IV.D.1 Conformable Hydrogen Storage Coil Reservoir

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Contract Number: DE-EE0006967

Subcontractors:

- High Energy Coil Reservoirs, LLC (HECR) Fort Wayne, IN
- The University of Texas at Austin Center for Electromechanics, Austin, TX
- Stan Sanders, Technical Expert, Fort Wayne, IN

Project Start Date: September 1, 2015
Project End Date: December 31, 2017

Overall Objectives

- To develop and demonstrate a conformable, lightweight, 700 bar gaseous hydrogen storage system with nominal capacity of approximately 1 kg.

Fiscal Year (FY) 2017 Objectives

- Identify suitable resins for the pressure vessel.
- Build and test pressure vessel prototypes.

Technical Barriers

- Resin selection that offers low permeability, flexibility, durability, impact resistance and thermoplastic (extrusion) performance.

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

Technical Targets

This project seeks to address the high cost of conventional gaseous 700 bar hydrogen storage, as well as the overall weight of the hydrogen storage system. Although this project will not improve the volumetric efficiency of gaseous storage, the pressure vessel design should allow a more flexible on-vehicle packaging than a conventional rigid cylinder. Possible tank layouts could optimize the use of areas in the same way that current gasoline tanks are molded to best use available space. Using HECR's pressure vessel technology for hydrogen storage promises to provide breakthroughs in commercially available pressure vessel costs, conformability, and weight.

There are additional project requirements for system selection:

- Low hydrogen leakage (<0.05 g/h-kg H_2 stored at 700 bar)
- Operational temperature limit (-40°C ≤ T ≤ 85°C)
- Corrugation process compatibility (i.e., needs to be process compatible, range of viscosity, melt temperature, and durometer)
- Burst pressure exceeding 2,170 bar

FY 2017 Accomplishments

- Revised braid design led to vessels that met a 10,000 psi burst pressure.
- A single high pressure burst test was conducted, with the burst occurring at over 33,000 psi, which meets Department of Transportation pressure vessel

TABLE 1. Progress towards Meeting Technical Targets for Hydrogen Storage

	DOE Projections for Type IV 700 bar Storage at 500,000 units/yr	DOE 2017 Target	DOE Ultimate Target	Proposed Project Vessel	Current Project Vessel
Gravimetric Capacity	1.5 kWh/kg (4.5 wt% H_2)	1.8 kWh/kg (5.5 wt% H_2)	2.5 kWh/kg (7.5 wt% H_2)	3.7 kWh/kg (10.0 wt% H_2)	Testing not complete
Volumetric Capacity	0.8 kWh/L (24 g H_2/L)	1.3 kWh/L (40 g H_2/L)	2.3 kWh/L (70 g H_2/L)	0.7 kWh/L (20 g H_2/L)	Testing not complete
Cost	$17/kWh ($570/kg H_2 stored)	$12/kWh ($400/kg H_2 stored)	$8/kWh ($267/kg H_2 stored)	$8.40/kWh ($280/kg H_2 stored)	Testing not complete

requirements for 700 bar (10,000 psi) nominal working pressure.

- Confirmed performance of leak test equipment with agreement between pressure lost from test sample to pressure rise in containment chamber using preliminary test vessels.

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INTRODUCTION

This project consists of four project partners: Center for Transportation and the Environment, project prime recipient responsible for project management; HECR, intellectual property owner; The University of Texas Center for Electromechanics, responsible for permeability testing and resin technical information; and Stan Sanders, technical expert.

The overall goal of this research and development project is to develop an approach for compressed hydrogen gas storage that will provide a cost-effective and conformable storage solution for hydrogen. The team will develop and demonstrate a conformable, lightweight 700 bar gaseous hydrogen storage system with a nominal capacity of approximately 1 kg. The nature of the HECR's technology allows for a higher capacity pressure vessel to be constructed simply by creating a longer vessel through the same process.

APPROACH

The hydrogen storage system development will occur over two budget periods beginning with an initial design, including candidate resin down selection and over-braid final development. The design includes overwrapping an extruded thermoplastic elastomeric resin liner with high performance Kevlar™. The team will then build test vessels and perform key testing to validate the suitability for hydrogen containment. This testing will include hydrostatic burst testing, hydrostatic pressure cyclic testing, and hydrogen permeability testing conducted on a number of resin liners.

RESULTS

Since the 2016 annual report, multiple hydrogen pressure vessels have been tested. Several vessels were built using an ethylene vinyl alcohol (EVOH) resin provided by the resin manufacturer Kuraray. The resin was able to adequately bend for manufacturing (Figure 1) using hot water to form the vessels. Using this hot water forming, HECR was able to build and test a hand-wrapped Kuraray cores with a proprietary tensile fiber for high pressure testing. The original end fittings split and burst at 34,000 psi, which exceeded the burst pressure requirement of 31,000 psi. This test indicates that there is a good likelihood that a conformable pressure vessel that meets Department of Transportation burst specifications at half the weight of a conventional hoop wound cylinder can be built.

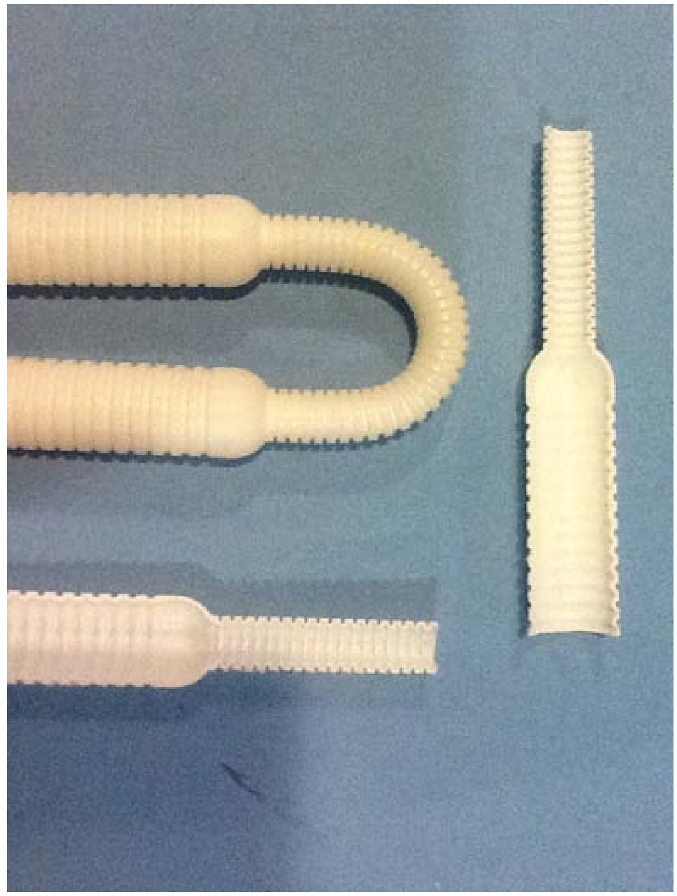

FIGURE 1. Initial EVOH cores and core section

Center for Electromechanics tested several iterations of the hydrogen storage vessels with a Hytrel resin material for the core liner. The initial tests were found to have high leak rates due to inadequate end fittings. Once the end fittings were improved and determined to be leak-free, Center for Electromechanics conducted two leak tests: one at 1,000 psi and one at 1,800 psi (Figure 2). In both cases, the leak rate did not meet the goals of the program. The 1,000 psi test leaked over 100 psi in less than 21 h, resulting in a 0.6 g/h-kg H_2 leak rate, while the 1,800 psi test leaked 200 psi in 23 h, resulting in a 0.6 g/h-kgH_2 leak rate. This was expected as the initially tested resin, Dupont Hytrel, was selected for process compatibility and to confirm the testing process while the material selection was on going.

The project team explored additional resins to examine if there were other possibilities that were both manufacturing-process compatible, and compatible with the flexibility requirements of the conformable vessel. This is a challenge because the least permeable resins are typically stiff and brittle, with a high crystallinity. For this prototype to work,

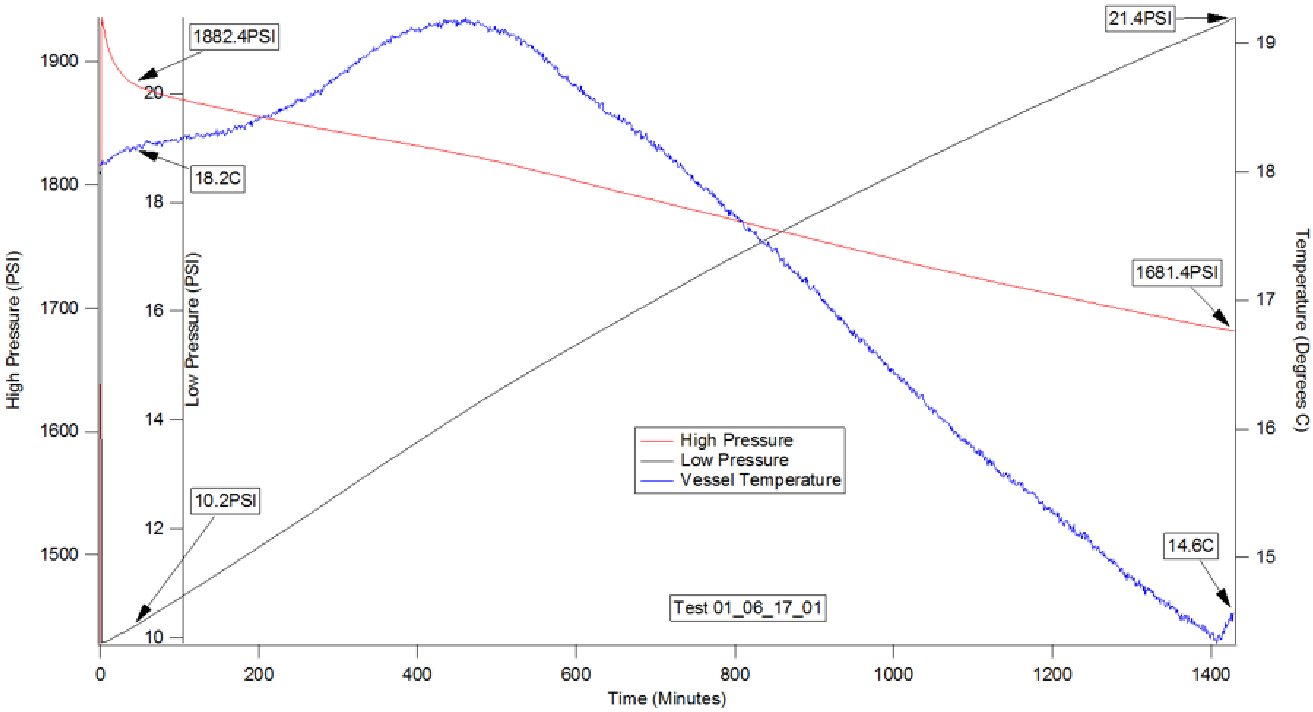

FIGURE 2. Example permeability data results

the vessel requires the highest permeability resistance to hydrogen available. Even with these high performance resins, a wall thickness of 20–40 thousandths may be required. This is at odds with the assembly flexibility required, where the vessel must bend 180° at the narrow body section, as well as undergo repeated expansion and contraction cycles during filling.

The team also planned to create hydrogen storage vessels with Kuraray-based resin cores, but the initial core production tests with the Kuraray resin have not been compatible with the manufacturing process. Kuraray provided a stiff and flexible EVOH formulation for testing, hoping one would be compatible with the manufacturing process. The stiff resin was too brittle, shattering easily, and the flexible resin had little to no resiliency, and tore easily. During Spring 2017, the manufacturing subcontractor was able to blend the two resins together, and arrive at core samples which meet the minimum flexibility requirements of the internal cores, which allows the cores to be bent 180° to allow a tight packing of vessels once the over-braiding is complete. These flexible cores are shown in Figure 3.

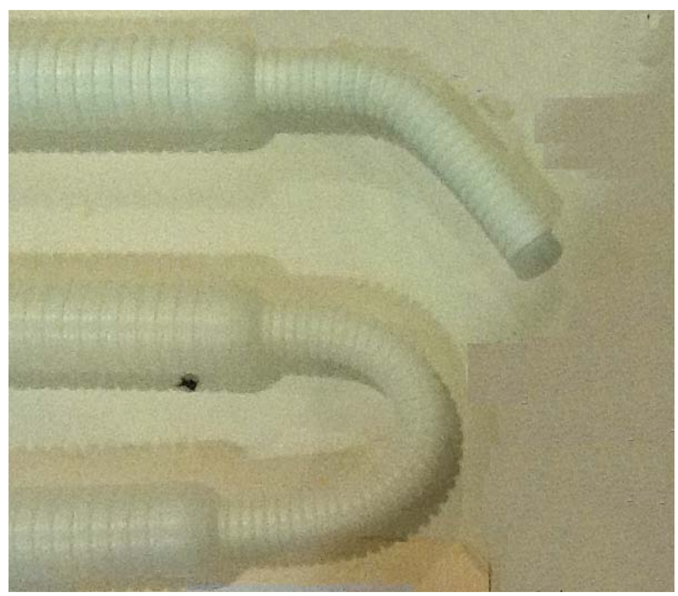

FIGURE 3. Blended EVOH core with greater flexibility

CONCLUSIONS AND UPCOMING ACTIVITIES

The project team currently has the new, more flexible, vessels in hand and is preparing to complete the over-braiding with a proprietary tensile fiber. When this is complete, the vessels will be sent to Center for Electromechanics for permeability testing. Additional burst testing to determine if the 31,000 psi burst pressure requirement can be met with a machine over-wrapped pressure vessel will be conducted. Meeting the project permeability goal, as well as the 31,000 psi pressure are the two key targets for the go/no-go determination to progress to Budget Period 2.