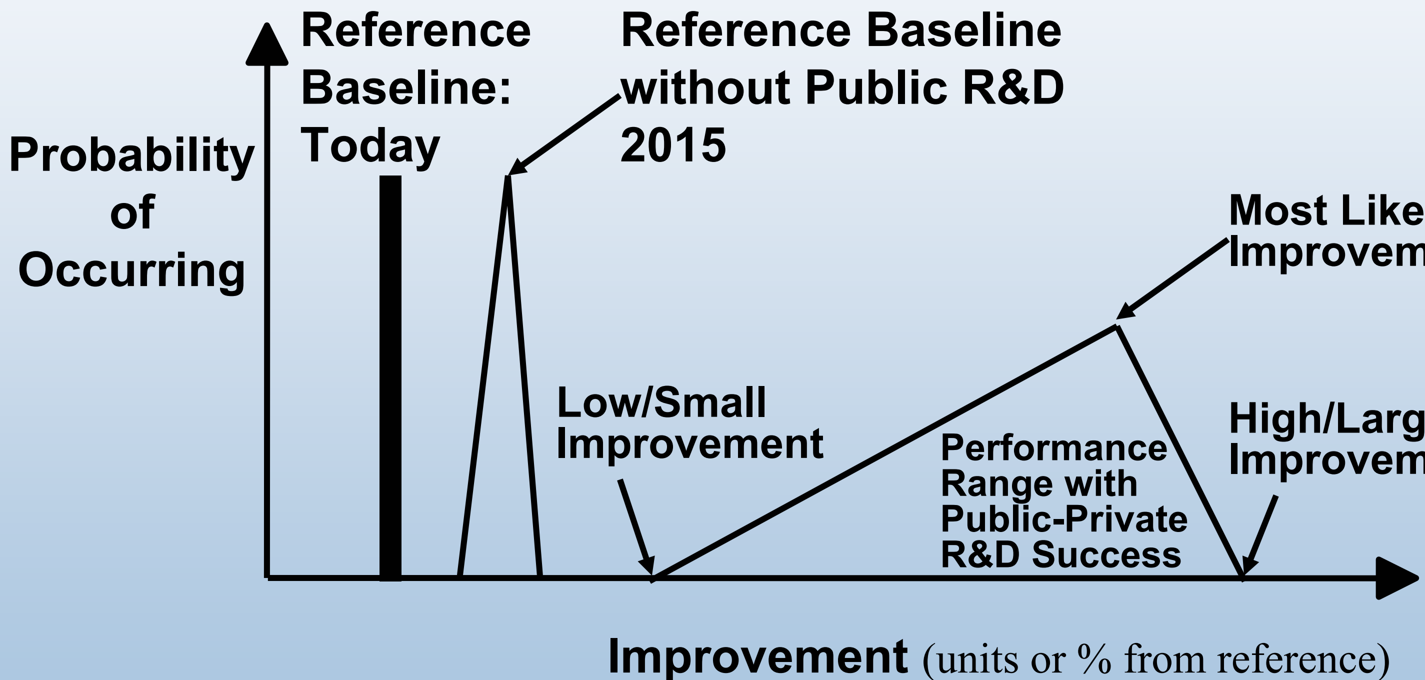
Issues

- What should the minimum number of expert responses be to develop and accept an aggregated response? Are opinions from only 2 or 3 experts enough?
- Could 2 or 3 pessimistic experts jeopardize portions/all of the HFCIT program?
- Can the experts be assembled in one location for a day or two next time?
- What is the best source of experts?
  - Private industry
  - Tech teams
  - National Labs
  - DOE contractors
- How can we ensure receipt of proprietary data
- How do we ensure private industry of anonymity
- How do we avoid biases?
- What is the best way of eliciting expert opinions?
  - Email questionnaires
  - Web conferences
  - Face-to-face group meetings

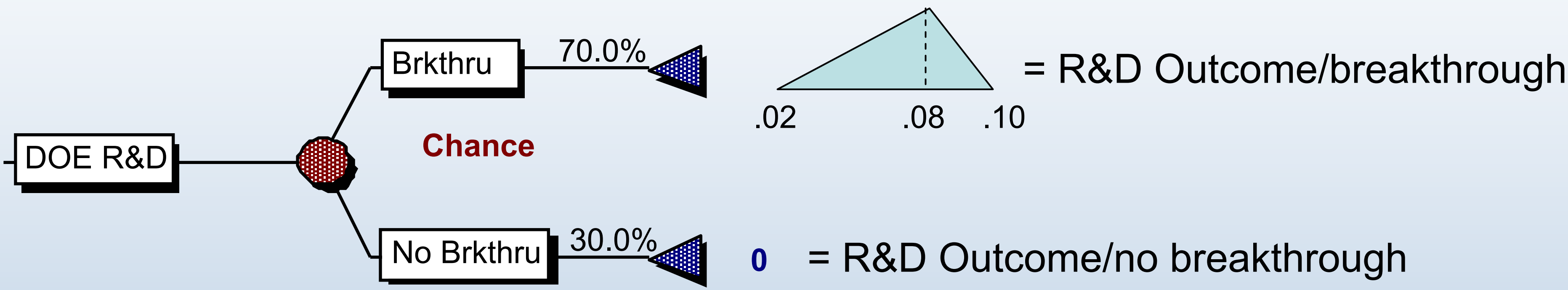
Recommendations

1. Planning
   - Initiate process at least 6 months before results required
   - Peer-review Questionnaires before sending out
   - Explain benefits of participating
   - Establish confidentiality agreement with private companies
2. Process
   - Decide on the best source of experts: Private Industry, Tech Teams, National Labs, or DOE Contractors
   - Stratify experts by performance parameters
   - Hold group meeting to explain process and facilitate assessments
   - Encourage qualitative comments
   - Seek 5-7 expert responses per performance parameter
3. Analysis
   - Review all analytical tools proposed for use
   - Change PTS to Probability of Breakthrough and explain via tree diagram
   - Resolve mode versus median response question

Specific Recommendation for PTS



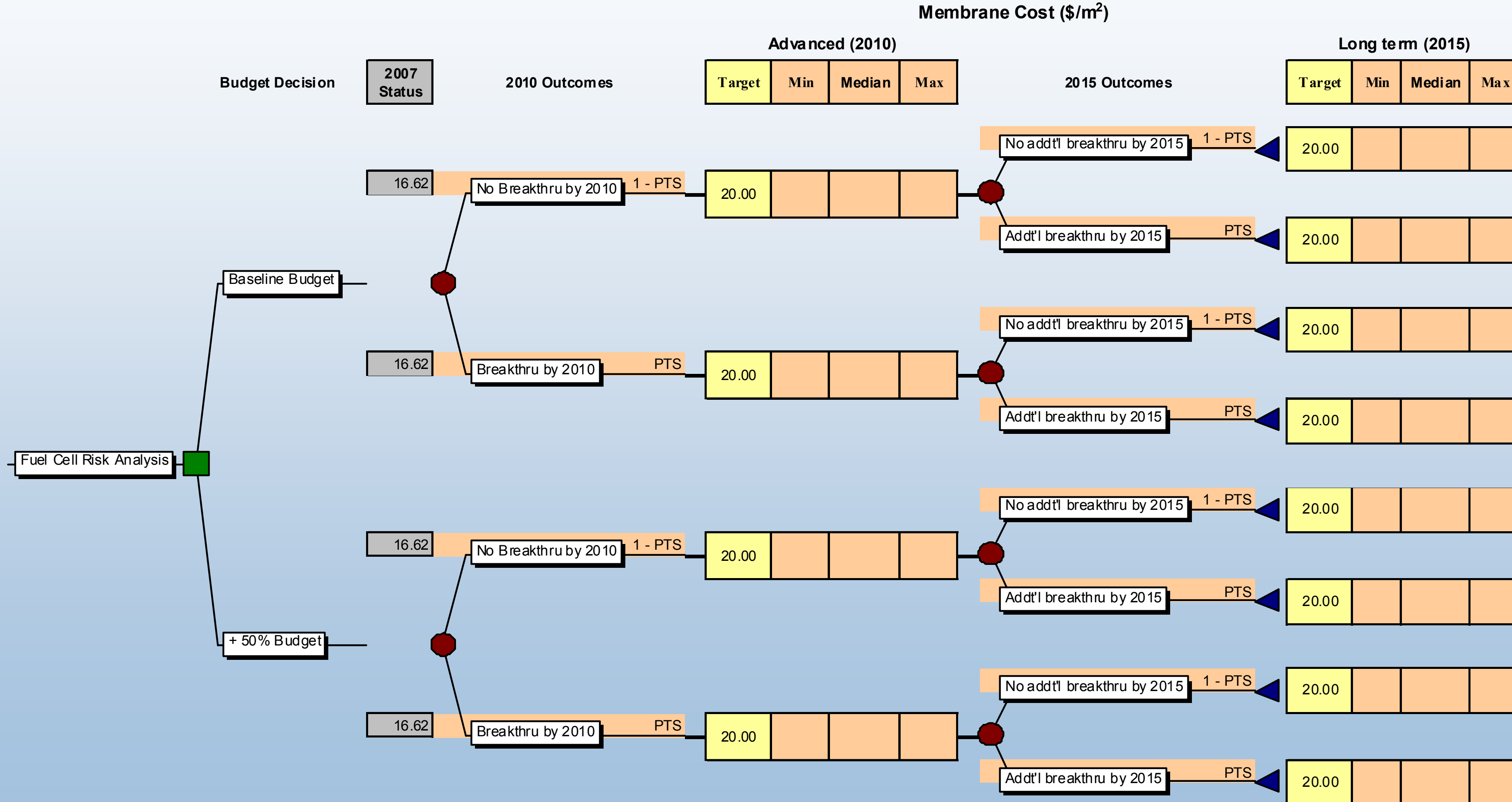
Specific Recommendation for PTS (continued)



Technical performance improvement resulting from DOE R&D

DOE R&D = P(Success) X (R&D Outcome/success) + P(Failure) X (R&D Outcome/failure)
= PTS X (triangular distribution)
= 0.7 X (triangular distribution)

Specific Recommendation for PTS (continued)



Future Work

- FY09
  - Update risk analyses for FY 2011 budget process
    - Hydrogen Production
    - On-board Storage
    - Fuel Cells for Transportation
  - EERE will conduct a portfolio analysis process across all 11 Programs
- FY11
  - Repeat Risk Analysis process every two years

Summary

- Relevance
  - Support EERE’s portfolio analysis of 11 Programs
- Approach
  - Expected performance improvements based on expert opinions
- Technical Accomplishments and Progress
  - Completed pilot analysis
  - Recommended risk analysis process improvements
- Future Work
  - Risk analyses for EERE to be conducted every two years