Cost Analyses of Fuel Cell Stacks/Systems

DE-FC02-99EE50587

2004 Hydrogen and Fuel Cells Merit Review Meeting

Philadelphia, PA

May 24-27, 2004

Eric J. Carlson
TIAX LLC
Acorn Park
Cambridge, Massachusetts
02140-2390

Reference: D0006

This presentation does not contain any proprietary or confidential information.

In support of our cost assessment of compression hydrogen storage this year, Argonne National Laboratory continued to provide modeling support.

Program Manager: Nancy Garland
ANL Technical Advisor: Robert Sutton

TIAX Team

Primary Contact: Eric J. Carlson

Core Team:
Dr. Suresh Sriramulu
Stephen Lasher
Yong Yang
Peter Kopf
Bob Rancatore
Robert Maloney

Argonne National Laboratory
System Thermodynamic Model

Primary Contacts: Dr. Romesh Kumar
Dr. Rajesh Ahluwalia

To assist DOE in the development of fuel cell system technologies by providing cost and manufacturing analysis.

- To develop an independent cost estimate of PEMFC system costs including a sensitivity analysis to:
  - Operating parameters
  - Materials of construction
  - Manufacturing processes
- To identify opportunities for system cost reduction through breakthroughs in component and manufacturing technology
- To provide annual updates to the cost estimate for the duration of the project

In FY04 we are focussing on the costing of compressed hydrogen storage.

We have conducted a five year program with 20% cost share.

	Project	FY04
DOE	$700,000	$63,896
TIAX	$175,166	$15,975
Total	$875,166	$79,871

For PEMFC powertrains to be viable in the market place, they must have attractive performance and cost attributes.

Technical Barriers	
Direct Hydrogen Fuel Cell Power System	
System Level	N. Cost O. Stack Material and Manufacturing Cost
H_2 Storage	A. Cost B. Weight and Volume (>300 mile range) C. Efficiency (compression losses) D. Durability (1500 cycles) E. Refueling Time F. Codes and Standards G. Life Cycle and Efficiency Analyses H. Sufficient Storage for Acceptable Range I. Materials (weight/volume/performance/cost) J. Lack of Tank Performance Data

For PEMFC powertrains to be viable in the market place, they must have attractive performance and cost attributes.

Technical Targets					
Direct Hydrogen Fuel Cell Power System			2010	2010	2015
System Level	Efficiency	%	60%		
	Cost	$/kW		**45**	**30**
H_2 Storage	Specific Energy Density	kWh/kg	1.5	2	3
		%	4.5	6	9
	Energy Density	kWh/L	1.2	1.5	2.7
	Cost	$/kWh	**6**	**4**	**2**
	Refueling Rate	kgH_2/min	0.5	1.5	2
	H_2 Losses	kgH_2/min	1.0	0.1	0.05
	Min Flow Rate	g/sec/kW	0.02	0.027	0.033

In this multi-year program, we developed a baseline system configuration and cost and then looked at various system scenarios and the impact of future technology developments.

Task 1: PEMFC System Technology Synopsis

- Develop baseline system specification
- Project technology developments
- Assess impact on system performance
- Identify manufacturing processes

Task 2: Develop Cost Model and Baseline Estimates

- Develop cost model
- Specify manufacturing processes and materials
- Develop production scenarios
- Baseline cost estimate

Task 3: Identify Opportunities for System Cost Reduction

- Perform sensitivity analysis to key parameters
- Evaluate the impact of design parameters and potential technology breakthroughs on subsystem and overall system costs
- Identify and prioritize opportunities for cost reduction in transportation PEMFC systems
- Obtain industry feedback

Tasks 4, 5, 6 & 7: Annual Updates

- Assess technology evolution
- Update baseline cost estimate based on technology developments

Year 1 (1999)) — *Year 2 (2000)* — *Years 3, 4, and 5*

Year 5 in FY04

In this presentation we report the preliminary results from the cost model for the compressed hydrogen storage system.

Technology Assessment	Cost Modeling	Model Refinement

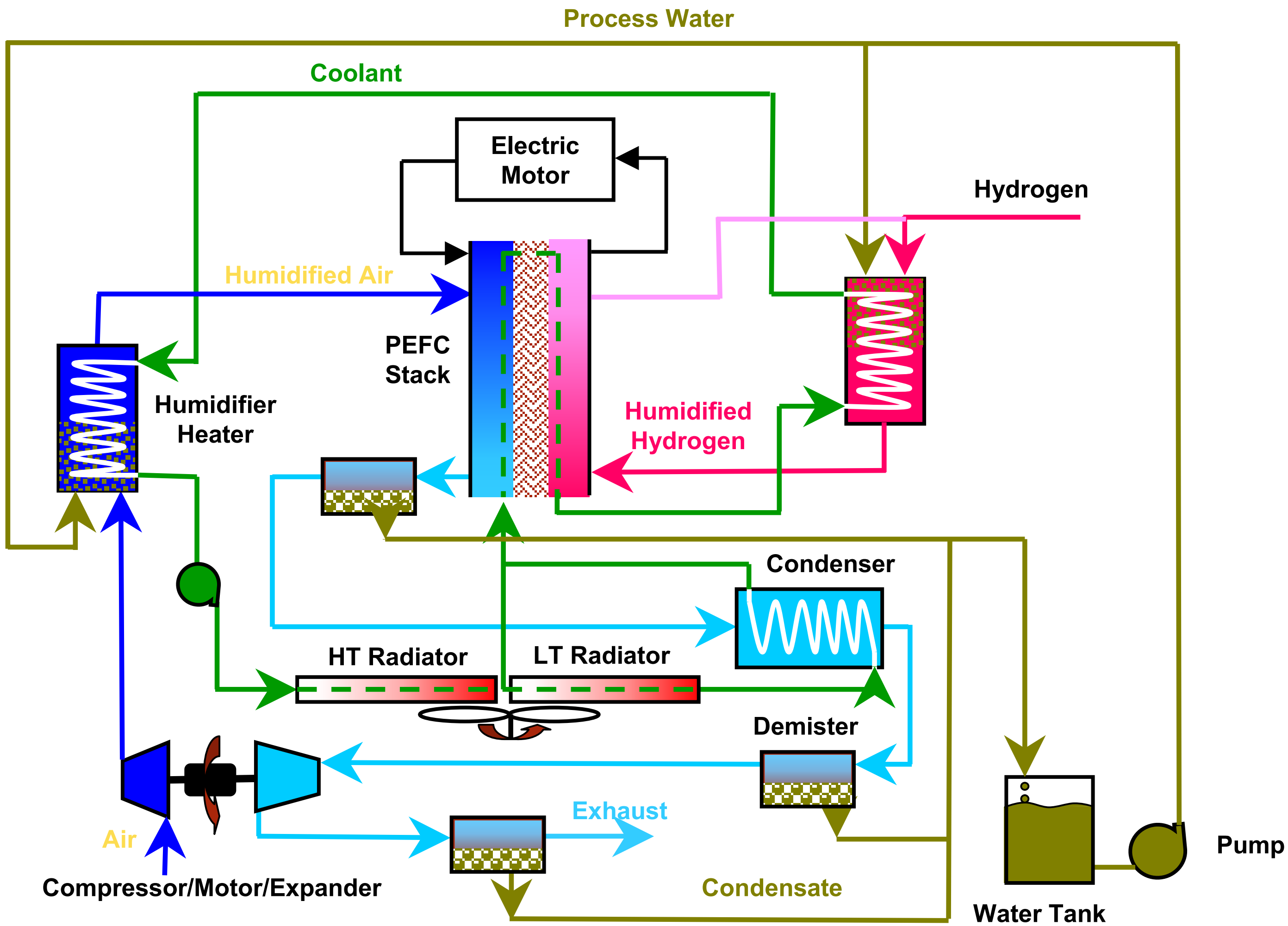
• Literature Search
  • Patents
  • Published Papers
  • DOE Reports
• Review of Pressurized Gas Storage Applications
• System Configuration and Modeling
	• Outline Assumptions
	• Document Bill of Material
	• Determine Material Costs
	• Identify Processes
	• Identify Manufacturing Equipment
	• Sensitivity Analysis
	• Monte Carlo Analysis
		• Obtain Industry and Incorporate Industry Feedback
		• Revise Model
		• Prepare Final Report

DELIVERABLES

• Design for Costing Exercise	• Preliminary Cost Estimate • Report for Discussion with Industry	• Final Report and Presentation

Complete by 6/04

We are working with Argonne National Laboratories* (ANL) to define the overall system and hydrogen requirements.



*From Dr. Rajesh Ahluwalia of ANL

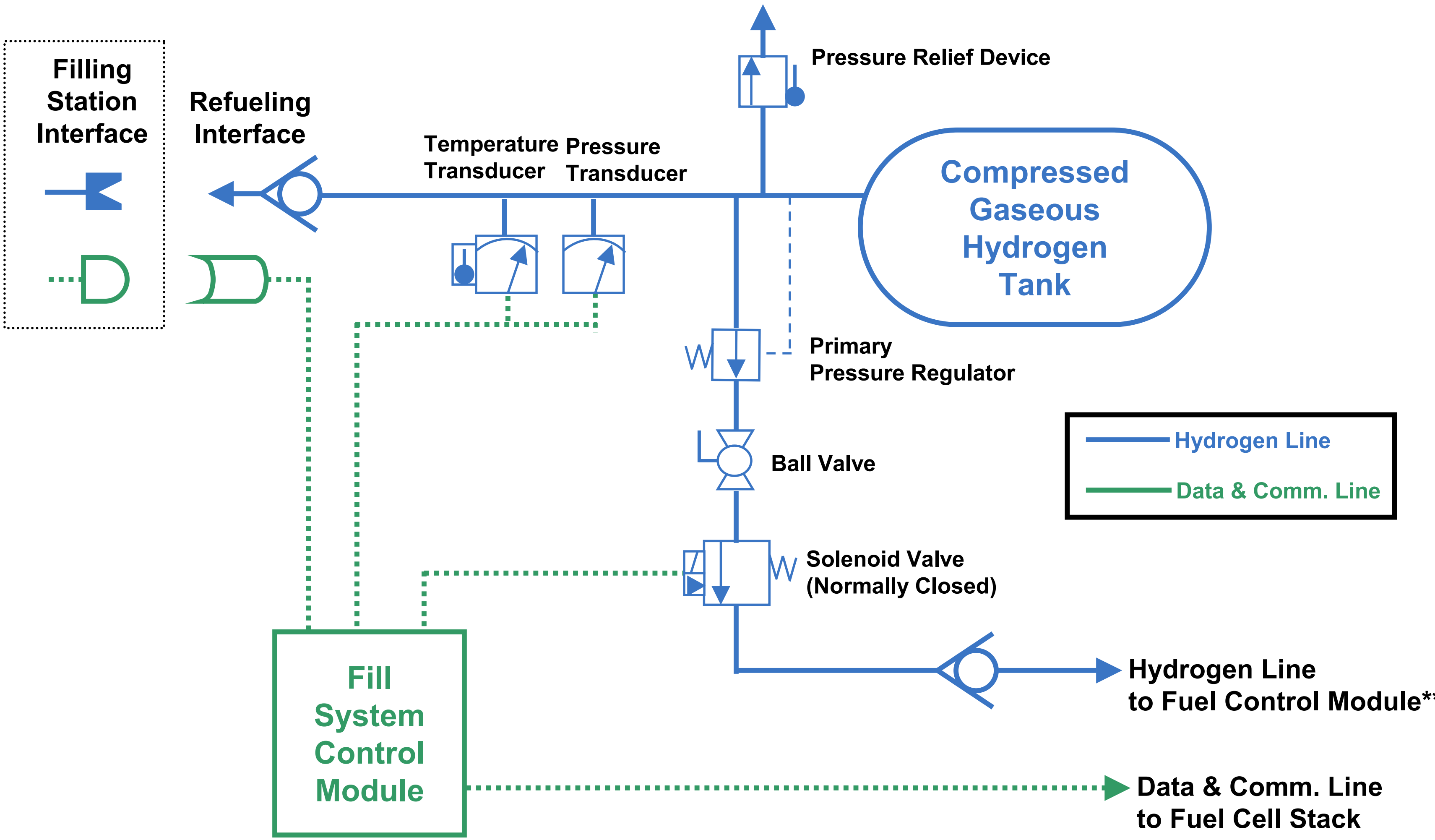
Several hybridization scenarios were considered before choosing an 80kW fuel cell with a "40kW" battery requiring 5.6 kg usable hydrogen.

ANL Results	ICEV 120 kW	FC EV 120 kW	FC HEV 100 kW	FC HEV 80 kW	FC HEV 60 kW
Engine/Fuel Cell Power, kW peak	114	120	100	80	60
Battery Power, kW peak	0	0	20	40	55
Fuel Economy, mpgge	23	59	65	68	69
Hydrogen Required	NA	6.3	5.9	5.6	5.6

From Dr. Rajesh Ahluwalia of ANL

The analysis was conducted for a mid-size, Taurus like, vehicle with a 370 mile range on a combined urban/highway drive cycle.

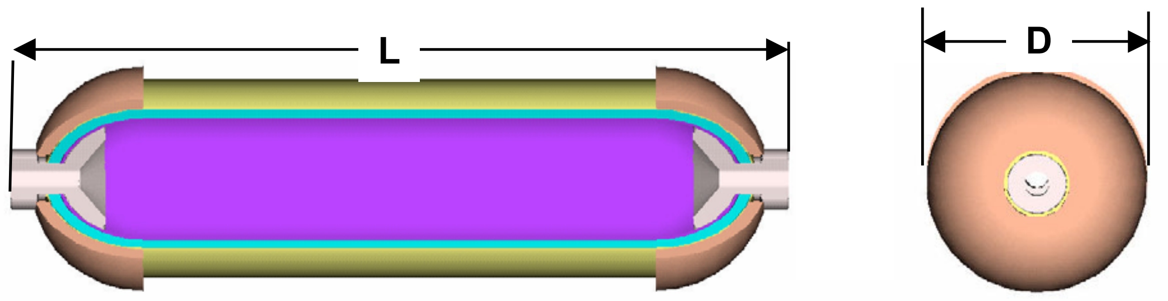
We used the hydrogen storage system below as a basis for the cost model.*



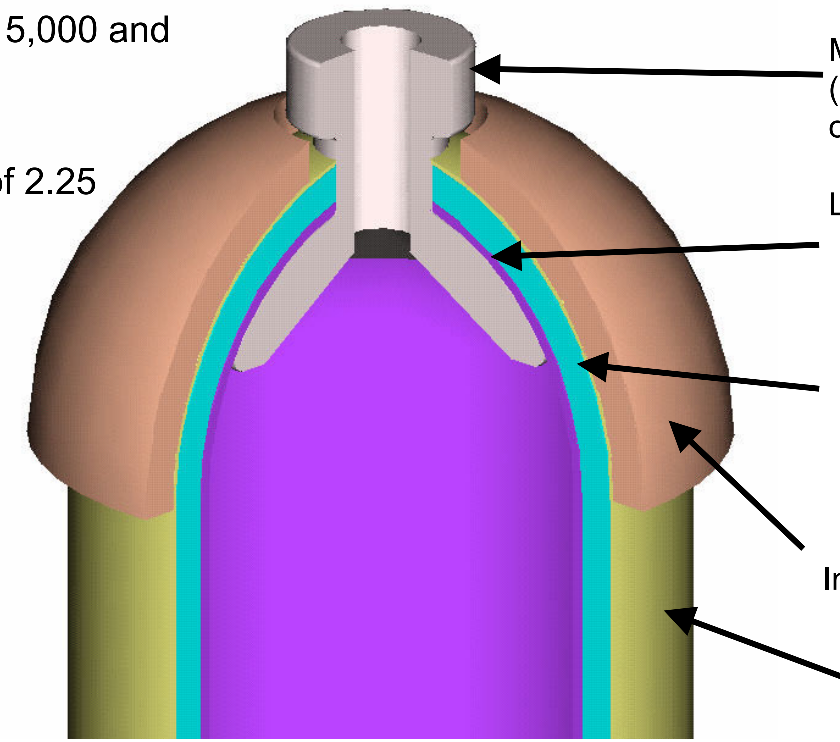
**Secondary Pressure Regulator located in Fuel Control Module.

*Schematic based on both the requirements defined in the draft European regulation for "Hydrogen Vehicles: On-board Storage Systems" and US Patent 6,041,762.

We used a typical Type III or Type IV tank as the basis for our costing effort.



- **Tank Design**
  - Pressures are 5,000 and 10,000 psi
  - L/D ratio is 3:1
  - Safety factor of 2.25



We believe aerospace grade properties and certifications will be required for CH_2 tank structures,consequently this sets the cost per pound in the $10-30 per lb range.

PAN Fiber Types					
Grade Designation	**Commodity**	**Standard Modulus**	**High Strength (HS)**	**HS Intermediate Modulus**	**High Modulus**
Use Class	Commercial	Commercial, Industrial	Industrial, Aerospace	Industrial, Aerospace	Aerospace
PAN precusor	Textile grade	HQ Industrial grade	Aerospace grade	Aerospace grade	Aerospace grade
Typical Tow Count, K	48, 160, 320	24, 48	12, 24	12, 24	12,24
Tensile strength, Ksi	550	550	700	750	700
Tensile modulus, Msi	33	33	33	43	55
Cost range, $/lb .	5-7	7-9	10-20	20-30	>30
Applications	Sporting goods, Automotive	Sporting goods, Industrial	Pressure Tanks, Industrial, Aerospace	Pressure tanks, Industrial, Aerospace	Aerospace
Suppliers	Zoltec	Fortafil, Grafil, SGL, Aldila	Toray, TohoTenax, Cytec, Hexcel	Toray, TohoTenax, Cytec, Hexcel	Toray, TohoTenax, Cytec, Hexcel

We used netting analysis to calculate the carbon fiber requirements. The higher strength fiber (M30S) reduces weight by 8-9%.

Pressure	Vol.	Fiber	Liner Type	Tank Component Weight (kg): Liner	Carbon Fiber Composite	Glass Fiber Composite	Foam	Tank Total
5,000 PSI	255 Liter	M30S	HDPE	14.4	33.0	5.8	5.9	59
			AL	14.8				
		T700S	HDPE	14.4	37.1	6.6	5.9	64
			AL	14.8				
10,000 PSI	155 Liter	M30S	HDPE	10.3	41.3	7.3	4.7	64
			AL	10.3				
		T700S	HDPE	10.3	46.6	8.2	4.7	70
			AL	10.3				

Carbon Fiber Glass Factor= 0.85; Carbon Fiber Weight% = 68; HDPE thickness= 0.25"; Al thickness= 0.09", Tank weight without bosses and regulator

For the assumed liner thicknesses, the liner choice does not effect weight.

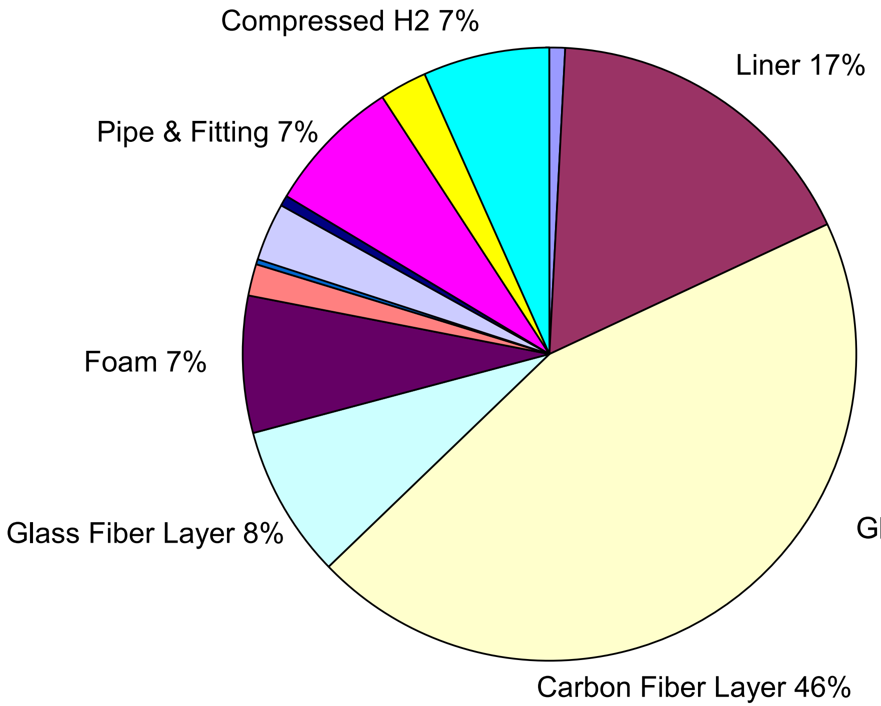
Tank capacity can meet the 80 kW vehicle H2 requirement even considering volume that can not be utilized.

Pressure	Design Capacity	Required H2	Total H2*	% of H2 Available
5,000 PSI	255 liter	5.6 kg	5.89 kg	95%
10,000 PSI	155 liter	5.6 kg	5.96 kg	94%

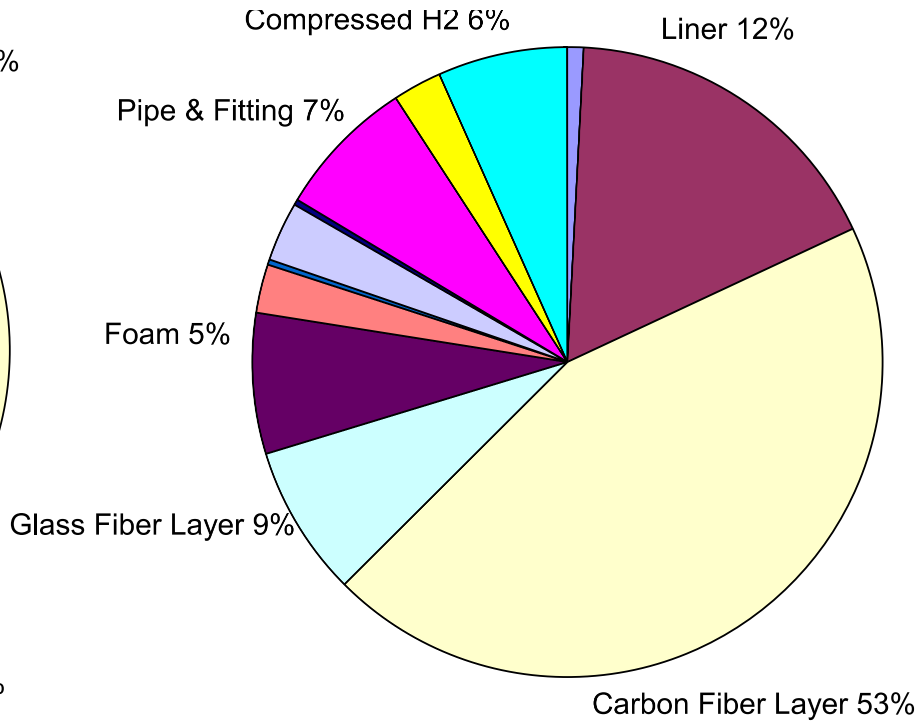
*@5,000 PSI tank, including H2 weight that can not pass through the regulator at 200 PSI.
@10,000 PSI tank, including H2 weight that can not pass through the regulator at 400 PSI

The 5,000 and 10,000 psi Baseline systems have similar weight distributions. The carbon fiber layer is the largest contributor.

5,000 PSI System Weight (83 kg)



10,000 PSI System Weight (89 kg)

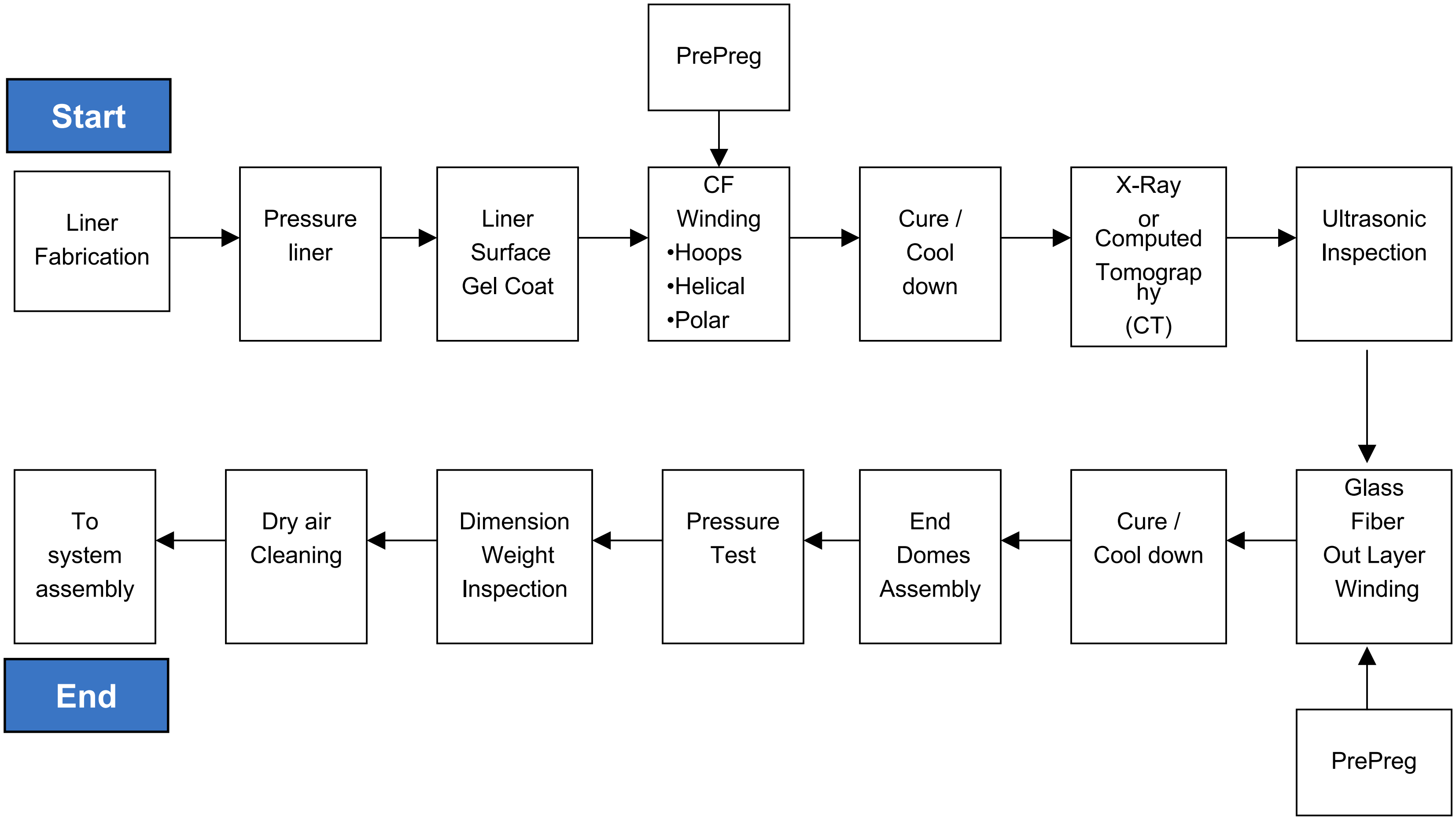


Other components (regulator, fill port, sensors, valves, bosses, and packaging), each contribute less than 3%.

For the baseline case, we have used a Toray T700S like carbon fiber and S-glass for the impact resistant outer layer.

Parameters	5,000PSI Baseline	10,000 PSI Baseline
Production Volume (System /Year):	500,000	
Working Pressure (PSI)	5,000	10,000
H_2 storage Weight (kg)	5.6	
Tank Volume (liter)	255	155
Tank Weight (kg)	64	70
Liner Thickness & Material	0.25 Inch HDPE or 0.090 Inch Aluminum	
Carbon Fiber Type	T700S	
Glass Fiber Type	S-Glass	
Fiber / Epoxy Ratio (wt ratio)	68 / 32	
Fiber Process	Filament Winding	
Regulator Type	In Tank	
Safety Factor	2.25	

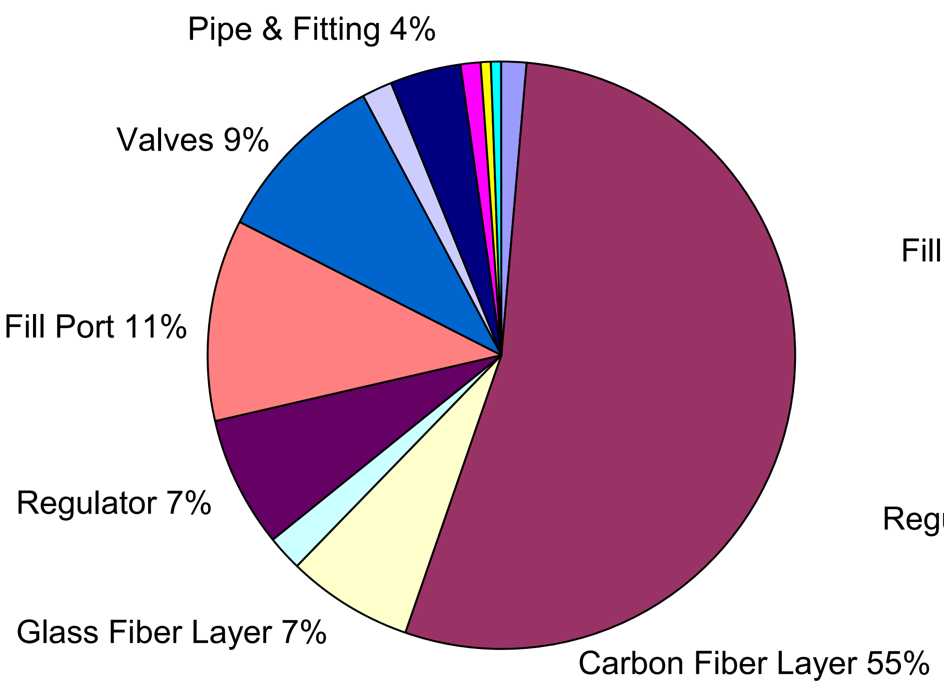
The process for manufacturing wound composite tanks is well established from the Compressed Natural Gas industry.



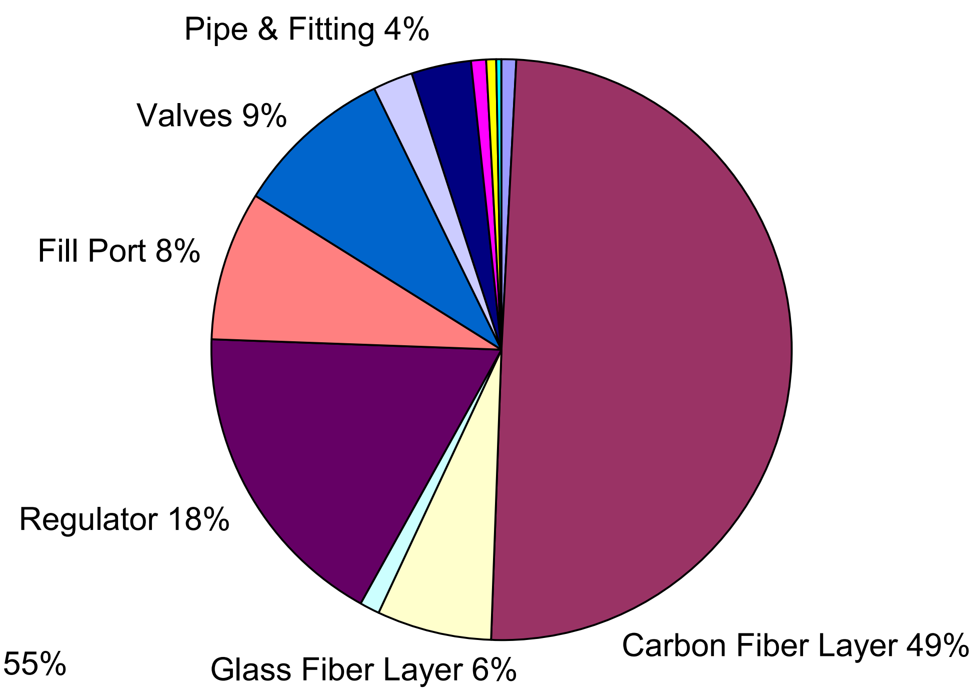
This is the process flow used in model for type III & IV tank fabrication.

The 5,000 and 10,000 PSI Baseline systems have a similar distribution of cost and the carbon fiber layer is the dominant cost contributor.

5,000 Psi System ($2,108)

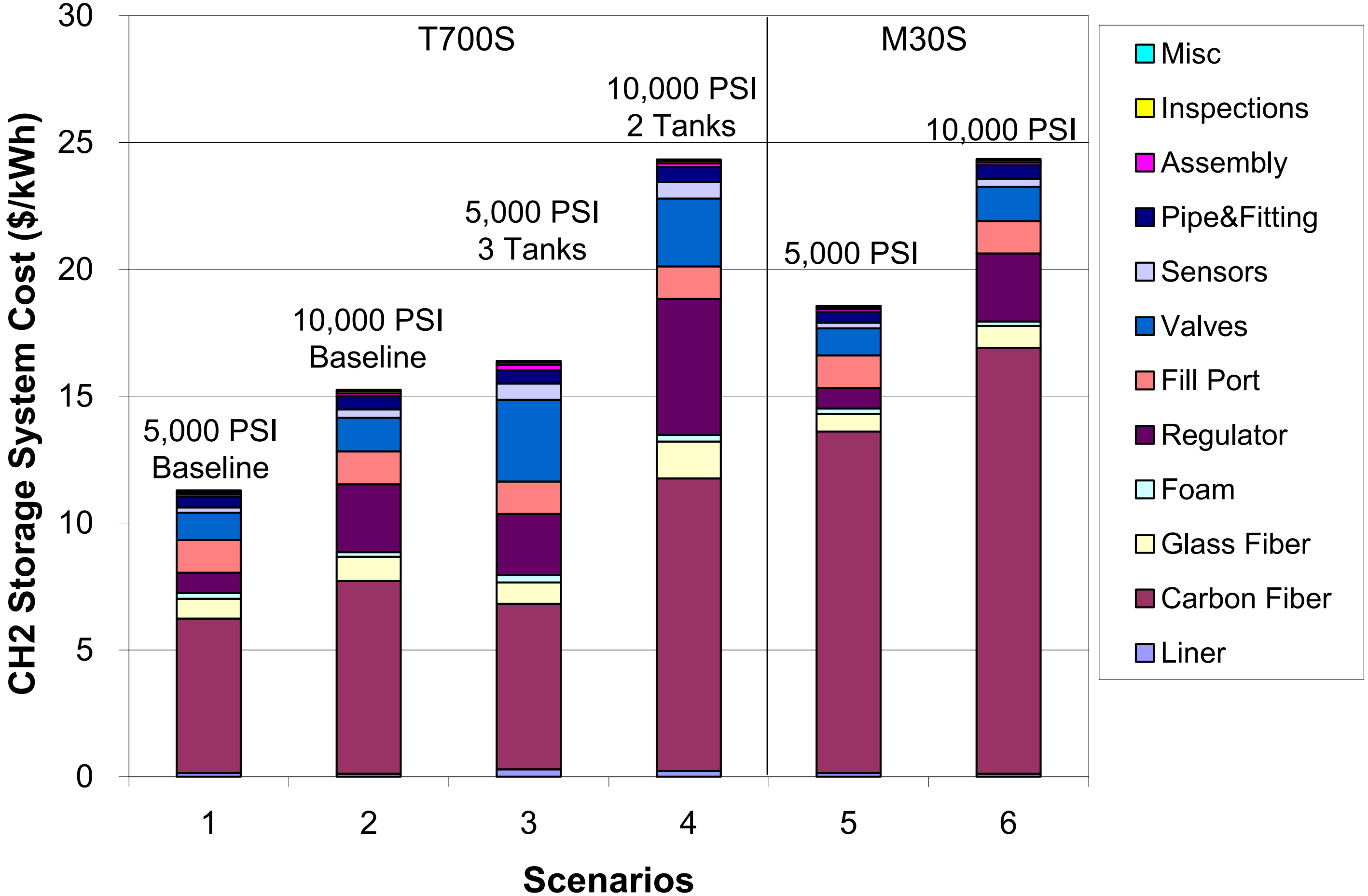


10,000 Psi System ($2,848)



Other components, including the liner, foam, sensors, pipe & fitting, contribute less than 3% each to the total.

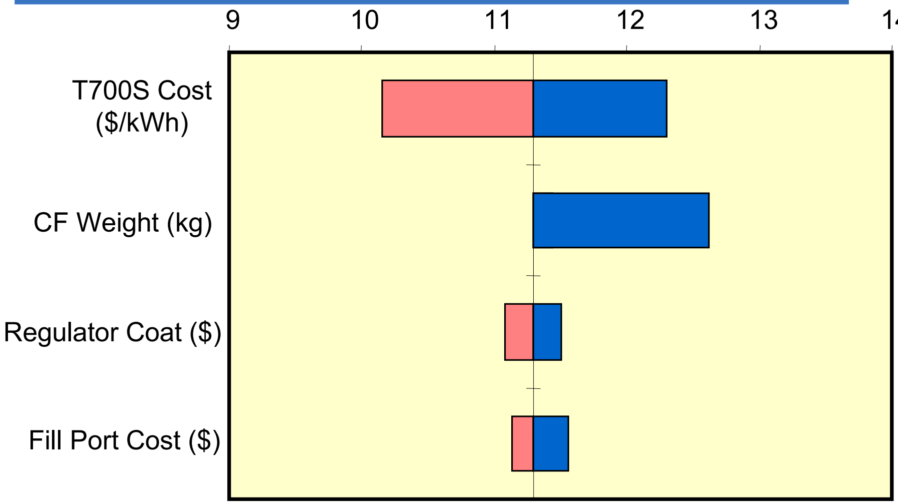
Use of multiple tanks to improve the form factor increases cost, primarily driven by the need for multiple regulators and valves.



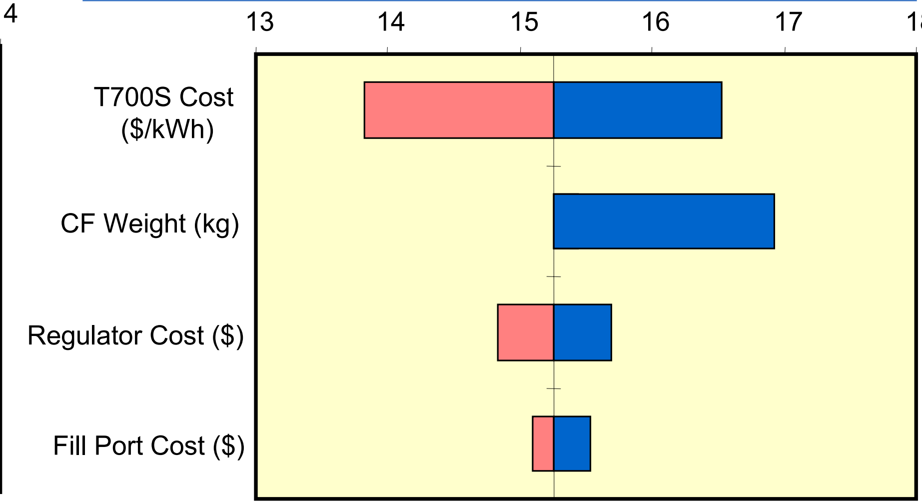
Multiple tank designs are the more likely scenario for automotive applications.

Overall system cost is dominated by the carbon fiber cost and weight. The next parameters have much less impact.

5,000 PSI (11 $/kWh)



10,000 PSI (15 $/kWh)

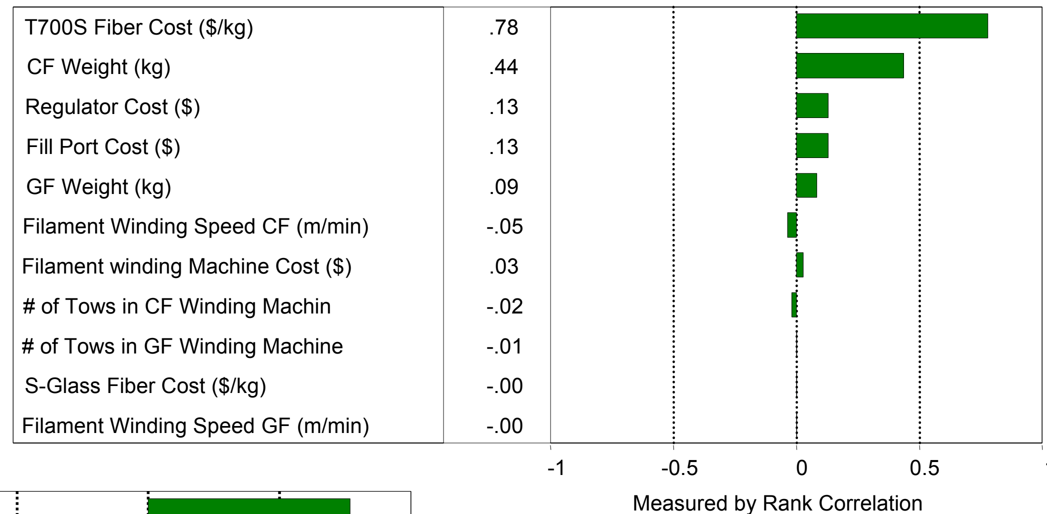


Factors	5,000 PSI / T700S			10,000 PSI / T700S		
	Baseline	Min	Max	Baseline	Min	Max
Carbon Fiber Cost ($/lb)	10.00	7.50	12.00	10.00	7.50	12.00
Carbon Fiber Weight (kg)	25.23	25.23	31.54	31.69	31.69	39.61
Regulator Cost ($)	150	100	200	500	400	600
Fill Port Cost ($)	240	200	300	240	200	300

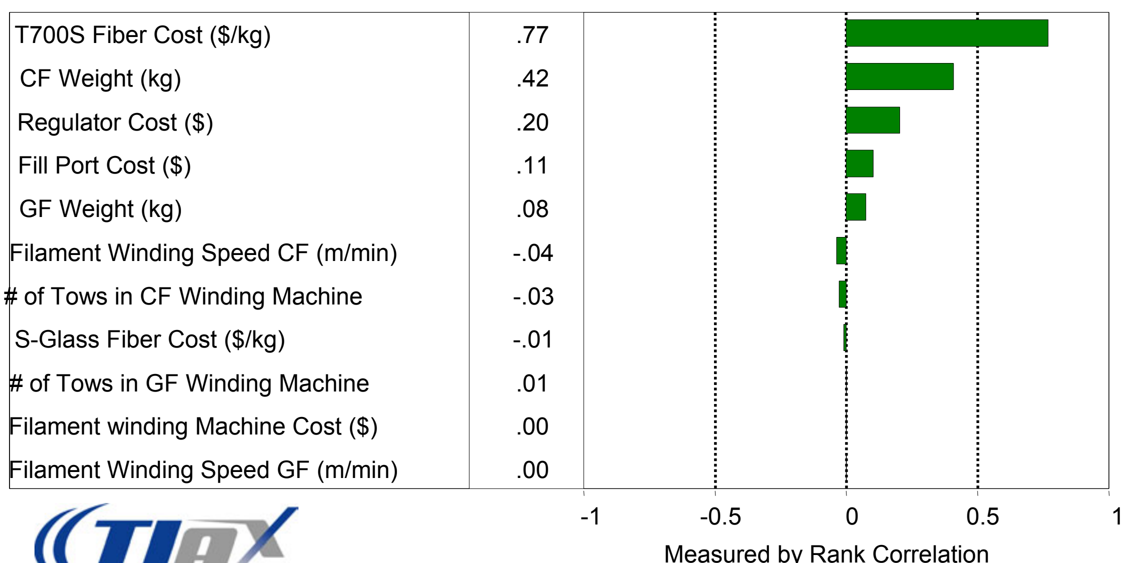
Tank system cost is most sensitive to carbon fiber cost and weight in both 5,000 PSI baseline and 10,000 PSI baseline.

5,000 PSI Baseline

Target Forecast: Storage System Cost ($/kWh)



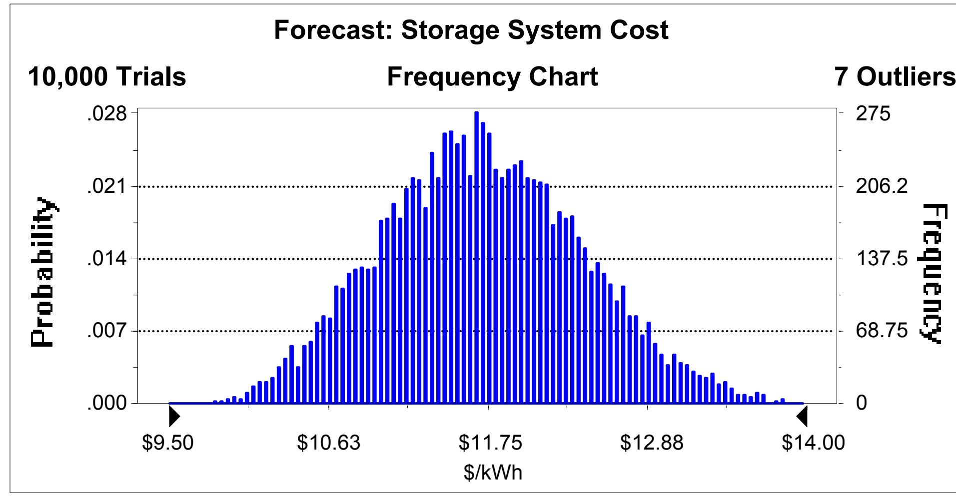
Target Forecast: Storage System Cost ($/kWh)

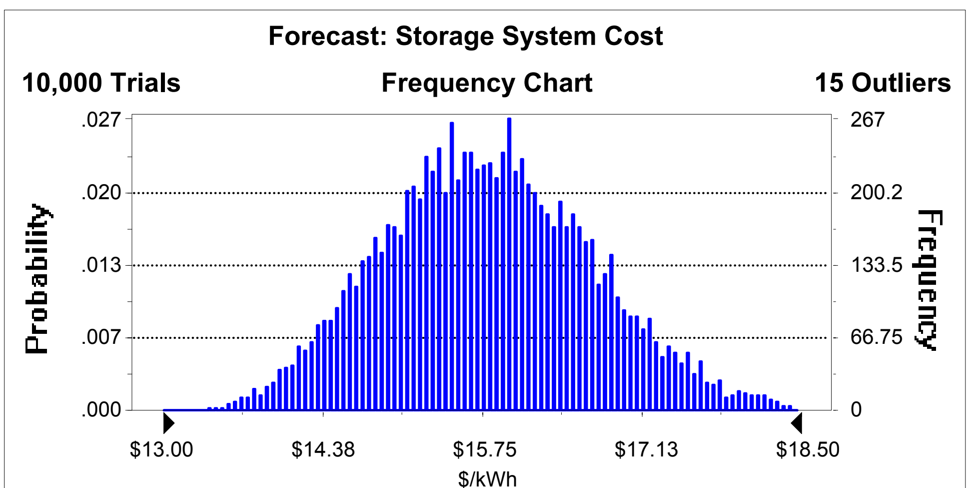


10,000 PSI Baseline

The Monte Carlo simulation for the two pressures still leads to costs double the 2005 target for compressed hydrogen storage.

5,000 PSI Case





10,000 PSI

Need to add weight and volume if possible

Our preliminary results, without feedback from the developers, indicate that compressed hydrogen will be more costly than the DOE near-term target, by approximately a factor of 2-3 times..

System Metric	DOE Targets 2005	DOE Targets 2010	DOE Targets 2015	Model Results 5,000 psi	Model Results 10,000 psi
Cost ($/kWh)	6	4	2	11 - 16	15 - 24
Specific Energy (Wt%)	4.5	6	9	5.3	4.2

Multiple tanks, T700S fiber

- **Underlying cost estimates by “suppliers” not challenged**
  - Inputs from suppliers are sought for near-term and long-term cost projections
  - Projections and our estimates factored into the sensitivity analyses
- **Activity-based costing misses synergistic holistics, which are necessary for overall system costs (trade-offs not thorough enough)**
  - Specification of system configuration and component technologies a critical first step in the cost process. Analysis based on thermodynamic models and available performance data to size the components
  - Different system scenarios have been considered with direction from DOE to address specific technology issues, I.e., benefit of high temperature membranes
  - Try to focus on major cost drivers and underlying controlling processes

Future Work

- Solicit feedback from compressed hydrogen storage system developers and refine preliminary cost model results
- Update direct hydrogen system cost projection