

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: April 30, 2013

Overall 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

Fiscal Year (FY) 2013 Objectives

The objective in FY 2013 is to continue improvement of the baseline 3,600 psi bulk hauling and storage solutions for hydrogen in terms of

- Cost
- Safety
- Weight
- Volumetric Efficiency

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

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. The original scope of project was to increase working pressure in the current design. Together with DOE, the scope has been changed to work towards increasing available volume at the 3,600 psi working pressure.

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Storage

Characteristic	Units	2010 Target	2015 Target	2020 Target	Status	Comments
Storage Costs	\$/kg	500	300		745	Primary driver is market price of carbon fiber. Potential to see \$710/kg with 5,000 psi Titan V Magnum
Volumetric Capacity	kg/liter (psi)	0.030 (6,815)	>0.035 (>8,265)		0.018 (3,600)	Trade studies indicate trailer cost optimization at 0.024 kg/liter (5,000 psi)
Delivery Capacity, Trailer	kg	700	700	940	800	Potential to see 1,050 kg with 5,000 psi Titan V Magnum

FY 2013 Accomplishments

- The TITAN™ module (see Figure 1) and TITAN™V integrated semitrailer configuration (see Figure 2) were successfully extended to the TITAN™V Magnum configuration, increasing 3,600 psi hydrogen capacity to 800 kg (30% increase relative to the baseline TITAN™ module). Figure 3 shows the TITAN™V Magnum and the arrangement of large and small tanks within.
- Hexagon Lincoln has also continued the design and evaluation of robust fire protection systems utilizing memory metal alloy as a trigger mechanism for de-pressurizing the tank in the case of a fire. Development will continue as improved components are aligned with required functionalities.



FIGURE 1. Assembled TITAN™ ISO Container (without outer panels) on Standard ISO Trailer

- The installation of a 100% hydrogen testing facility is complete. Candidate liner materials are being characterized and qualified as a means to ensure reliability and to reduce the permeation rates that are present in current Type 4 cylinders.
- Hexagon Lincoln was an active participant in the Hydrogen Compression-Storage-Delivery Workshop at Argonne National Laboratory on March 20, 2013.



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 delivery infrastructure. Today, compressed hydrogen is shipped in tube trailers at pressures up to 3,000 psi (200 bar). However, the low hydrogen carrying capacity of these tube trailers results in high delivery costs. Hexagon Lincoln has developed large composite tanks and optimized hauling systems for the efficient and cost-effective storage and transportation of energy gasses, including compressed hydrogen gas.

The TITAN™ module is an ISO frame system that is currently in use worldwide to store and transport compressed natural gas over road, rail, or water. Hexagon Lincoln's TITAN™ module will not only provide a technically feasible method to transport compressed hydrogen over road, rail, and water, but a more cost and weight efficient means as well.

APPROACH

In Phase 1 of this project, Hexagon Lincoln 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, and 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



FIGURE 2. TITAN™V Trailer Concept and TITAN™V Trailer Prototype delivered in the First Quarter of 2012

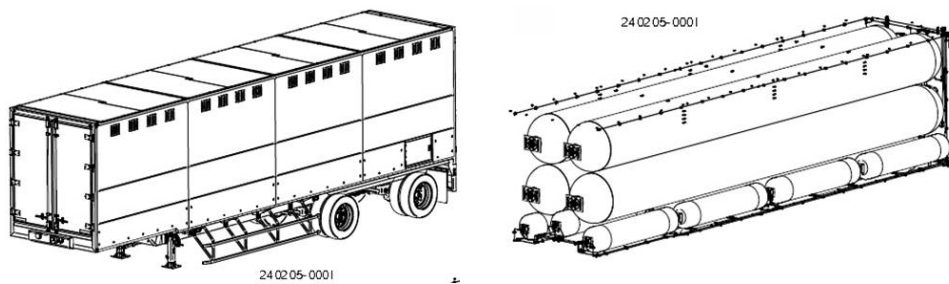


FIGURE 3. TITAN™V Magnum Trailer System with Arrangement of Tanks Shown at Right

approximately 2,485 kg. The internal volume is equal to 8,500 liters water capacity and will contain 154 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 616 kg of hydrogen. 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.

Phase 2 of the project was originally scoped to evaluate using the same approximate sized vessel(s) and ISO frame at elevated pressures. Trade studies completed in 2011 indicated that cost and volumetric efficiency of the TITAN™ module would be optimized at an operational pressure of 5,000 psi. In the next year however, Hexagon Lincoln identified concerns with moving forward with higher pressure delivery modules. The market is difficult to forecast at this time and the cost to fully qualify a higher pressure module is estimated at \$5MM to complete. Based on this, it was determined that Hexagon Lincoln would work with our current product and move forward with increasing the potential volume per load as well as improvements in safety. Other projects include the evaluation, testing and qualification of improved fire protection systems, as well as development of a laboratory capability to investigate the effects of hydrogen on liner materials.

RESULTS

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. Figure 1 is a photograph of the TITAN™ module qualification test unit.

The design and analysis of a TITAN™V integrated semitrailer system was realized that adds an additional 18% capacity with respect to the baseline TITAN™ module. A prototype unit was delivered to Hexagon Lincoln in the first quarter of 2012, as shown in Figure 2. This configuration was successfully extended to the TITAN™ V Magnum configuration shown in Figure 3, increasing 3,600-psi hydrogen capacity to 800 kg (30% increase relative to the baseline TITAN™ module).

Trade studies completed in 2011 indicated that cost and volumetric efficiency of the TITAN™ module would be optimized at an operational pressure of 5,000 psi. However, Hexagon Lincoln has worked directly with DOE in determining that progression to the qualification of a 5,000 psi pressure vessel is not feasible at this time. This

development is on hold pending solidification of a business case that justifies the high cost of qualification. Hexagon Lincoln is therefore concentrating efforts on the further development of our hauling equipment using the 3,600 psi TITAN™ pressure vessel, while continuing to evaluate all reasonable configuration options for operation with increased capacity and higher system pressures. Figure 4 shows a hydrogen payload and gross vehicle weight (GVW) comparison of feasible options vs. existing technology. (GVW includes the mass of an appropriate prime mover and a trailer chassis, if required.)

The three configurations at the left-hand side of Figure 4 are existing steel tube trailer configurations. The next two configurations are the TITAN™ module and TITAN™V Magnum™ trailer systems operating at 3,600 psi (250 bar). With these systems, an increased hydrogen payload can be achieved without exceeding the maximum allowed GVW for general use on the interstate system in the United States of 80,000 lb (36.3 tonne). Further increases in hydrogen payload can be achieved without exceeding the maximum GVW by extension of the TITAN™ equipment to higher operating pressures. As was identified in our previous trade studies, a 5,000 psi (350 bar) TITAN™V Magnum trailer system offers a particularly attractive option in terms of hydrogen hauling efficiency. However, qualification costs for this configuration are very high. In addition, higher level trade studies performed to determine the operating parameters of an optimized hydrogen delivery infrastructure may indicate that better overall efficiency will be achieved through operation of the bulk hauling equipment at pressures of 7,600 psi (525 bar) or higher. Consideration is therefore given to the extension of the SmartStore™ product line to hydrogen storage and transport, in particular during the critical phase of infrastructure development and deployment. SmartStore™ modules incorporate as many as 40 smaller diameter tanks in ISO-format containers. The options of operating 30-foot versions of the SmartStore™ system at 7,600 psi (525 bar) and 10,000 psi (700 bar) are also shown. The lower qualification costs and packaging flexibility of smaller diameter tanks facilitates SmartStore™ module optimization at these higher pressures.

Hexagon Lincoln has also continued the design and evaluation of robust fire protection systems utilizing memory metal alloy as a trigger mechanism for de-pressurizing the tank in the case of a fire. Development will continue as improved components are aligned with required functionalities.

The installation of a 100% hydrogen testing facility is complete. Candidate liner materials are being characterized and qualified as a means to ensure reliability and to reduce the permeation rates that are present in current Type 4 cylinders.

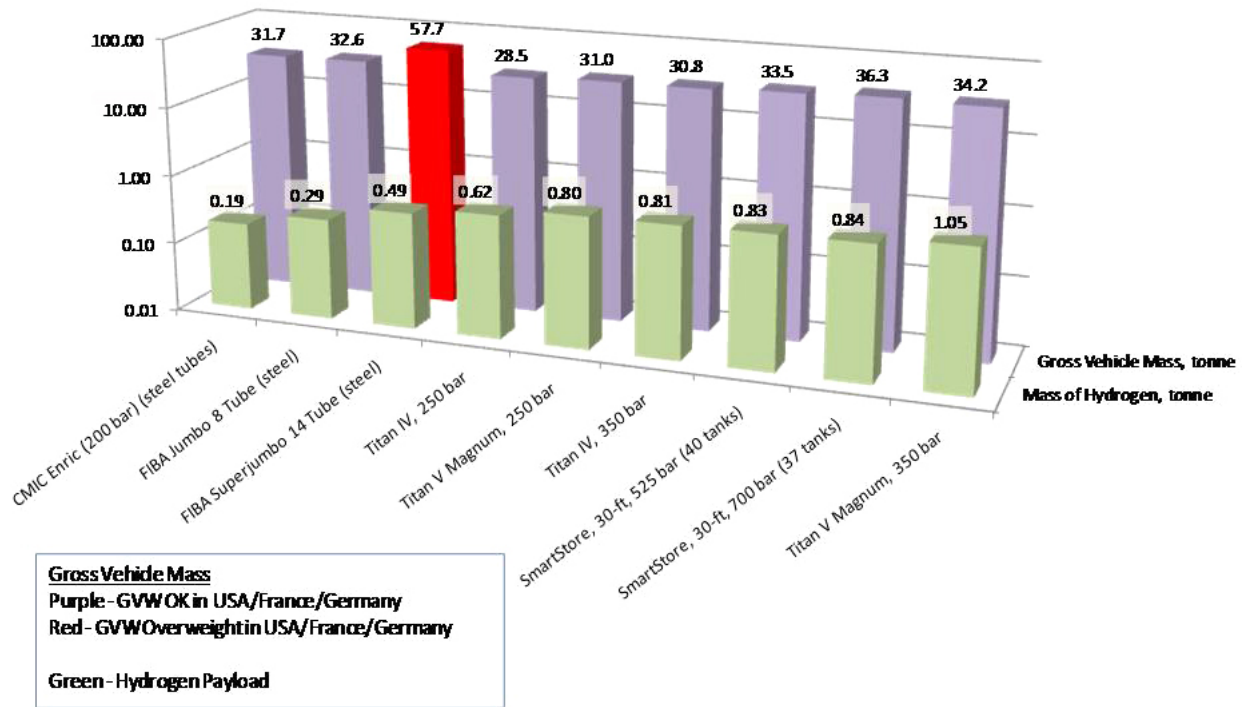


FIGURE 4. Comparison of GVW and H₂ Capacity for Current and Potential Bulk Hauling Configurations

CONCLUSIONS AND FUTURE DIRECTIONS

- The TITAN™V integrated semitrailer configuration was successfully extended to the TITAN™V Magnum configuration, increasing 3,600 psi hydrogen capacity to 800 kg (30% increase relative to the baseline TITAN™ module).
- Completion of the qualification and implementation of a safer and more reliable fire protection system. This includes integration of memory metal trigger mechanisms for distributed fire sensing and fast reacting dump system for safe evacuation of the hydrogen payload.

- Extreme low-temperature testing will be performed to ensure safe extension of the lower temperature operating limit of the TITAN™ tanks from the current -40°C to -50°C.
- Laboratory investigation of the short and long term effects of compressed hydrogen gas on pressure vessel liner materials will continue.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. 2013 DOE Hydrogen Program Annual Merit Review, May 15, 2013