Development of Improved Composite Pressure Vessels for Hydrogen Storage

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Project ID# ST047

Overview

Timeline

- Start 1 Feb 2009
- End 31 Jan 2014
- 50% complete

Budget

- Project funding $2,000,000
  - DOE share $1,600,000
  - Contractor share $400,000
- FY10 = $250,000
- FY11 = $150,000

Barriers

- Barriers addressed
  - A. System Weight and Volume
  - B. System Cost
  - G. Materials of Construction
- Targets (2010)
  - Gravimetric capacity > 4.5%
  - Volumetric capacity > 0.045 kg H_2/L
  - Storage system cost - TBD

Partners

- HSECoE HSECoE

  SRNL, PNNL, LANL, JPL, NREL, UTRC, GM, Ford, LC, Oregon State Univ, UQTR
- Project lead = Don Anton, SRNL SRNL

Pacific Northwest National Laboratory, Los Alamos National Laboratory, JPL, NREL National Renewable Energy Laboratory, United Technologies Research Center, GM, Ford, Lincoln Composites, OSU Oregon State University, UQTR

Objectives - Relevance

- Meet DOE 2010 and 2015 Hydrogen Storage Goals for the storage system by identifying appropriate materials and design approaches for the composite container

	2010	**2015**
Gravimetric capacity	> 4.5%	> 5.5%
Volumetric capacity	> 0.028 kg H_2/L	> 0.040 kg H_2/L
Storage system cost	TBD	TBD

- Maintain durability, operability, and safety characteristics that already meet DOE guidelines for 2010 and 2015
- Work with HSECoE Partners to identify pressure vessel characteristics and opportunities for performance improvement, in support of support of system options selected by HSECoE Partners
- Develop high pressure tanks as are required to:
  - Enable hybrid tank approaches to meet weight and volume goals
  - Allow metal hydrides with slow charging kinetics to meet charging goals

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Phase 1 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

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Phase 1 Approach

- Material evaluation for cost and weight reduction, internal volume increase
  - Higher strength boss materials
  - Alternate fiber reinforcements
  - Reduced safety factors
  - Thinner liner
- Evaluate design and materials against operating requirements of storage systems selected by HSECoE Partners
  - Identify new solutions
  - Identify gaps for further development
- Maintain durability, operability, and safety

Progress – Baseline Design/Materials

- Design
  - Fiber reinforced composite
  - Plastic liner /permeation barrier
  - Metallic end bosses

- Materials
  - T-700 Carbon fiber
  - Epoxy resin
  - HDPE liner
  - AA 6061-T6 bosses

Service pressure	5000 psi	345 bar
Gas settling temperature	59 °F	15 °C
Maximum fill pressure	6500 psi	448 bar
Service life	20 years	
Gas fill temperature limits	-40 to +149 °F	-40 to +65 °C
Operating temperature limits	-40 to +180 °F	-40 to + 82 °C
Proof test pressure	7500 psi	517 bar
Minimum rupture pressure	11,700 psi	807 bar
Cylinder external diameter	21.4 inches	543 mm
Cylinder length at zero pressure	63 inches	1600 mm
Cylinder length at maximum fill pressure	63.34 inches	1609 mm
Cylinder empty weight	231 lbs	105 kg
Cylinder volume at zero pressure	15,865 cu. in.	260 L
Cylinder volume at service pressure	16,132 cu. in.	264.4 L
Cylinder internal diameter	19.2 inches	488 mm

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Progress - Alternate Boss Material

- Baseline is 6061-T6 Aluminum
  - 316 Stainless Steel is another common material, used at higher pressures
  - Yield strength is not high for 6061-T6 or 316 SS
  - Stainless steel is significantly heavier and more expensive, but has better tensile strength and fatigue properties
- Investigating 7075 Aluminum to reduce weight and cost
  - High strength would allow reduction in boss size and allow aluminum use at high pressures
  - Proper heat treat is a challenge to get correct strength properties, avoid embrittlement
- Accomplishments
  - Near net shaped bosses machined from 7075-T6 Aluminum
  - Bosses have been heat treated to intended condition
  - Tensile testing confirms proper heat treatment

- Benefits
  - Yield strength is 2 times that of 6061-T6 or 316 SS
  - Weight of finished boss could be about 1/2 that of 6061-T6, 1/5 that of 316 SS
  - Cost of finished boss could be same to 1.5 times that of 6061-T6, 1/5 that of 316 SS

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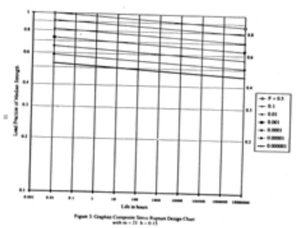
Progress - Alternative Fibers

- Baseline Fiber – T-700
  - PAN based
  - Excellent manufacturability
- Five alternate carbon fibers tested
  - Two indicated higher strength than baseline
  - Four potentially lower cost per pound
  - Initial testing did not meet expectations, strength/cost did not indicate improvement
- LC worked with two fiber suppliers to obtain improved strength
  - Subsequent testing with these fibers matched the baseline strength in burst test
  - Three fibers now could be used interchangeably
- Benefits of multiple qualified vendors
  - Expected to result in 10% to 15% lower fiber costs
  - Improved availability in times of fiber shortage

Progress – Reduced Safety Factor

- Safety factor influences performance
  - Fiber stress rupture and cyclic fatigue are directly related to stress ratio
  - Damage tolerance is affected
- Reduction in safety factor from 2.25 to 2.00 is planned
  - Studies indicate that high reliability is maintained
  - Field experience indicates safe operation as long as damage tolerance is addressed
  - Damage tolerance can be addressed by other design and testing
- Benefits of reduced safety factor
  - Cost of carbon fiber is reduced by about 10%
  - Potential for increased cylinder volume by about 2%
  - Potential for weight reduction by about 5%
  - Must be balanced against cost, envelope, and weight of other means of damage protection, if necessary



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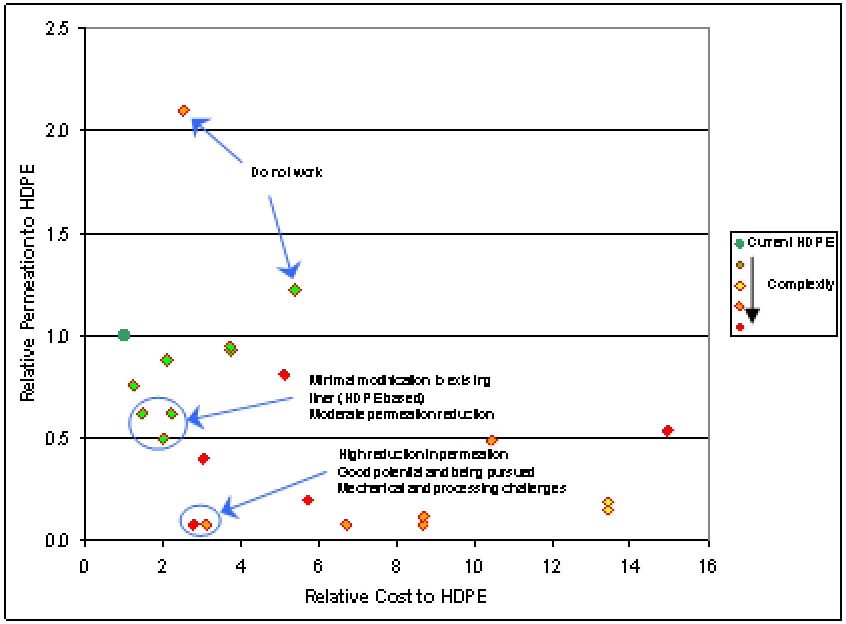
Progress – Thinner Liner

- Liner serves as a permeation barrier and winding mandrel
  - Permeation reduction is being investigated, 40% reduction currently feasible
  - Manufacturability issues with using a thinner liner (i.e. winding mandrel) are being addressed
- Benefits of thinner liner
  - Reduction in tare weight, about 4% of cylinder
  - Increase in internal volume, about 2%
  - Potential for reduction in cost, depending on cost of new liner materials

Progress – Thinner Liner

Alternate Liner Material Permeation versus Cost

- HDPE is baseline (1,1)
- Comparison of relative cost and permeation rates
- HDPE fillers show 40% reduction with limited cost increase
- Alternate materials show promise of significant permeation reduction
- Some alternate materials are prohibitively expensive



Future Work

- Alternate boss material
  - Incorporate 7075 aluminum into new designs
- Alternate fibers
  - Continue to monitor strength levels of top 3 fibers
- Reduced safety factor
  - Continue to evaluate damage tolerance of alternate fibers
  - Continue to evaluate improved damage tolerance using toughened epoxy resins
- Thinner liner
  - Continue to evaluate permeation reduction
    - Testing of full cylinders
    - Testing of additional liner materials
- Evaluate producibility of new liner materials

Future Work – Phase 2

- Support cylinder design activity of HSECoE team for baseline systems
- Define materials and demonstrate liner and resin matrix suitability for extreme high and low temperatures expected for baseline systems
  - Candidates exist for high temperature resin and liner
  - Candidates exist for low temperature resin
  - Low temperature liner is being investigated
- Provide means to incorporate hardware identified for selected designs
  - Internal and external insulation
  - Heat transfer hardware

Accomplishments

- Higher strength aluminum boss material confirmed
  - Lighter weight
- Alternate fibers qualified
  - Reduces cost, improves availability
- Reduced safety factor selected for carbon fiber
  - Reduces cost, weight
- Permeation reduced by 40%
  - Allows thinner wall, lighter weight
- 3 Face to Face Meetings with HSECoE Team in 2010
- Tech Team Review Meeting February 16-17, 2011, Washington, DC

Collaborations

- Periodic teleconferences with PNNL and team on pressure vessels and containment
- Periodic teleconferences with UTRC and team on IPPSS Modeling
- Periodic teleconferences with GM supporting storage system modeling
- Working with aerospace industry colleagues regarding stress rupture, including NASA, JPL
- Pressure vessel and containment group meeting was held at LC in November 2010
- Co-authored paper/presentation, *"Potential Diffusion-Based Failure Modes of Hydrogen Storage Vessels for ON-Board Vehicular Use"*, Yehia Khalil (UTRC), Norman Newhouse (LC), Kevin Simmons (PNNL), Daniel Dedrick (SNL) , *at AIChE 2010 Annual Meeting, Salt Lake City, November 2010*

Summary

- Design, material and process improvements have been identified that support efforts to meet DOE 2010 and 2015 goals for the storage system
- Identified improvements to date include
  - Reduced cost and weight from improved boss material
  - Reduced fiber cost by developing alternate fibers of equal strength
  - Reduced cost, potential reduced weight and increased volume, by reducing carbon fiber factor of safety
  - Reduced weight, increased volume, by reducing liner thickness
- Specific value of improvements is dependent on overall system design
  - For cylinder itself, approximately 11% lower weight, 4% larger internal volume, 10% lower cost
  - For total system, influence of other components is needed