2009 DOE Hydrogen Program Low-Cost High-Efficiency High-Pressure H_2 Storage

Quantum Fuel Systems Technologies Worldwide Inc.

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Project ID # STP_04_Liu

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Overview

Timeline

- Project start date: 07/2008
- Project end date: 01/2010
- Percent complete: 36%

Barriers

- Materials development
- Manufacturability
  - Blow molding/injector molding capability

Budget

- **Total budget: $2,865,932**
- DOE share: $1,438,733
- QT share: $1,432,199
- FY08 funding: $0
- Funding for FY09: $226,476

Partners

- None currently

Project Objectives- Relevance

Improve the cost and weight efficiency of Type IV compressed H_2 storage vessels to approach the 2010 DOE targets by reducing raw material costs through material development and design & manufacturing parameter modifications.

The project is split into the following tasks:

- Plastic liner development
- Metal fitting development
- Optimization of carbon fiber composite usage

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Milestones

Month	Milestone
07/08-11/08	Program Kick-off Liner material literature review; *100% complete*
11/08-01/09	Liner material property characterization/evaluation; *90% complete* Investigate blow molding processes to find appropriate vendors & manufacture "liners"; *60% complete*
01/09-04/09	Liner test evaluations; *60% complete* Metal fitting material candidate literature review; *100% complete* Metal fitting to liner interface design & FEA; *30% complete* Composite optimization literature review; *100% complete*
04/09-10/09	Complete liner evaluations Evaluate metal fitting candidate materials for hydrogen compatibility Composite Tank fabrication
10/09-01/10	EIHP tests to evaluation of new boss-liner assembly EIHP tests to evaluate composite optimization and process development
01/10	Provide cost model Final report preparation & submittal (inclusive of EIHP results)
05/10	Merit Review

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Approach Outline

Each task aims to reduce cost and weight to meet DOE 2010 targets:

- **Liner Development**
  - Materials study (H_2 compatibility; permeation; toughness)
  - Liner-Metal interface design (new design)
  - Investigation of mass-production methods (blow-molding)
- **Metal Fitting Development**
  - Metal fitting material investigation
  - Stress analysis
  - Liner-Metal interface redesign (new design)
- **Composite Design Optimization**
  - Manufacturing process evaluation
  - Further optimization of composite design to improve fiber translation[1] and reduce composite usage

[1] translation= reinforcing efficiency of carbon fibers

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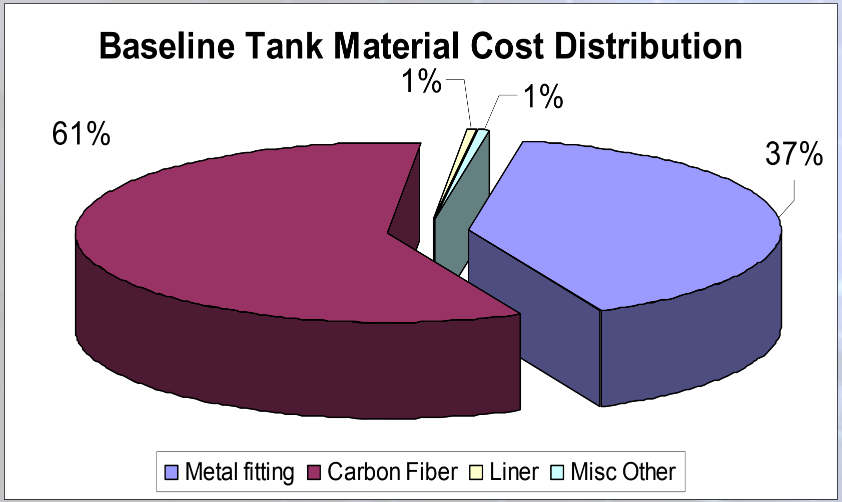
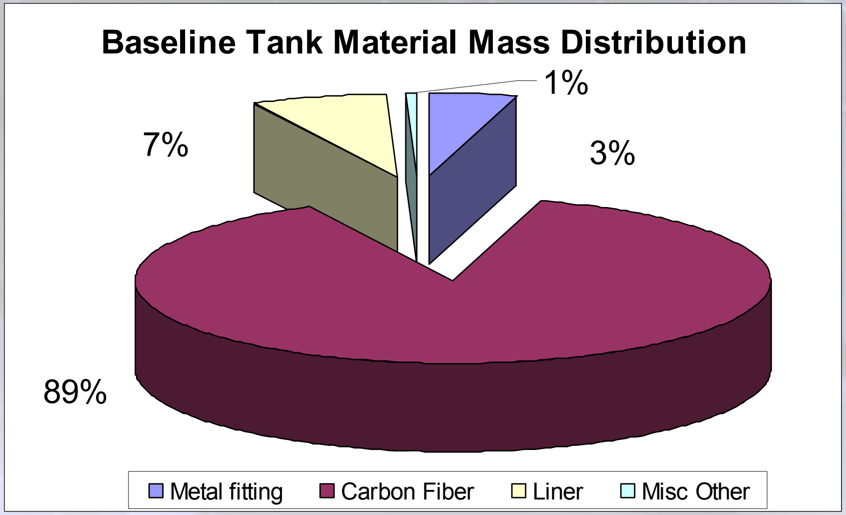
Accomplishments- Baseline

**Material Cost Distribution:
129L 70 MPa Tank (Baseline)**



**Material Weight Distribution:
129L 70 MPa Tank (Baseline)**



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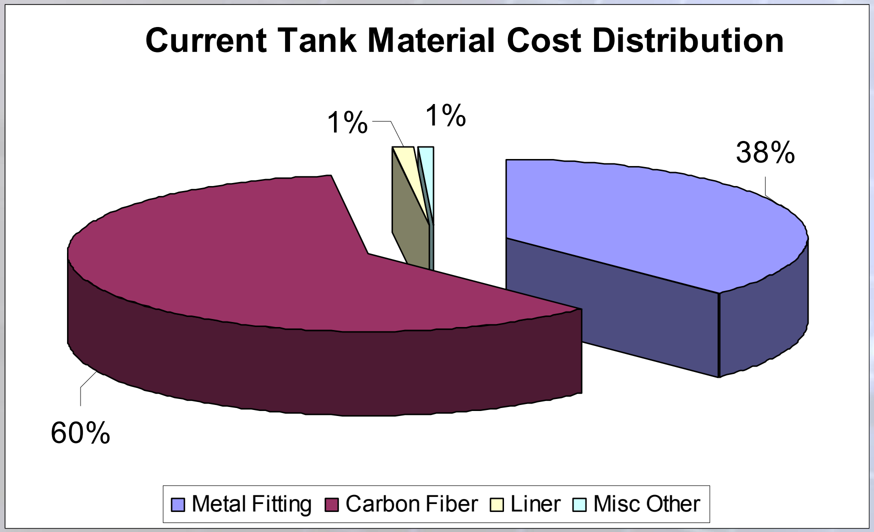
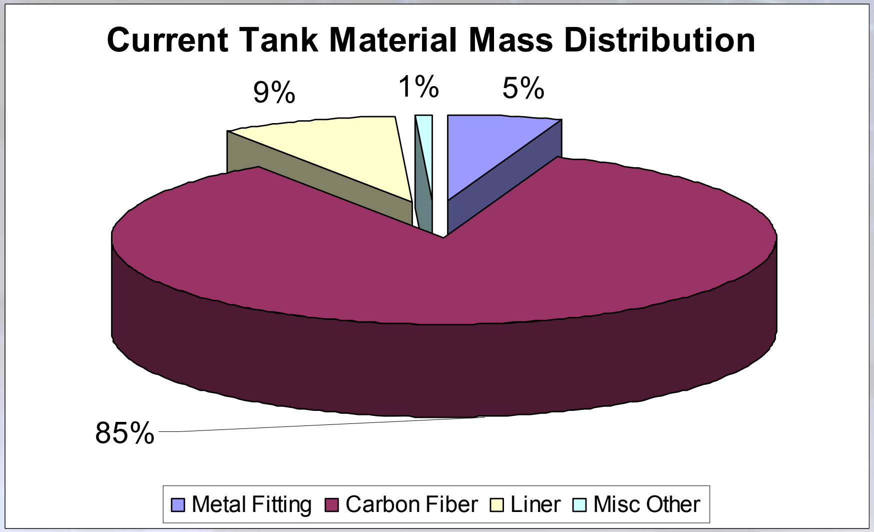
Accomplishments- Current

Material Cost Distribution: 129L 70 MPa Tank (2008)



Material Weight Distribution: 129L 70 MPa Tank (2008)



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Accomplishments- Current tank

Tank Nominal Capacity: 129 Liter, 5.6 kg H_2

Raw Material Cost (62% of baseline [previous version] tank):

Composite Usage (60%) + Liner (1%) + Metal Fittings (38%)

Tank Weight (80% of baseline [previous version] tank):

Composite Usage (85%) + Liner (9%) + Metal Fittings (5%)

Metal Fittings = Polar Boss + Adapter + Valve
Composite Usage = Carbon fiber + Resin matrix

Current Efficiency:
0.08 kWh/$: Energy / Cost
2.36 kWh/kg: Energy / Mass
1.72 kWh/L: Energy / Volume

2010 DOE targets:
System energy cost= 0.25kWh/$
System gravimetric capacity= 2.0kWh/kg
System volumetric capacity= 1.5kWh/L

Data based on current manufacturing cost/mass/volume for a **single** tank. There are no components in addition to what is listed above.

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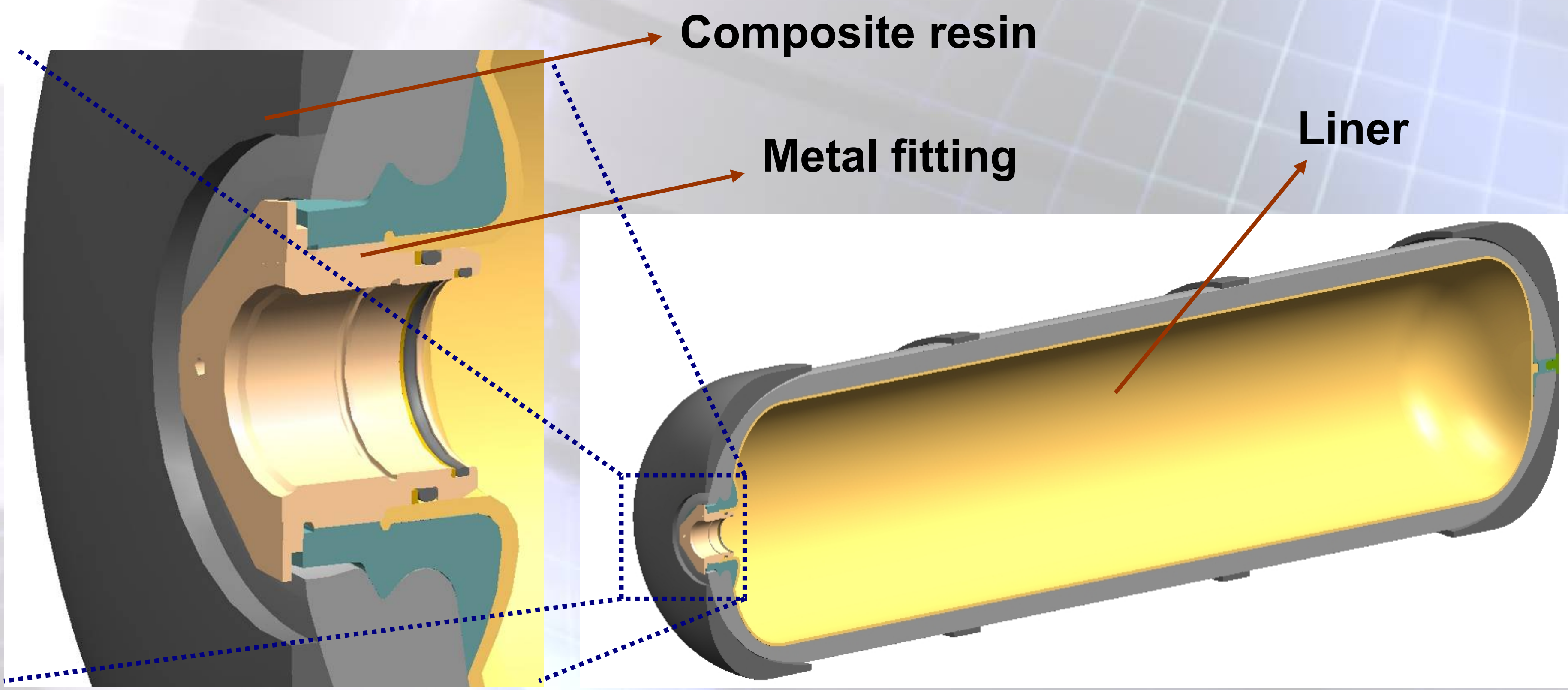
Accomplishments- Tank Cross-section



129L tank polar end close-up cross section

129L tank cross section

Technical Accomplishments: Liner Development

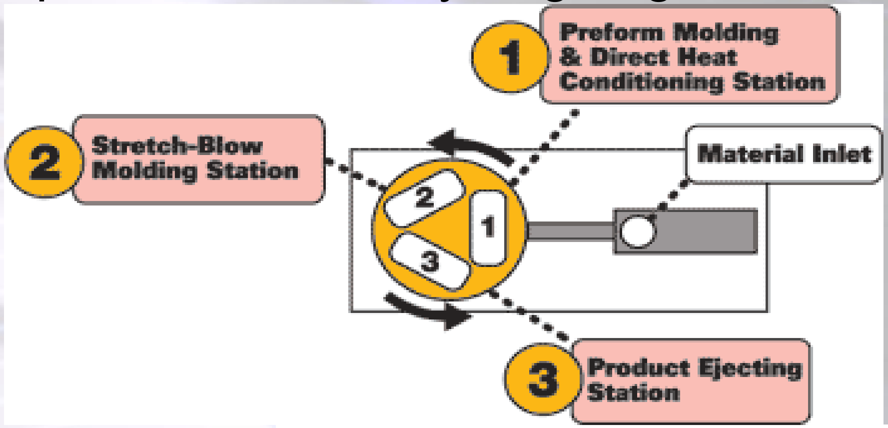
- Evaluated blow-molded plastics: HDPE, PET, PEN, POM, Multi-layered
  - Toughness
  - Tensile properties
  - Durability
  - Permeability
- Manufactured and evaluated plastic liners out of the 1st molding iteration according to EIHP standards: Pressure Cycle Fatigue, Permeation, Boss-Liner seal

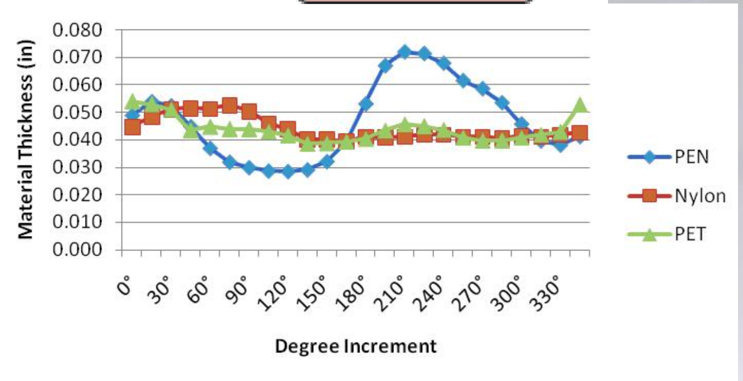
Technical Accomplishments: Metal Fittings

- Investigated different materials (literature review);
- Design development
  - Material choices:
    - Stainless steel
    - Aluminum alloys
  - Component elimination: new design= valve & boss only
  - Geometry reduction

Future Work: Liner Development

- Blow molding process iteration for improved:
  - toughness and fatigue resistance
  - heat resistance in the anneal process
  - thickness distribution
  - barrier performance to hydrogen gas





Future Work: Liner Development

- Liner interface design to metal fitting development: effective seal against→
  - pressure
  - temperature fluctuation
  - vibration
  - automotive fluid corrosion
  - torque applied during operation

Future Work: Metal Fitting Development

- Statistical evaluation of polar boss hydrogen compatible metals to reduce material costs

$$Y = \beta_0 + \beta_1 T + \beta_2 P + \beta_3 \sigma + \beta_4 t + \beta_5 TP + \beta_6 P\sigma + \beta_7 T\sigma + e$$

T: exposure temperature in H_2

P: pressure

σ: pre-stress level

t: charging time

TP, Tσ, Pσ: interaction terms

e: error

Target = 20% of current metal fitting cost; 50% weight savings vs. start-of-project value

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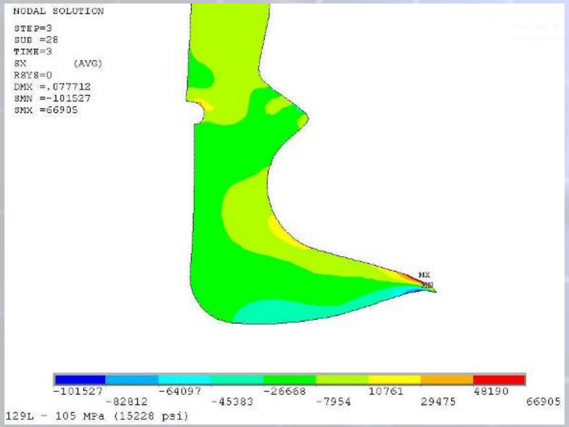
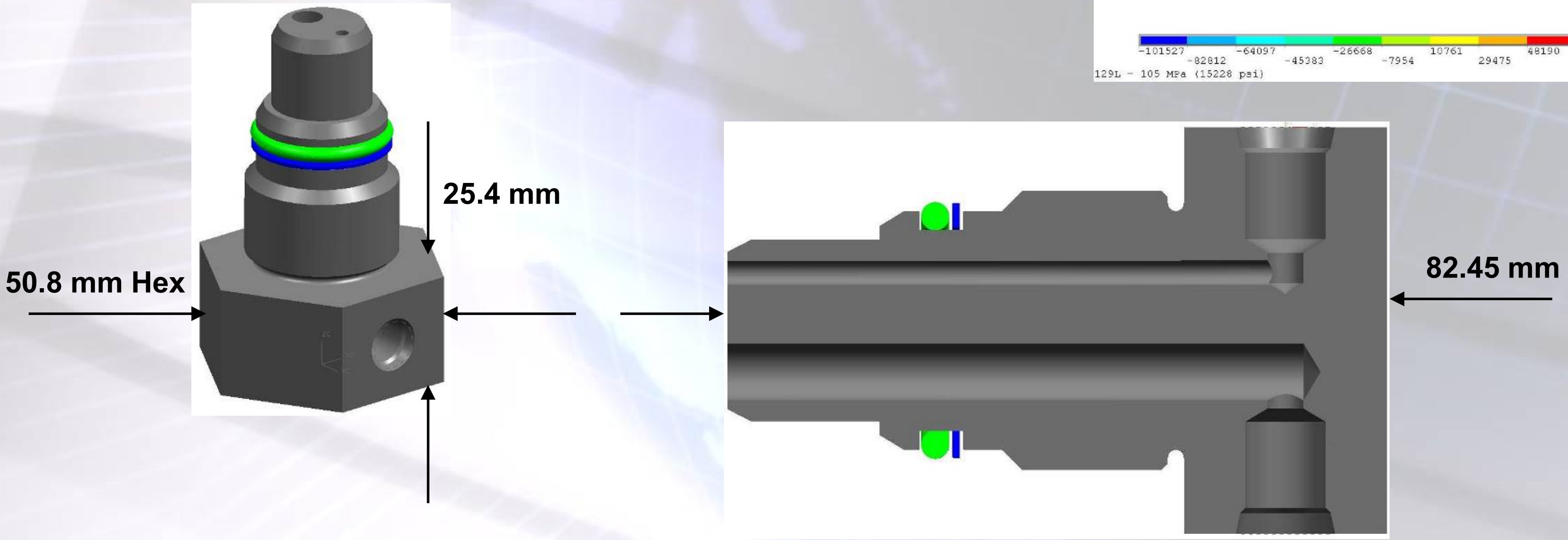
Future Work: Metal Fitting Development

- Design and evaluate the liner-metal interface, with the aim to eliminate the metal adapter & reduce part size
- Stress analysis through FEA
- Concurrent tank valve development





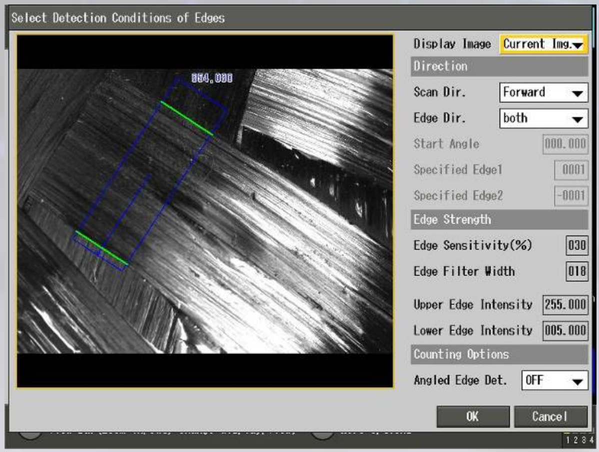
Future Work: Composite Optimization

- Composite translation efficiency improvement
  - Manufacturing process
  - Fiber lay-out
- Optimize fiber lay-out design and FEA stress analysis accuracy
  - Characterize the appropriate surface curvature to the software
  - Calculate the best surface fiber orientation with certain principal radii of curvature
  - Investigate the element types used in FEA

Future Work: Composite Optimization

- Evaluate the fiber translation efficiency effects on manufacturing parameters and optimize them correspondingly
  - Bandwidth and position distribution: balance between accuracy and winding speed
  - Balance between fiber tow tension and surface curvature to reach the desired compaction
  - Resin appropriate cure profile for less residual stress
  - Resin bath temperature control

Target= 25% reduction in composite usage vs. start-of-project value



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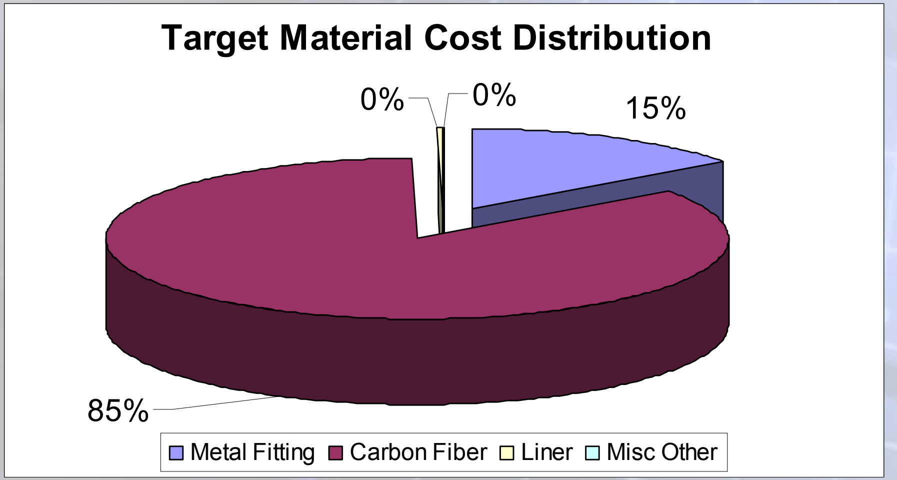
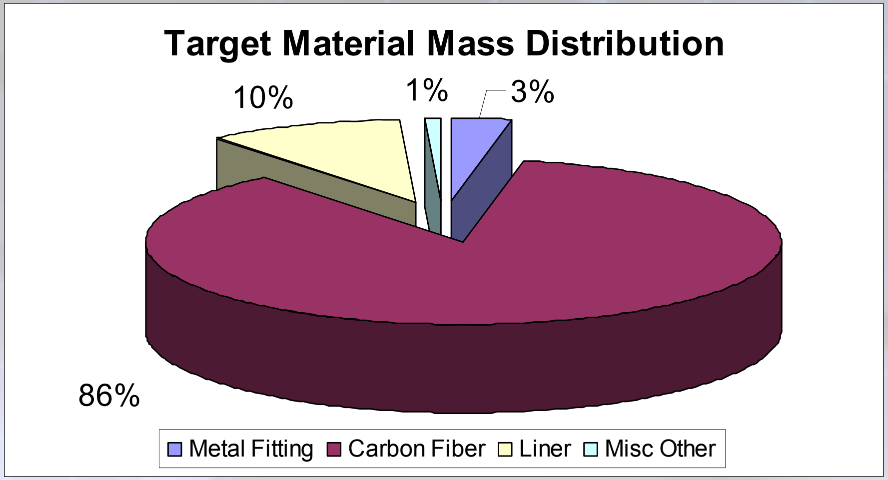
Future Work

Material Cost Distribution:
2010 Target 129L 70 MPa Tank



Material Weight Distribution:
2010 Target 129L 70 MPa Tank



Future Work

Tank Nominal Capacity: 129 Liter, 5.6 kg H_2

Raw Material Cost (44% of current version tank):

Composite Usage (85%) + Liner (0.3%) + Metal Fittings (15%)

Tank Weight (87% of current version tank):

Composite Usage (86%) + Liner (10%) + Metal Fittings (3%)

Metal Fittings = Polar Boss + Valve
Composite Usage = Carbon fiber + Resin matrix

Target Efficiency:
0.19 kWh/$: Energy / Cost
2.72 kWh/kg: Energy / Mass
1.72 kWh/L: Energy / Volume

2010 DOE targets:
System energy cost= 0.25kWh/$
System gravimetric capacity= 2.0kWh/kg
System volumetric capacity= 1.5kWh/L

Data based on DOE volume of 500k units/year for a **single** tank (metal fittings, composite & liner). There are no components in addition to the one tank for this specific project.

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Project Summary

Relevance	Optimization of current manufacturing processes for low cost H_2 storage vessels
Approach	Liner and metal fitting development Carbon fiber translation optimization
Proposed Work	Liner development (material & process) Metal fitting development (material and interface design) Carbon fiber manufacturing process design of experiment (optimization)

Project Progress

	Current	Target	DOE 2010 Goals
Cost	0.08 kWh/$	0.19 kWh/$	0.25kWh/$
Weight	2.36 kWh/kg	2.72 kWh/kg	2.0kWh/kg

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