III.8 Development of High Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery

Jon Knudsen (Primary Contact), Don Baldwin
Lincoln Composites
5117 N.W. 40th Street
Lincoln, NE 68524
Phone: (402) 470-5039
E-mail: jknudsen@lincolncomposites.com

DOE Technology Development Manager:
Monterey Gardiner
Phone: (202) 586-1758
E-mail: Monterey.Gardiner@ee.doe.gov

DOE Project Officer: Paul Bakke
Phone: (303) 275-4916
E-mail: Paul.Bakke@go.doe.gov

Contract Number: DE-FG36-08GO18062

Project Start Date: July 1, 2008
Project End Date: June 1, 2011

Objectives

The objective of this project is to design and develop the most effective bulk hauling and storage solution for hydrogen in terms of:

- Cost
- Safety
- Weight
- Volumetric Efficiency

Technical Barriers

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

(G) Storage Tank Materials and Costs

Technical Targets

This project has focused primarily on the design and qualification of a 3,600 psi pressure vessel and International Organization for Standardization (ISO) frame system to yield a storage capacity solution of approximately 8,500 liters of water. Second phase is to perform and qualify same size container at higher pressures.

Accomplishments

- Successful completion of design and qualification of a 3,600 psi pressure vessel.
  - Qualification testing included:
    - Hydrostatic Burst
    - Ambient Pressure Cycle Test
    - Leak Before Burst Test
    - Penetration Test
    - Environmental Test
    - Flaw Tolerance Test
    - High Temperature Creep Test
    - Accelerated Stress Rupture Test
    - Extreme Temperature Cycle Test
    - Natural Gas Cycle Test with Blow-down
- Successful completion of design and qualification of an ISO frame capable of holding four 3,600 psi pressure vessels with a combined capacity of 600 kg of hydrogen. In addition to the structure, a system for loading, unloading, and pressure relief have been designed and implemented.
  - Qualification testing included:
    - Stress Analysis
    - Dimensional Analysis
    - Stacking
    - Lifting – Top and Bottom
    - Inertia Testing

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Storage

Characteristic	2010 Target	2015 Target	Status	Comments
Storage Costs	\$500/kg	\$300/kg	\$675-\$750/kg	5,000 psi tank is expected to lower the cost
Volumetric Capacity	0.030 kg/liter	0.035 kg/liter	0.018 kg/liter	Estimated: 5,000 psi => 0.024 kg/liter 8,300 psi => 0.035 kg/liter
Delivery Capacity, Trailer	700 kg	1,100 kg	600 kg	Estimated: 5,000 psi => 800 kg 8,300 psi => 1,150 kg

- Impact Testing
- Bonfire Testing

Introduction

Hydrogen holds the long-term potential to solve two critical problems related to energy use: energy security and climate control. The U.S. transportation sector is almost completely reliant on petroleum, over half of which is currently imported, and tailpipe emissions remain one of the country's key air quality concerns. Fuel cell vehicles operating on hydrogen produced from domestically available resources would dramatically decrease greenhouse gases and other emissions, while also reducing our dependence on oil from politically volatile regions of the world.

Successful commercialization of hydrogen fuel cell vehicles will depend upon the creation of a hydrogen delivery infrastructure that provides the same level of safety, ease, and functionality as the existing gasoline delivery infrastructure. Today, compressed hydrogen is shipped in tube trailers at pressures up to 3,000 psi (about 200 bar). However, the low hydrogen-carrying capacity of these tube trailers results in high delivery costs.

Hydrogen rail delivery is currently economically feasible only for cryogenic liquid hydrogen; however, almost no hydrogen is transported by rail. Reasons include the lack of timely scheduling and transport to avoid excessive hydrogen boil-off and the lack of rail cars capable of handling cryogenic liquid hydrogen. Hydrogen transport by barge faces similar issues in that few vessels are designed to handle the transport of hydrogen over inland waterways. Lincoln Composites' ISO Tank Assembly will not only provide a technically feasible method to transport compressed hydrogen over rail and water, but a more cost and weight efficient means as well.

Approach

In Phase 1 of this project, Lincoln Composites will design and qualify a large composite pressure vessel and ISO frame that can be used for storage and transport of compressed hydrogen over road, rail or water.

The baseline composite vessel will have a 3,600 psi service pressure, an outer diameter of 42.8 inches and a length of 38.3 feet. The weight of this tank will be approximately 2,485 kg. The internal volume is equal to 8,500 liters water capacity and will contain 150 kg of compressed hydrogen gas. The contained hydrogen will be approximately 6.0% of the tank weight (5.7% of the combined weight.

Four of these tanks will be mounted in a custom-designed ISO frame, resulting in an assembly with a combined capacity of 600 kg of hydrogen (Figure 1). Installing the compressed hydrogen vessels into an ISO frame offers a benefit of having one solution for both transportable and stationary storage. This decreases research and development costs as well as the amount of infrastructure and equipment needed for both applications.

The large size of the vessel also offers benefits. A limited number of large tanks is easier to package into the container and requires fewer valves and fittings. This results in higher system reliability and lower system cost. The larger diameter also means thicker tank walls, which will make the vessel more robust and damage tolerant.

Phase 2 of the project will be to evaluate using the same approximate sized vessel(s) and ISO frame at elevated pressures. The pressures that are targeted for scope are 5,000 psi and 8,300 psi. Basic design of the individual vessels will remain approximately the same size at the 5,000 psi pressure and minor changes may be needed for the higher pressure. Higher pressures are needed to accommodate goals of the project.

Results

Design and Manufacture of a 3,600 psi Pressure Vessel

The design of the 3,600 psi pressure vessel architecture has been completed using finite element analysis to find a composite solution that resolves the internal pressure requirements and expected external loads. This design was translated into a manufacturing process that addresses the feasibility of vessel production. Several development units were fabricated and pressurized until burst to validate the proposed manufacturing process and design.

With the completed design and working manufacturing process, several additional vessels were fabricated and tested to address optimizing manufacturing issues and minimize production expenses.

FIGURE 1. Assembled ISO Container without Outer Panels

One of the units was fabricated and tested to ensure the highest risk associated with material availability could be addressed. By ensuring multiple sources of supplied materials, more leverage is available during procurement and lower production costs can be realized. Another vessel was fabricated to help establish confidence with migrating to a design having a higher margin of safety. Both of these vessels were subjected to a proof cycle and hydraulic burst test. The result of the testing met the expectations predicted by the design.

Qualification of 3,600 psi Vessel

Due to the tanks geometry and construction, there are no published standards that can be used to directly qualify the product. There do exist, however, standards to qualify small pressure vessels of similar construction. These standards were reviewed for input to determine the appropriate requirements that would apply to a vessel of this geometry and construction and include:

- ISO 11439, gas cylinders – High Pressure Cylinders for the On-board Storage of Natural Gas as a Fuel for Automotive Vehicles
- ISO 11119-3, Gas Cylinders of Composite Construction (fully wrapped non-metallic liners)
- ANSI/CSA NGV2-2007, American National Standards for Natural Gas Vehicle Fuel Containers
- ASME Code Case in Work/ASME BPV Project Team on Hydrogen Tanks and Section X

All qualification vessels have successfully been fabricated and completed through the following tests:

- Hydrostatic Burst
- Ambient Pressure Cycle Test
- Leak Before Burst Test
- Penetration Test
- Environmental Test
- Flaw Tolerance Test
- High Temperature Creep Test
- Accelerated Stress Rupture Test
- Extreme Temperature Cycle Test
- Natural Gas Cycle Test with Blow-down

Qualification of the ISO Frame

A complete assembly was constructed including ISO frame, four pressure vessels, and all relevant plumbing including pressure relief system. The following tests were performed on the entire assembly:

- Stress Analysis
- Dimensional Analysis
- Stacking
- Lifting – Top and Bottom
- Inertia Testing
- Impact Testing
- Bonfire Testing

American Bureau of Shipping has successfully approved the entire ISO assembly for production including, pressure vessels, ISO frame and subsequent valves, fittings and pressure relief system.

Conclusions and Future Directions

Proposed objectives for Phase 1 of this project were completed in the fourth quarter of 2009. This includes successful completion of a large 3,600 psi pressure vessel able to contain 8,500 liter water capacity. The successful qualification of an entire assembly into an ISO container was also completed. Lincoln Composites will continue to evaluate cost reductions in design of the vessel as well as in the manufacturing processes. Pursuant of a higher pressure vessel is underway and will continue. Trade studies will be completed followed by fabrication and testing of the higher pressure vessels. Pressure targets are set at 5,000 and 8,300 psi. This will show results more closely to the targets for Hydrogen Storage.

FY 2010 Publications/Presentations

1. 2010 DOE Hydrogen Program Annual Merit Review, June 9, 2010.