IV.F.4 Synergistically Enhanced Materials and Design Parameters for Reducing the Cost of Hydrogen Storage Tanks

Kevin L. Simmons (Primary Contact),
Kenneth Johnson, and Kyle Alvine
Pacific Northwest National Laboratory (PNNL)
902 Battelle Blvd
Richland, WA 99352
Phone: (509) 375-3651
Email: Kevin.Simmons@pnnl.gov

Norman Newhouse (Lincoln Composites, Inc.),
Mike Veenstra (Ford Motor Company),
Anand V. Rau (TORAY Carbon Fibers America) and
Thomas Steinhausler (AOC, L.L.C.)

DOE Managers
HQ: Ned Stetson
Phone: (202) 586-9995
Email: Ned.Stetson@ee.doe.gov

GO: Jesse Adams
Phone: (720) 356-1421
Email: Jesse.Adams@go.doe.gov

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Fiscal Year (FY) 2012 Objectives

Our objective is to reduce carbon fiber (CF) usage and associated tank cost through a series of combined material and design synergistic approaches whose total contribution is estimated to be nearly 37% in overall cost savings. It is probable that these cost savings, combined with future reductions in CF cost could lead to the 50% DOE target. The project will take a holistic approach to improve performance by modifying the operating envelope down to the composite constituent level. As such, the project team includes industry experts in each of the following focus areas of improvement: enhanced operating conditions to improve energy density/pressure ratios, load translational efficiency improvements by CF surface modification, resin matrix modifications and alternatives, and alternate fiber placement and materials. We expect these savings approaches to be compatible and additive.

Technical Barriers

This project addresses the following technical barriers from the Storage section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

General to All Storage Approaches

(A) System Weight and Volume
(B) System Cost
(D) Durability/Operability
(G) Materials of Construction
(H) Balance of Plant (BOP) Components

Technical Targets

Combining new tank design at enhanced operating conditions and more efficient use of CF through new materials and lower cost materials is estimated to save 37% of overall tank cost compared to a standard Type-IV, 700-bar tank. These cost savings, combined with future reductions in CF costs, should result in the 50% DOE target. Specifically the approaches are (A) enhanced operating conditions to improve energy density/pressure ratios; (B) load translational efficiency improvements through CF surface modification and resin matrix modifications and resin alternatives; and (C) improved CF use efficiency through advanced fiber placement and the use of alternate fibers. We expect the cost savings to be generated by offsetting CF usage as follows: (A) 25%, (B) 20%, (C) 10%, for a combined savings (assuming multiplicative) of ~46% of the CF cost or a savings of ~37% of the overall tank cost.

FY 2012 Accomplishments

- Developed baseline cost model of 350- and 700-bar 5.6-kg hydrogen pressure vessel
- Developed fiber surface treatments for testing with low-cost resin systems
- Identified three low-cost resin systems for testing composite performance
- Identified initial temperature and pressure operating conditions for tank design
- Established test protocol for comparing material property improvements

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Introduction

The goal of this research is to reduce the cost of 350- and 700-bar compressed gas hydrogen storage vessels by at least 50% from the current high volume projections of \$15.4/kWh to \$6/kWh for commercialization in early market and light-duty hydrogen fuel cell vehicles. This will be done by developing enhanced materials and manufacturing methods to reduce the cost of hydrogen storage tanks. The baselines for cost and performance comparisons are the current 350- and 700-bar, high-pressure storage vessels primarily constructed of standard-modulus, high-strength CF in an epoxy matrix that is overwrapped on a metallic or polymeric liner, which are classified as Type-III and Type-IV tanks, respectively. The use of high-strength CF composite accounts for nearly 80% of the overall tank costs.

Our objective is to reduce CF usage and associated tank cost through a series of combined material and design synergistic approaches whose total contribution is estimated to be nearly 37% in overall cost savings. It is probable that these cost savings, combined with future reductions in CF cost could lead to the 50% DOE target. The project will take a holistic approach to improve performance by modifying the operating envelope down to the composite constituent level. As such, the project team includes industry experts in each of the following focus areas of improvement: (A) enhanced operating conditions to improve energy density/pressure ratios, led by Ford Motor Company (Ford); (B.1) load translational efficiency improvements by CF surface modification, led by Toray and (B.2) resin matrix modifications and alternatives, led by Pacific Northwest National Laboratory (PNNL) and AOC; and (C) alternate fiber placement and materials, led by Lincoln Composites (Lincoln). We expect the cost savings to be generated by offsetting CF usage as follows: (A) 25%, (B) 20%, and (C) 10%, for a combined savings (assuming multiplicative combination) of ~46% of the CF cost or a savings of ~37% of the overall tank cost. We expect these savings approaches to be compatible and additive.

Improvements in CF composites and other fiber/resin systems gained in this project will have synergistic benefits for other industries and applications beyond high-pressure hydrogen storage tanks. Applications of high-strength fiber/resin composites in other industries include advanced turbine blades for wind energy, aerospace composites, light-weight automobile components, and other pressure-vessel applications. Each of these industries will benefit from advances in the areas of lower-cost and higher-strength composites. Other benefits may include the expansion of the low-cost or higher-strength resin to glass or other alternative fiber applications and a broader market for higher-strength CF through surface modification.

Approach

The project consists of improving specific important properties of the constituent materials to synergistically improve the overall performance of the composite. This will reduce the material needed and optimize the use of alternate lower cost materials. The initial phase focuses on each key property in the tank materials, starting with specifying the operating conditions of the tank that can maximize energy storage down to the specific critical properties where improvements can have the greatest gain in tank performance. The second phase will progressively combine the individual material improvements into lamina structures that can be used to optimize the tank structure design. Upon successful demonstration of improvements in each task, the modeling of the new improved property will be compared to the initial modeling effort to demonstrate how the effect changes the overall cost and performance. The project will then integrate the new materials and material systems into a sub-scale prototype that will be designed and constructed at Lincoln.

At the conclusion of the project, PNNL and its partners will have built and tested a sub-scale prototype pressure vessel. A second prototype will be delivered to DOE for independent testing and verification of its performance and improvement. A final report detailing the unique improvements in performance and the outcome of the cost analysis will be completed.

Results

Enhanced Operating Conditions

The enhanced operating conditions task within this quarter conducted a literature search of previous concepts that have considered cold gas (200 K) as an onboard hydrogen storage option. In addition, well-to-wheels analyses for the cold gas concept were examined based on prior studies using the DOE models such as H2A and the Hydrogen Delivery Scenario Analysis Model. The tank requirement document was discussed but needs to be further developed based on the baseline cost analysis and projections.

Low-Cost Resins and Resin Matrix Modifications

AOC has identified three resin systems for the team to initiate their research. The resin properties were selected based on typical epoxy properties and with variations of high and low elongations for toughness. The data from these studies will further guide AOC with additional resin changes that will be optimal for fiber and filler materials.

Two materials have been received for modifying the resin. The first material is a nanoclay with amine surface modifications and the second is a silicate nanofiber that has just become commercially available. Safety protocols are being developed for handling the materials.

CF Surface Modifications

Toray has developed several surface treatments for T700 that are being tested with the AOC resin sources. Short-beam shear tests specimens are being fabricated and prepped for testing.

Cost Analysis

The Argonne National Laboratory/TIAX baseline 350-bar, 258 L, L/D=3 Type-IV tank provides a good baseline to what was done before. It also corresponds to 5.6 kg of usable hydrogen, which is the DOE standard of comparison. Another considerations is a standard Lincoln Composites product that is a 350-bar, 200 L tank with outside diameter of 16 inches.

A spreadsheet was developed for comparing tanks at different operating conditions. The spreadsheet estimates the tank volume, weight, and cost of tank materials based on netting analysis and the reported lamina strength for T700S fibers. The spreadsheet is improved over the simple netting analysis formula for the thick-walled geometry effect and the difference in elastic modulus inline and transverse to the fibers. The spreadsheet calculates those effects to estimate the translation factor and increase the hoop strain at the inside wall, which increases the lamina stresses in the hoop and helical fibers at the inside surface. With user input for the desired inside radius and length of the cylindrical section, the lamina strength, fiber and matrix moduli, safety factor, coefficient of variation, etc. The user can then modify the layer thicknesses and angles (two helical plus hoop layers) in the model until the thick-wall stresses are slightly less than the allowable lamina stress. Currently it assumes spherical dome ends, but a solution for the iso-tensoid dome shape is under consideration to improve the model for additional variations. Other factors could be applied to account for the extra composite needed to pass drop, ballistic, and fire tests.

Conclusions and Future Directions

- New vinylester resin compounds to replace more expensive epoxy systems.
- Development of new sizing on carbon fiber for vinylester resin systems.
- Enhanced vinylester resin properties utilizing nanoclays and silicate nanofibers for improved load transfer in through thickness of the composite.
- Cost analysis:
  - Complete baseline model.
  - Compare material property changes and their effects on tank costs.
- Cost analysis being combined with vessel design models.

Future work for FY 2013:

- Combining new improvements to resin and combining with surface treated carbon fiber for filament winding and tank testing.
- Development of tank fiber placement.
- Cost analysis:
  - Update analysis with new material properties and design.

FY 2012 Publications/Presentations

Presentations

1. Simmons K., M Veenstra, D Houston, N Newhouse, M Dettre, T Steinhausler, K Johnson, K Alvine 2012. "Project Kickoff for Low Cost Manufacturing of Hydrogen Storage Pressure Vessels." Presented by Kevin Simmons and team members (Invited Speaker) Golden, CO on February 1, 2012.

2. Simmons K., M Veenstra, D Houston, N Newhouse, M Dettre, T Steinhausler, K Johnson, K Alvine 2012. "Annual Merit Review for Low Cost Manufacturing of Hydrogen Storage Pressure Vessels." Poster Presented by Kevin Simmons and team members Arlington, VA on April 16, 2012.