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Hydrogen Storage Engineering

CENTER OF EXCELLENCE

Development of Improved Composite Pressure Vessels for Hydrogen Storage

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Lincoln Composites

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Project ID# ST047

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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 H_2/L
  - Storage system cost - TBD

Partners

- HSECoE 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

	2010	**2017**
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 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

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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
  - 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

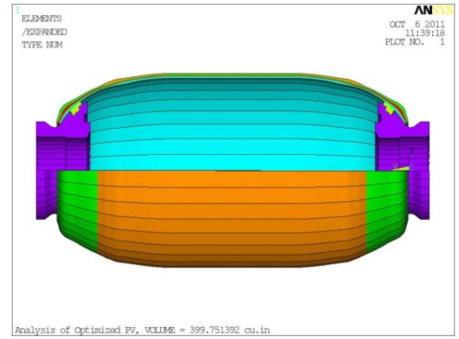
- Confirm operating conditions
- Select baseline design and materials
- Evaluate alternate designs
- Evaluate alternate materials
  - Fiber, Resin, Liner
- Develop bench-top test vessel

Progress – Phase 2 Test Vessel Criteria

- Consensus input from HSECoE Partners:

Dimension	Value
Design Pressure	200 bar
Maximum operating pressure	250 bar
Minimum operating pressure	Vacuum, < 1e-5 torr
Internal liquid volume (dimensional priority)	~6 Liters
Internal Liner ID	16.6 cm (6.54 inches)
Vessel OD	2:1 aspect ratio for a 6 Liter tank
Temperature range	20ºK to 373ºK

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

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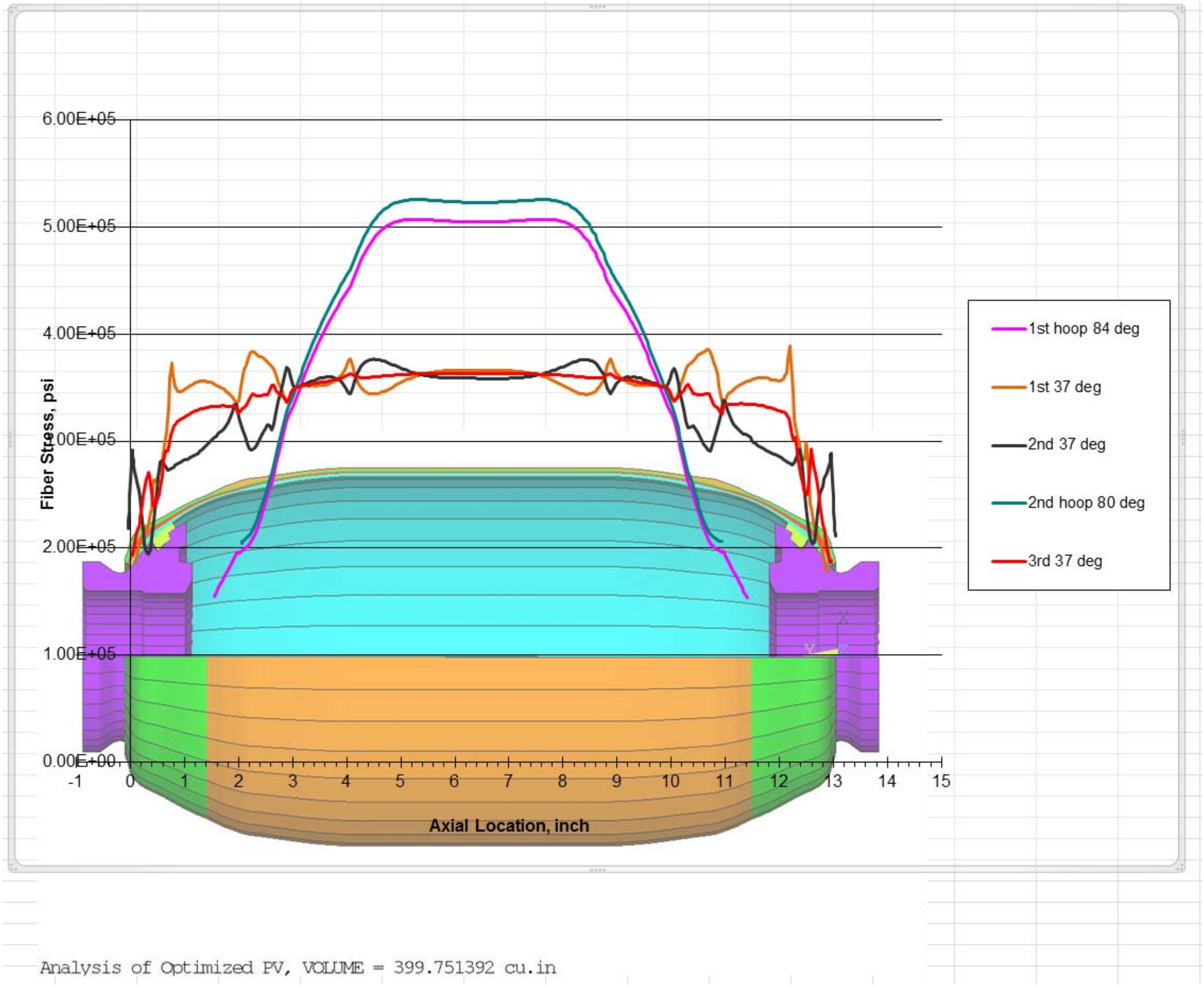
Progress - Test vessel analysis



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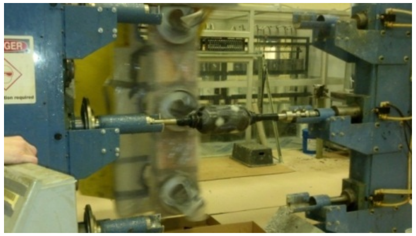
Progress - Test vessel fabrication

- 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



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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

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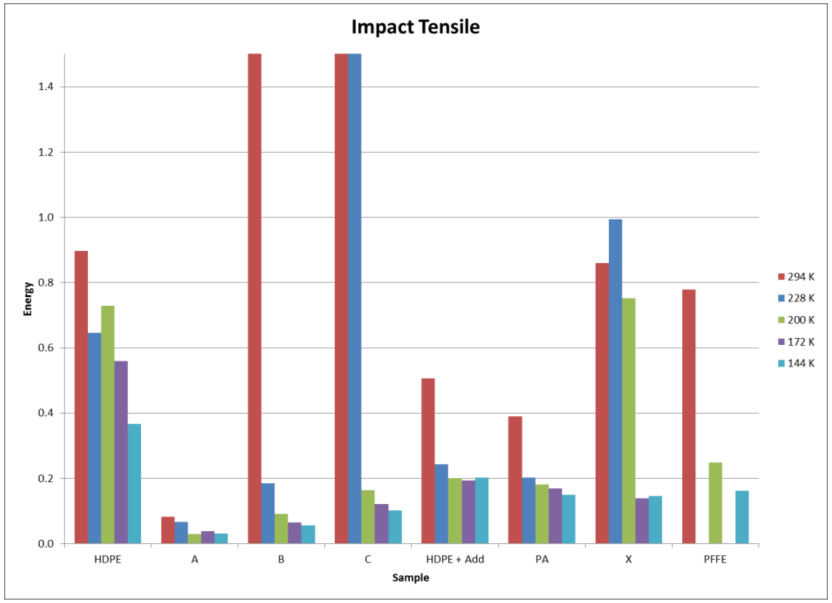
Progress - Liner material investigation

- 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)



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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