Development of Improved Composite Pressure Vessels for Hydrogen Storage

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Lincoln Composites
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Project ID#
ST047

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Overview

Timeline

• Start 1 Feb 2009
• End 30 Jun 2014
• 55% complete

Budget

• Project funding $1,781,251
  – DOE share $1,425,000
  – Contractor share $356,251
• FY11 = $ 54,156
• FY12 = $215,000
• Project funding was reduced as metal hydrides were removed from scope

Barriers

• Barriers addressed
  – A. System Weight and Volume
  – B. System Cost
  – G. Materials of Construction
• Targets (2017)
  – Gravimetric capacity > 5.5%
  – Volumetric capacity > 0.040 kg H₂/L
  – Storage system cost - TBD

Partners

• HSECoE
  SRNL, PNNL, LANL, JPL, NREL, UTRC, GM, Ford, LC, Oregon State Univ, UQTR, Univ of Michigan, Caltech, BASF
• Project lead = Don Anton, SRNL
Objectives - Relevance

• Meet DOE 2010 and 2017 Hydrogen Storage Goals for the storage system by identifying appropriate materials and design approaches for the composite container

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravimetric capacity</td>
<td>&gt; 4.5%</td>
<td>&gt; 5.5%</td>
</tr>
<tr>
<td>Volumetric capacity</td>
<td>&gt; 0.028 kg H₂/L</td>
<td>&gt; 0.040 kg H₂/L</td>
</tr>
<tr>
<td>Storage system cost</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

• Maintain durability, operability, and safety characteristics that already meet DOE guidelines for 2010 and 2017

• Work with HSECoe Partners to identify pressure vessel characteristics and opportunities for performance improvement, in support of system options selected by HSECoe Partners

• Develop high pressure tanks as required to:
  – Contain components and materials of the selected hydrogen storage system
  – Operate safely and effectively in the defined pressure and temperature range
Approach

• *Establish and document baseline* design, materials, and manufacturing process
• Evaluate potential improvements for design, material, and process to achieve cylinder performance improvements for weight, volume, and cost
• *Down select* most promising engineering concepts as applicable to HSECoE selected systems
• Evaluate design concepts and ability to meet Go/No-Go requirements for moving forward
• Document progress in periodic reports and support HSECoE Partner meetings and teleconferences
Phase 1 Approach

• Material evaluation for cost and weight reduction, internal volume increase
  – Projected cylinder improvements: 11% lower weight, 4% greater internal volume, 10% lower cost
    • Higher strength boss material confirmed (weight reduction ≈3%)
    • Alternate fiber reinforcements qualified (cost reduction ≈5%)
    • Reduced safety factors for carbon fiber selected (cost reduction ≈5%, weight reduction ≈4%, volume increase ≈2%)
    • Thinner liner designed (weight reduction ≈4%, volume increase ≈2%)

• Evaluate design and materials against operating requirements of storage systems selected by HSECoE Partners
  – Baseline design approach established
  – Liner material development is most significant issue

• Maintain durability, operability, and safety
Phase 2 Approach

• Confirm operating conditions
• Select baseline design and materials
• Evaluate alternate designs
• Evaluate alternate materials
  – Fiber, Resin, Liner
• Develop bench-top test vessel
Progress – Phase 2 Test Vessel Criteria

- Consensus input from HSECoE Partners:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Pressure</td>
<td>200 bar</td>
</tr>
<tr>
<td>Maximum operating pressure</td>
<td>250 bar</td>
</tr>
<tr>
<td>Minimum operating pressure</td>
<td>Vacuum, &lt; 1e-5 torr</td>
</tr>
<tr>
<td>Internal liquid volume</td>
<td>~6 Liters</td>
</tr>
<tr>
<td>Internal Liner ID</td>
<td>16.6 cm (6.54 inches)</td>
</tr>
<tr>
<td>Vessel OD</td>
<td>2:1 aspect ratio for a 6 Liter tank</td>
</tr>
<tr>
<td>Temperature range</td>
<td>20°K to 373°K</td>
</tr>
</tbody>
</table>
Progress - Test vessel design

• Baseline dimensions
  – ID = 166 mm (6.54 inches)
  – OD (Liner) = 174 mm (6.84 inches)
  – OD (Tank) = 183 mm (7.18 inches)
  – OAL = 372 mm (14.64 inches)
  – Boss opening = 60.7 mm (2.39 inches)
  – Volume = 5.68 liters

• Baseline construction
  – Fiber = T700
  – Resin = epoxy
  – Liner = HDPE
  – Bosses = 6061 Aluminum

• Phase 2 bench-top test vessel will be “heavyweight” for enhanced safety in lab setting
• Alternate all-metal and metal lined composite designs also prepared
Progress - Test vessel analysis

Analysis of Optimized PV, VOLUME = 399.751392 cu.in
Progress - Test vessel fabrication

• 21 vessels have been fabricated
  – 3 burst to confirm strength
  – 3 used for cryo and leak testing
  – 15 available to HSECoE team members now
  – Additional tanks will be fabricated as needed for team members

• Next steps
  – Document cryo handling procedures
  – Further performance characterization
    • Strength
    • Fatigue
    • Impact
Progress – Test Vessel Use

• Lincoln Composites will supply Type 4 test vessels to HSECoE partners to support development and testing of prototype systems
  – Distribution in April
  – End closures provided
  – Cryo-seals provided

• Common test vessel will save time and cost for project
Progress - Liner material investigation

• Tensile Impacts of
  – HDPE (baseline)
  – Modified EVOH
  – HDPE with nano-additives
  – PA
  – PTFE

• Dog-bone samples
• ~2.5 m/s
• Energy of impact provides relative values only
• Of materials tested, HDPE has best cold/cryo properties (tested to 144ºK)
Progress - Fiber materials

• T700 is baseline reinforcing fiber
  – Alternate fibers are of similar strength
  – Slight loss in strength at cryogenic temperatures

• Prototype tank will be cryo-burst
  – JPL is coordinating test
  – Tank will be holding some pressure while cooling to liquid nitrogen temperature
  – Tank will be burst with liquid nitrogen
Progress - Resin materials

• Epoxy resins have been used successfully at cryogenic temperatures

• Tensile testing confirms performance
  – Tensile strength within 5%
  – Elongation within 30%

• Resin tougheners will be evaluated

• Alternate resin materials will be considered
Progress – Cold vessel testing

- Existing vessel design, baseline materials
  - 15 x 66 in (380 x 1680 mm) 3000 psi (205 bar)
  - Start at 1000 psi (68 bar) internal pressure at 21 °C
- Insulated box with circulating fans
- Thermocouples on inside and outside of composite
- Temperatures (min achieved)
  - Liner 108 °K (-165 °C)
  - Outside composite dome 108 °K (-165 °C)
  - Outside composite cylinder 77 °K (-196 °C)
- Two cylinders - two cycles each
- No effect on room temperature burst properties.
  - 9253 psi & 9077 psi
  - Configuration nominal is 8978 psi, min required 8021 psi
Future Work - Planned Tasks

• Insulation evaluation
• Permeation and outgassing at temperature
• Evaluate contaminants
• Evaluate installation of components and sorbent contents
• Evaluate pressure relief devices
• Evaluate qualification test requirements
• Report on ability to develop Type 4 and Type1 tanks for Phase 3
Future Work – Tank Type Issues

• Type 4 tank is lightest weight, Type 1 is heaviest
• Type 1 tanks are less expensive than Type 3 and Type 4
• At lower pressures, and resultant thinner walls, Type 3 and Type 4 tanks may need additional reinforcement for durability
• Some steel materials and polymer materials are brittle at low temperatures, aluminum and composite are less affected
• Thermal coefficient of expansion differences between different materials must be considered
Accomplishments

• Phase 1 improvements can be incorporated into Phases 2 & 3
  – 11% lower weight, 4% greater volume, 10% lower cost

• Phase 2 test vessel has been designed and manufactured
  – Team consensus on vessel requirements
  – Analysis and burst testing confirms design and safety

• Cryogenic testing of liner and fiber materials to confirm selection and properties
Collaborations

• Monthly teleconferences with PNNL and team on pressure vessels and containment
• Monthly teleconferences with adsorbant team
• Monthly HSECoE Coordinating Council telecons
• Face to Face Meetings with HSECoE Team
  – May 9, 2011, Washington, DC
  – Oct 11-13, 2011, Santa Fe, NM
• Tech Team Review Meeting February 15-16, 2012, Southfield, MI
Summary

• Design, material and process improvements have been identified that support efforts to meet DOE 2010 and 2017 goals for the storage system

• Identified improvements to date for cylinder provide:
  • 11% lower weight
  • 4% larger internal volume
  • 10% lower cost

• Phase 2 test vessel requirements established, test vessels have been manufactured for use by HSECoe Partners