III.3 Development of High-Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery

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Project Start Date: July 1, 2008
Project End Date: June 30, 2015

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) in terms of:

- Cost
- Safety
- Weight
- Volumetric Efficiency

FY 2014 Objectives

Project activity in 2014 is focused on:

- Continuing to investigate cost improvements
- Improving performance and reliability of safety system(s) through evaluation and adoption of new technologies
- Increasing 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 Research, 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 liters of water. The original scope of project was to increase working pressure in the current design. Together with DOE, the project focus has shifted towards increasing available volume at the 3,600-psi working pressure. Technical targets for this project are listed in Table 1.

FY 2014 Accomplishments

Completed the design, manufacture and assembly of integrated TITAN V Magnum trailer system capable of storing ~800 kg H_2 @ 3,600 psi. This new bulk hauling system was first deployed in compressed natural gas (CNG) service in 2013. Many improvements to the trailers were implemented in 2014 based on customer feedback from the field.

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INTRODUCTION

Successful commercialization of hydrogen fuel cell vehicles requires 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 3,000 psi (about 200 bar). However, the low

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Storage

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

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. The Hexagon Lincoln TITAN ISO-format module will not only provide a technically feasible method to transport CHG over road, rail and water, but a more cost- and weight-efficient means as well.

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 inches and a length of 38.3 feet. The weight of this tank is approximately 2,485 kg. The internal volume is equal to 8,500 liters 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 project was originally scoped to evaluate vessel(s) of approximately the same size 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 $5MM 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 V 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 liters water capacity and will contain 150 kg of CHG.

The initial Hexagon Lincoln TITAN V trailer prototype increased total payload capacity by 18% as compared with the baseline Titan module. This new integrated trailer utilized the same four 40’ TITAN cylinders with the addition of a single 30’ 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 de-pressurizing the tank in the case of a fire. This technology

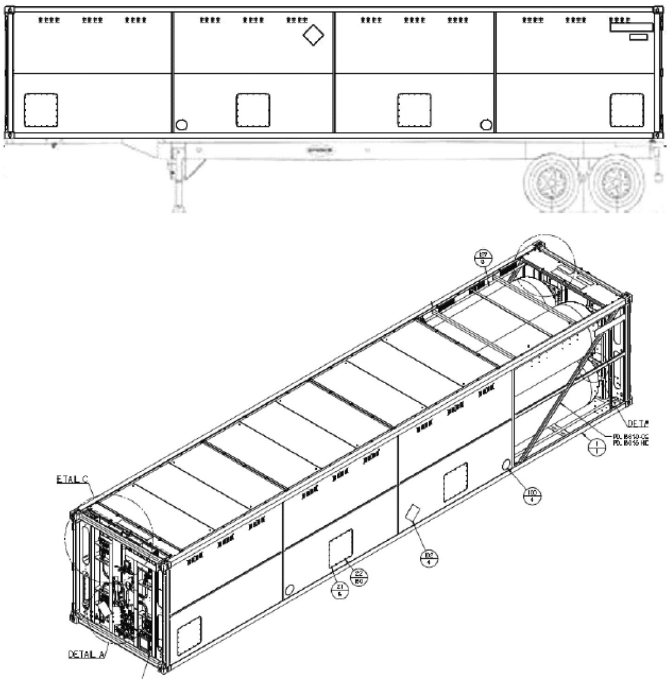

FIGURE 1. TITAN ISO-Format Module

greatly reduces the cost of the system in both components and labor for assembly. The reduction of components in the system affects the potential number of failure modes that could occur and thus making 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 for them to be integrated into liners. Specifically, these alternate materials will be quantified and qualified as a means to reduce the permeation rates that are present in current Type 4 cylinders.

To further enhance system volume, the development/design of the TITAN V Magnum trailer with additional tankage has been completed. This design utilizes the TITAN V as a baseline with the addition of up to nine smaller tanks on either side of the 30' single tank at the bottom of the module. See Figure 2 for illustration of this design. This configuration has increased capacity by 26% when compared to the standard 4-cylinder TITAN module. This translates to an overall payload of 775 kg of hydrogen. The TITAN V Magnum trailer system is currently deployed in CNG service in South and Central America as shown in Figure 3.

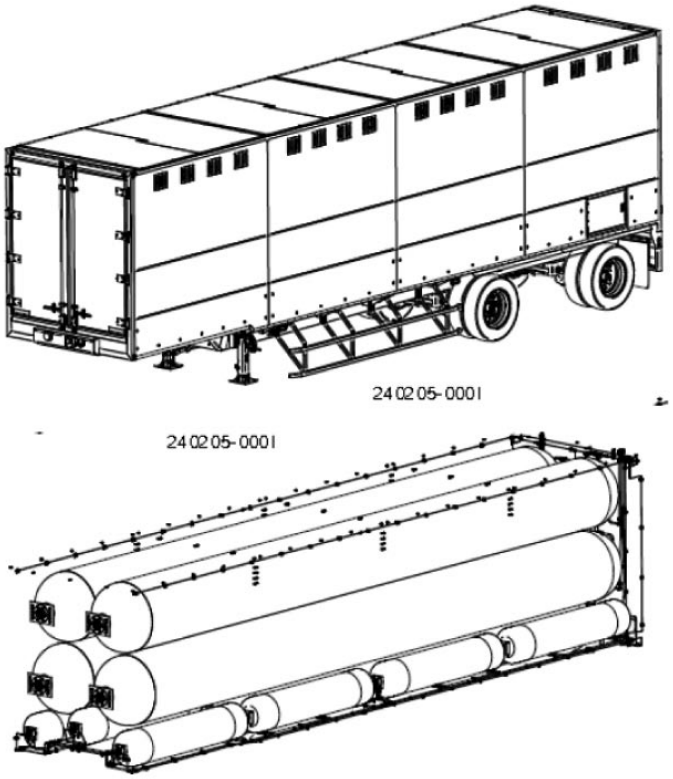

FIGURE 2. TITAN V Magnum Integrated Trailer System

CONCLUSIONS AND FUTURE DIRECTIONS

- The TITAN V Magnum integrated trailer configuration has an increased capacity of 26% when compared to the standard 4-cylinder TITAN module. This translates to an overall payload of 775 kg of hydrogen.
- Deep cycle testing of TITAN pressure vessels with CHG will be performed in the fourth quarter of 2014 and first quarter of 2015 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 Special Permit approval with the U.S. Department of Transportation for the manufacture, making, sale and use of TITAN V trailer systems in the United States. Initial discussions with the Department of Transportation indicate structural testing analogous to ISO 1496 will be required.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. 2014 DOE Hydrogen Program Annual Merit Review, June 17, 2014

FIGURE 3. TITAN V Magnum Trailer in CNG Service