2009 DOE Hydrogen Program
Low-Cost High-Efficiency High-Pressure H₂ 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%

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

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

### Partners
- None currently
Project Objectives- Relevance

Improve the cost and weight efficiency of Type IV compressed H₂ 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
## Milestones

<table>
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<tr>
<th>Month</th>
<th>Milestone</th>
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| 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                                                    |
Approach Outline

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

• **Liner Development**
  – Materials study (H\textsubscript{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\textsuperscript{1} and reduce composite usage

\textsuperscript{1} translation= reinforcing efficiency of carbon fibers
Accomplishments - Baseline

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

Material Weight Distribution: 129L 70 MPa Tank (Baseline)
Accomplishments - Current

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

Material Weight Distribution:
129L 70 MPa Tank (2008)
Accomplishments- Current tank

Tank Nominal Capacity: 129 Liter, 5.6 kg H₂

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.
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
- \( \sigma \): pre-stress level
- \( t \): charging time
- \( TP, T\sigma, P\sigma \): interaction terms
- \( e \): error

Target = 20% of current metal fitting cost; 50% weight savings vs. start-of-project value
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
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 H₂

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.
# Project Summary

<table>
<thead>
<tr>
<th>Relevance</th>
<th>Optimization of current manufacturing processes for low cost H₂ storage vessels</th>
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| 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

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<tr>
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<th>Current</th>
<th>Target</th>
<th>DOE 2010 Goals</th>
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<tbody>
<tr>
<td>Cost</td>
<td>0.08 kWh/$</td>
<td>0.19 kWh/$</td>
<td>0.25 kWh/$</td>
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