IV.D.6 Achieving Hydrogen Storage Goals through High-Strength Fiber Glass

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Subcontractors
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- Pacific Northwest National Laboratory (PNNL), Richland, WA

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Project End Date: August 30, 2016

Overall Objectives

Our objective is to demonstrate a Type IV composite overwrapped pressure vessel reinforced exclusively with glass fiber. We expect to achieve this goal with the following:

- Develop a new glass fiber with strength exceeding T-700 at less than half its cost
- Demonstrate a novel glass fiber manufacturing process
- Conduct composite validation laboratory tests to determine the safety factor for the tank made by using new high strength glass fiber
- Build cost models to demonstrate the new tank will reduce the composite contribution to system cost by nearly 50% with minimal impact on tank weight and capacity compared to tanks made with T-700 carbon fiber.

Fiscal Year (FY) 2015 Objectives

- Develop two candidate high-strength glass fibers that offer pristine tensile strength greater than 5,000 MPa
- Identify two candidate sizing chemistries to be used for coupling with specific epoxy resin currently used for the hydrogen storage tank
- Perform bushing runs to produce high-strength glass fibers of the two candidate compositions with two pre-selected sizing chemistries
- Build vessels using both high-strength fibers and reference E-glass fibers (as a control) for mechanical tests compared with performance of the vessels made from T-700 carbon fibers
- Demonstrate throughput enhancement of the proposed new high-temperature glass melting platform

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Storage section (3.3.5) of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan:

(B) System Cost

Technical Targets

The project is to demonstrate the technical and commercial feasibility of using high strength fibers to match with the tensile strength of T-700 carbon fibers at about 50% of the cost. At the completion of the project, experimental results and modeling output will enable us to benchmark with key parameters shown in Tables 1 and 2. The actual targets for our project, as written in our proposal, are detailed in the Introduction section of this report.

TABLE 1. Technical System Targets: Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles [1]

Storage Parameter	Units	2020	Ultimate	Project towards targets (2015)
System Gravimetric Capacity	kWh/kg	1.8	2.5	TBD
System Volumetric Capacity	kWh/L	1.3	2.3	TBD
Storage System Cost	\$/kWh net \$/kg H_2 stored	10 333	8 266	TBD TBD

TBD – to be determined

TABLE 2. Projected Performance of Hydrogen Storage Systems [1] [a]

Hydrogen Storage System	Gravimetric (kWh/kg sys)	Volumetric (kWh/L sys)	Cost (\$/kWh; projected to 500,000 units/yr)	Project towards targets (2015)
700-bar compressed (Type IV) [b]	1.7	0.9	19	TBD

[a] Assumes a storage capacity of 5.6 kg of usable hydrogen
[b] Based on Argonne National Laboratory performance and TIAX cost projections

FY 2015 Accomplishments

During the first phase of our project in FY 2015, the team has successfully completed the following objectives:

- Developed two new high-strength glass fiber chemistries with their pristine tensile strength close or slightly higher than T-700 carbon fibers
- Successfully produced glass cullets of the two fiber glass chemistries for the planned fiber production
- Identified two fiber glass sizing chemistries for use
- Built all of the required E-glass reference vessels and started testing the vessels
- Built environmentally controlled stress corrosion test apparatus after a thorough evaluation of grips
- Completed design of the new high-temperature glass melting vessel for demonstration; the system installation is scheduled.

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INTRODUCTION

This project addresses the FCTO's intermediate 2017 goals for onboard hydrogen storage for light-duty fuel cell vehicles. Specifically, we target a fiber cost less than $6/lb, a composite contribution to system cost of less than $6/kWh, a volumetric capacity of 0.86 kWh/L (26 g/L), and a gravimetric capacity of 1.3 kWh/kg (4 wt%), while minimizing increases in tank mass compared to T-700 carbon fiber vessels. The project tasks are organized to continually decrease project risk, moving from a Technology Readiness Level of 4 to 6.

APPROACH

To begin, we develop fibers at the bench and characterize stress rupture at the fiber level. We then develop a pilot version of our new glass manufacturing process to produce the high-strength fibers, and we ended Year 1 with test data from prototype tanks built from up to four new fiber samples, i.e., fiber chemistry and sizing chemistry in combination.

In Year 2, we will optimize the best performing fiber and the production process, characterize stress rupture at the composite level, and investigate alternate tank designs. We will end the project with a prototype tank built according to a design tailored to the properties of the new glass that can be tested against a wide range of industry testing.

RESULTS

The development of new high-strength fibers, shown in Table 3, can address DOE's technical barrier in the system cost reduction described earlier.

Successful glass cullet production of both high-strength fiber compositions, using conventional combustion technology, was another important milestone that demonstrated that both high-strength glass fibers can be produced at large scale using improved commercial glass melting technology that can adequately reduce production costs towards the DOE target.

Although there are still some challenges for the fiber forming process, our initial production of fibers using a small scale pilot platform will successfully demonstrate the technical feasibility of the fiber drawing processes close to existing commercial fiber forming process.

TABLE 3. High-Strength Glass Fiber Properties

ID	Chemistry A	Chemistry B
ρ (g/cm^3)	2.64	2.63
E (GPa)	91.8	92.6
s_f (MPa)	5243	5583
ε (%)	5.7	6.0

Note 1: ρ – average fiber density; E – average pristine fiber Young's modulus by sonic method; s_f – average pristine fiber strength; ε – average pristine fiber failure strain

Production of high strength fibers has been delayed against the original plan due to equipment issues. Currently we have identified a new solution that will enable us to draw fibers with good stability at appropriate temperatures without introducing a busing control problem.

One of the fiber sizing chemistries has been tested by Hexagon Lincoln using our reference E-glass roving packages; the vessel quality, i.e., uniformity of strand distribution and level of broken filaments, through the fiber winding process is satisfactory compared with standard commercial fiber glass wound composite vessels. During the composite vessel winding process, we also obtained data to determine translation losses (about 10%) in terms of the vessel burst strength between using large direct draw product without assembling and using assembled roving from small packages.

Stress rupture test apparatus with temperature and humidity controls has been built at PNNL (Figures 1a, 1b). The set up and design have been validated by testing our reference fibers, INNOFIBER® CR 2026 fiber glass, as illustrated in Figure 2. The section of final grips (Figure 3)

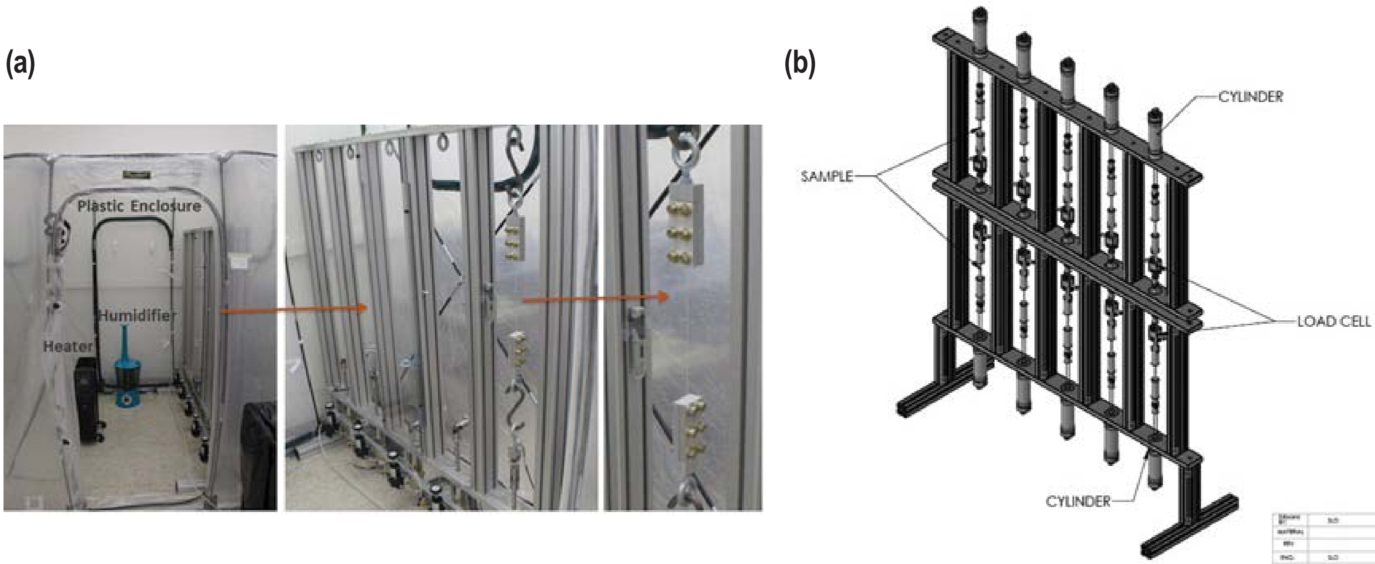

FIGURE 1. Stress rupture test apparatus: (a) environmental control and (b) test frame design (PNNL)

BareFiber PNNL Custom Grip	Average	Stdev	Min	Max
Peak Load (LbF)	270.64	9.87	251.0476	282.2207
Extension (mm)	8.30	2.80	8.1159	10.1112
Elongation at Break (%)	6.14	0.41	5.4106	6.7408

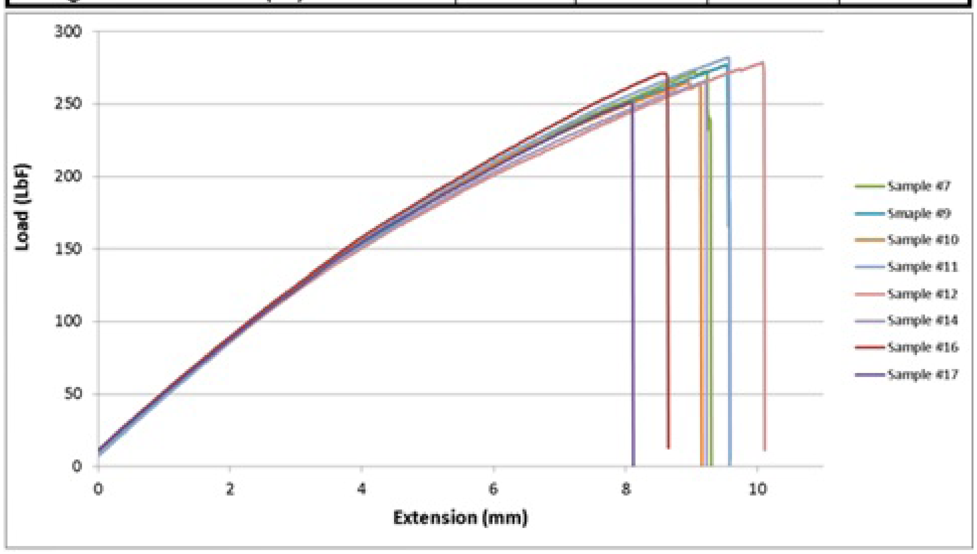

FIGURE 2. Example of stress rupture tests using INNOFIBER® CR 2026 glass fiber as control

was made based on evaluations of sample tap geometry and different types of commercial grips.

CONCLUSIONS AND FUTURE DIRECTIONS

The project has developed two new high-strength fiber glass chemistries with some positive confirmation from the glass melting and limited fiber forming process. The challenging part in the short term is to produce a sufficient amount of fiber packages for composite tank testing as well as stress corrosion or stress rupture tests. For the long term, the key is to reduce translation loss of fibers through each step of fiber forming and package drying processes. In FY 2016, we plan to complete all new high-strength fiber making, composite vessel tests, and fiber stress corrosion tests. The new results will enable us to achieve:

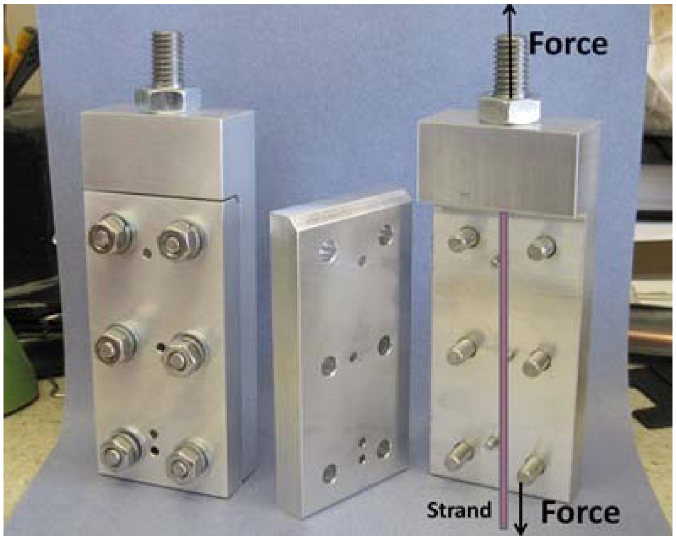

FIGURE 3. Grips selected for the stress rupture test

- Model-based cost prediction on high-strength fiber glass cost contribution to the system cost.
- Feasibility of high strength fiber replacing T-700 carbon fiber for hydrogen storage tank.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. H. Li, Achieving Hydrogen Storage Goals through High-Strength Fiber Glass, at the Hydrogen Material Workshop and PI Meeting in Golden, CO, on January 29, 2015.

2. H. Li, Achieving Hydrogen Storage Goals through High-Strength Fiber Glass, at U.S. DRIVE Technical Meetings in Detroit, MI, on March 19, 2015.

3. H. Li, Achieving Hydrogen Storage Goals through High-Strength Fiber Glass, at 2015 U.S. DOE Fuel Cell Technologies and Vehicle Technologies Annual Merit Review and Peer Evaluation Meeting, Washington, DC, June 8–12, 2015.

REFERENCES

1. http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22