III.5 Development of High Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery

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Overall Objectives

The objective of this project is to design and develop the most effective bulk hauling and storage solution for compressed hydrogen gas (CHG).

- Cost
- Safety
- Weight
- Volumetric efficiency

Fiscal Year (FY) 2015 Objectives

Project activity in 2015 is focused on the following.

- Continue to investigate cost improvements
- Improve performance and reliability of safety system(s) through evaluation and adoption of new technologies
- Increase volume/capacity per payload at operating pressure of 250 bar

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Relearch, Development, and Demonstration Plan

(E) Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

(I) Other Fueling Site/Terminal Operations

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 combined storage capacity solution of approximately 34,000 L of water. The original scope of the project was to increase working pressure in the current design. Together with DOE, the project scope has been changed to work towards increasing available volume at the 3,600 psi working pressure. Further technical targets can be found in Table 1.

Accomplishments

- Successfully completed the design and qualification of a 3,600 psi pressure vessel (fourth quarter [4Q] 2009).
- Successfully completed the design and qualification of an ISO frame capable of holding four 3,600 psi pressure vessels with a combined capacity of 616 kg of hydrogen (third quarter [3Q] 2009).
- U.S. Department of Transportation (DOT) Special Permit (SP) 14951 issued to Hexagon Lincoln on February 22, 2012. SP 14951 authorizes the manufacture, making, sale, and use of TITAN™ modules in the United States.
- A trade study was performed in the first quarter [1Q] 2011; results indicated that CHG storage at 350 bar optimized hauling efficiency and system cost. However,

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Storage

Characteristic	Units	2010 Target	2015 Target	2020 Target	Status	Comments
Storage Costs	$/kg	$500/kg	$730/kg	$575	$800/kg	
Volumetric Capacity	kg/L	0.030 kg/L	>0.035 kg/L		0.018 kg/L	
Delivery Capacity, Trailer	kg	700 kg	700 kg	940 kg	720 kg	Titan5 Magnum trailer capacity is 800 kg Titan5 XL40 trailer capacity is 890 kg

development of a 350-bar system was not completed as part of this project due to insufficient market demand.

- Completed the design, manufacture and assembly of integrated TITAN™ 5 Magnum trailer system capable of storing ~800 kg H_2 at 3,600 psi. This new bulk hauling system was first deployed in compressed natural gas (CNG) service in 2013.
- Completed the design, manufacture and assembly of integrated TITAN™ 5 XL40 trailer system capable of storing ~890 kg H_2 at 3,600 psi. This new bulk hauling system was first deployed in CNG service in 2015.

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INTRODUCTION

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 and diesel fuel delivery infrastructure. Today, CHG is shipped in tube trailers at pressures up to 7,252 psi (about 500 bar). However, the capacity of these tube trailers results in high delivery costs. Hydrogen rail delivery is currently economically feasible only for cryogenic liquid hydrogen; 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. The Hexagon Lincoln TITAN™ ISO-format module will enable low-cost transport of gaseous hydrogen by increasing the carrying capacity of 250-bar tube trailers.

APPROACH

In Phase 1 of this project, Hexagon Lincoln has designed and qualified a large composite pressure vessel and ISO frame that can be used for storage and transport of CHG over road, rail, or water.

The baseline composite vessel has a 250 bar (3,626 psi) service pressure, an outer diameter of 42.8 in and a length of 38.3 ft. The weight of this tank is approximately 2,485 kg. The internal volume is equal to 8,500 L water capacity and will contain 150 kg of CHG. The contained hydrogen will be approximately 6.0% of the tank weight (5.7% of the combined weight).

Four of these tanks are mounted in a custom-designed ISO frame, resulting in an assembly with a combined capacity of 600 kg of hydrogen. Installing the 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 program was originally scoped to evaluate using the same approximate sized vessel(s) and ISO frame at elevated pressures. Trade studies performed in 2011 indicate optimization of hauling efficiency and system cost for CHG at 350 bar (5,076 psi). Due to differences in the compressibility of CHG and CNG, 350 bar operation is not an attractive option for CNG. The CHG market is difficult to forecast at this time and the cost to fully qualify a higher pressure module estimated at $5 million to complete. Based on insufficient CHG market definition to support a stand-alone business case for CHG, development of a 350 bar (5,076 psi) system has been placed on hold and will not be pursued under this project.

Consequently, it was determined that Hexagon Lincoln would work with our current 250 bar product and move forward with increasing the potential volume per load as well as improvements in safety. Increased volume has been achieved with the development of the TITAN™ 5 Magnum, an integrated trailer system with additional tankage. Other system improvements supported by the project include the evaluation, testing, and qualification of an improved emergency venting systems as well as development and installation of laboratory capabilities to evaluate the effects of hydrogen on liner materials.

RESULTS

Hexagon Lincoln completed qualification of the TITAN™ pressure vessel and ISO frame in 2009. The baseline 250 bar system shown in Figure 1 has an internal volume of 34,000 L water capacity and will contain 150 kg of CHG.

The initial Hexagon Lincoln TITAN™ 5 trailer prototype increased total payload capacity by 18% as compared with the baseline TITAN™ module. This new integrated trailer utilized the same four 40 ft TITAN™ cylinders with the addition of a single 30 ft TITAN™ tank placed lower in the assembly to utilize space between the frame rails of the trailer.

Lincoln Composites has continued the design and evaluation of a more robust emergency venting system utilizing memory metal as a trigger mechanism for depressurizing the tank in the case of a fire. This technology greatly reduces the cost of the system in both components and labor for assembly. The reduction of components in the

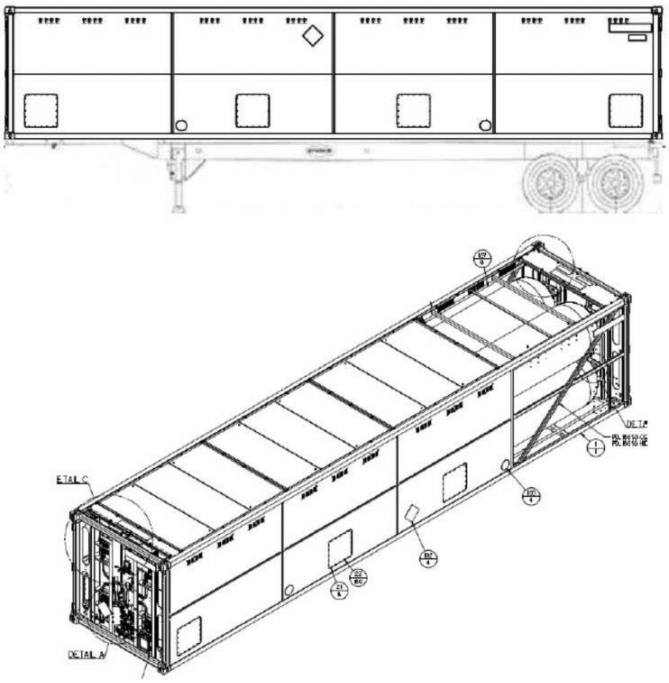

FIGURE 1. TITAN ISO-format module

system affects the potential number of failure modes that could occur and thus makes for a more reliable product.

The installation of a 100% hydrogen testing facility is complete. This laboratory will be used to fully investigate new materials with the potential to be integrated into liners. Specifically, these alternate materials will be qualified for their potential to reduce the permeation rates that are present in current Type 4 cylinders.

To further enhance system volume, the development/design of the TITAN™ 5 trailer systems was extended to the XL40 configuration with larger auxiliary tankage. This design utilizes four 38.5 ft and one 28.5 ft TITAN™ tanks with seven 26 in diameter tanks developed specifically for trailer installation. The new trailer is shown in Figure 2. This configuration has increased capacity by 44% when compared to the standard four cylinder TITAN™ module. This translates to an overall payload of 890 kg of hydrogen. This increase in capacity was achieved without increasing the loaded mass of the trailer because the trailer structure was designed and configured using high strength (100 ksi) steels. The TITAN™ 5 XL40 trailer system is currently deployed in CNG service in Central America.

The TITAN™ tanks were subject to rapid defueling events to assess their liners' potential for inward buckling or collapse. Testing involved defueling tanks from 250 bar to 25 bar within 25 min. The tests were performed once a week to allow for saturation of the liner prior to the defueling. The liner appeared to remain intact but will be further analyzed for localized deterioration in FY 2016.

FIGURE 2. TITAN™ 5 XL40 integrated trailer system

CONCLUSIONS AND FUTURE DIRECTIONS

- Proposed objectives for Phase 1 of this project were completed (4Q 2009). This includes successful qualification of a large 3,600 psi pressure vessel able to contain 8,500 L water capacity, and qualification of an ISO frame capable of holding four of these vessels with a combined capacity of 616 kg of hydrogen.
- DOT SP 14951 issued to Hexagon Lincoln on February 22, 2012. SP 14951 authorizes the manufacture, making, sale and use of TITAN™ modules in the United States.
- The TITAN™ 5 Magnum integrated trailer configuration has an increased capacity of 26% when compared to the standard four cylinder TITAN™ module. This translates to an overall payload of 775 kg of hydrogen.
- The TITAN™ 5 XL40 integrated trailer configuration has an increased capacity of 44% when compared to the standard four cylinder TITAN™ module. This translates to an overall payload of 890 kg of hydrogen.
- A program of deep cycle testing of TITAN™ pressure vessels with CHG was initiated in 1Q 2015 with completion in 3Q 2015. The goal of this demonstration is to characterize CHG-specific operating protocols for use of TITAN™ systems in CHG service at 250 bar.
- Hexagon Lincoln will prepare and submit an application for SP approval with DOT for the manufacture, making, sale, and use of TITAN™ 5 trailer systems in the United States Initial discussions with DOT indicate structural testing analogous to ISO 1496 will be required.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. Quarterly Reports.

2. 2015 DOE Hydrogen Program Annual Merit Review, June 10, 2015.