IV.B.9 Development of Improved Composite Pressure Vessels for Hydrogen Storage

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Overall Objectives

- Improve the performance characteristics, including weight, volumetric efficiency, and cost, of composite pressure vessels used to contain hydrogen in adsorbants.
- Evaluate design, materials, or manufacturing process improvements necessary for containing adsorbants.
- Demonstrate these improvements in prototype systems through fabrication, testing, and evaluation.

Fiscal Year (FY) 2013 Objectives

- Confirm operating conditions chosen for adsorbent technology-based hydrogen storage system.
- Evaluate design options for Type 1, Type 3, and Type 4 tanks to meet system requirements for demonstrating adsorbent technology-based hydrogen storage system.
- Fabricate and test leading candidate designs to confirm suitability for Phase 3 use.

Technical Barriers

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

(A) System Weight and Volume

(B) System Cost

(G) Materials of Construction

Technical Targets

This project is conducting fundamental studies for the development of improved composite pressure vessels for hydrogen storage, and developing an optimized vessel for use by Hydrogen Storage Engineering Center of Excellence (HSECoE) partners in demonstrating a functioning vehicle storage system using adsorbant materials. The targets apply to the storage system, of which the vessel is a part. Insights gained from these studies will be applied toward the design and manufacturing of hydrogen storage vessels that meet the following DOE hydrogen storage targets:

	2017	Ultimate
• Gravimetric capacity:	5.5 wt%	7.5 wt%
• Volumetric capacity:	40 g/L	70 g/L
• Storage system cost:	$12/kWh	$8/kWh

FY 2013 Accomplishments

- HSECoE partners confirmed operating requirements for the Phase 2 test vessel, including a reduction in operating pressure from 200 bar to 100 bar, which will reduce the cost and weight of the vessel while essentially maintaining system performance.
- The Phase 1 test vessel, of Type 4 construction, was subjected to a burst test at cryogenic temperatures to confirm composite strength is not degraded at cryogenic temperatures reflecting operating conditions. Two units were tested. The liner cracked in both tests due to high stresses in the liner. There was no evidence of strength loss in the composite.
- The Phase 2 test vessel, of Type 1 construction, was designed and manufactured. It was subjected to a burst test at ambient temperature, achieving 370 bar, which confirmed the design and safety for use. The Type 1 vessel is heavier than Type 4, but about 30% to 50% lower cost.
- Phase 2 test vessels were distributed to HSECoE partners as requested.
- The Phase 2 test vessel was subjected to 200 pressure cycles followed by a burst test at cryogenic temperatures to confirm strength at expected operating conditions. The burst pressure of 460 bar exceeded requirements, and as expected was greater than the ambient temperature burst.

- Full-scale designs for Type 1 and Type 4 tanks were evaluated. If Type 4 liner performance at cryogenic temperatures was acceptable, the DOE SMART milestones for weight could be met.
- A patent is being pursued for an external vacuum insulating shell, with Hexagon Lincoln and Pacific Northwest National Laboratory engineers as inventors. The vacuum shell insulates the tank during service, and additionally improves system performance as it permits pre-cooling of the tank using liquid nitrogen during the filling operation, and venting of any gas that permeates or leaks from the tank without compromising the vacuum insulation.

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INTRODUCTION

Hexagon Lincoln is conducting research to meet DOE 2017 Hydrogen Storage goals for a storage system by identifying appropriate materials and design approaches for the hydrogen container. At the same time, the pressure vessels must continue to maintain durability, operability and safety characteristics that already meet DOE guidelines for 2017. There is a continuation of work with HSECoE partners to identify pressure vessel characteristics and opportunities for performance improvement. Hexagon Lincoln is working to develop high-pressure vessels as are required to enable tank design approaches to meet weight and volume goals and to allow adsorbant materials that operate at cryogenic temperatures to operate efficiently.

APPROACH

Hexagon Lincoln established a baseline design for full scale and test tank using HSECoE team operating criteria as a means to compare and evaluate potential improvements in design, materials and process to achieve cylinder performance improvements for weight, volume and cost. Hexagon Lincoln selected the most promising engineering concepts to meet Go/No-Go requirements for moving forward. The emphasis was on demonstrated technology to ensure ability of HSECoE partners to test their system components.

During Phase 2, operating conditions were updated and confirmed, and new baselines were developed. Testing of bench-top test vessels was conducted to confirm their safety for use. Alternate designs and materials were evaluated to assess ability to meet established targets for weight and volume.

RESULTS

HSECoE partners established updated criteria for operation at 100-bar service pressure, with an operating temperature range from 80 K to 373 K. A test vessel configuration with Type 1 construction and a 2-liter volume was also established to demonstrate component technology. Test vessels were designed, manufactured, tested, and distributed to HSECoE partners to facilitate testing of prototype components.

A concept for insulating the tank during operating, and providing the means for cooling the tank prior to refueling, was further developed. A patent application was filed during the past year, with Hexagon Lincoln and Pacific Northwest National Laboratory engineers listed as authors.

The test vessel developed during Phase 1 had previously been burst tested to confirm safety for use. Another Type 4 vessel design had been successfully exposed to liquid nitrogen and subsequently burst at ambient temperature to assess capability for the liner and composite to tolerate exposure to cold temperatures. Two Phase 1 test vessels were pressurized with liquid nitrogen with the intent to burst (Figure 1). Both leaked due to a cracked liner, one at 285 bar, the other at 230 bar. The liner was analyzed, and it was determined the crack was likely the result of a high stress at the boss/liner interface that was exacerbated by the cold temperature. However, the test confirmed the liner would remain intact to strains representative of operating pressure

FIGURE 1. Type 4 Tank Test

and temperature, and there was no indication of strength loss in the carbon fiber composite.

The Phase 2 Type 4 test vessel was designed using aluminum 6061-T6 and a three-piece construction (Figures 2 and 3). The three-piece construction allowed HSECoE partners to remove and replace components in the vessel between tests. A Type 1 vessel would be higher weight than Type 4 construction, but would be 30% to 50% lower cost. A burst test to 370 bar confirmed safety. The test vessel was subjected to 200 cycles to service pressure at 80 K, then burst at 460 bar. This test confirmed safety for use by HSECoE partners in laboratory testing.

A study was conducted comparing Type 1 and Type 4 vessels that would meet HSECoE design requirements for a full-scale vessel. A Type 1 vessel made with AA 6061-T6 would have no problem with the low temperature of 80 K. The Type 4 vessel appears to have no problem with composite operating at lower temperatures, but an high-density polyethylene (HDPE) liner has some sensitivity to the low temperature.

FIGURE 2. Type 1 Tank Assembly

FIGURE 3. Type 1 Tank Components

The American Society of Mechanical Engineers pressure vessel code was referenced as a goal to meet. It was practical to meet Section X Class III requirements when the service pressure was >210 bar, but below that, Class I requirements would apply, and the resulting design would be overly conservative. The federal requirements for this application would be under the jurisdiction of the Department of Transportation, National Highway Traffic Safety Administration. The requirements of Department of Transportation/National Highway Traffic Safety Administration would be met by the full-scale tank design.

Calculations were made for Type 1 and Type 4 tanks. The goal was for tank mass to be less than 10 kg for a volume of 120 liters and an operating pressure of 60 bar. The results of calculations are provided in Table 1. One design change that enables the weight goal to be met is to reduce the thickness of the liner in the Type 4 tank, possibly by using a high elongation resin layer to prevent leakage. Permeation is not a significant issue for the given operating conditions, because permeation is significantly reduced by virtue of operating at the cold temperature.

TABLE 1. Type 1 and Type 4 Tank Calculations

Material	Dia (mm)	L (mm)	Wt (kg)
AA6061-T6	440	950	30.00
Carbon/HDPE	440	950	11.35
Carbon/tbd	434	950	8.61

Dia – diameter; L – length; Wt – weight; tbd – to be determined

CONCLUSIONS AND FUTURE DIRECTIONS

- A Type 1 tank can meet the pressure and temperature requirements for Phase 3 testing and component development, and has the lowest project risk. A revised design of lighter weight will be developed and tested.
- The Type 4 tank that was tested was marginal in terms of ability to meet project requirements due to the liner sensitivity to low temperature. The composite is believed to be suitable for cold temperature. A Type 4 tank has the potential to significantly reduce weight if a suitable liner is developed. Efforts will be made in Phase 3 to develop a suitable liner and conduct additional testing.
- Type 1, Type 3, and Type 4 tank full-scale designs will be developed and evaluated for suitability.
- The concept for insulating and pre-cooling the tank appears to be useful to the project. A full-scale component will be designed and modeled. A subscale unit will be manufactured and tested.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. A patent application was filed on the concept for a thermal insulation shell system that would also allow cooling of the tank prior to refilling.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. 2013 DOE Hydrogen Program Annual Merit Review, May 14, 2013.