CENTER FOR TRANSPORTATION AND THE ENVIRONMENT

Conformable Hydrogen Storage Coil Reservoir

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Project ID: ST126

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Start: August 2015

End: March 2017

Budget

Total Project Budget: $1,250,161

Total Recipient Share: $265,500

Total Federal Share: $984,661

DOE Funds Spent: $67,347*

*As of 2/28/16

Barriers Addressed

- High cost of 700 bar gaseous H_2 storage
- Rigid, cylindrical layout of conventional 700 bar tanks

Funded Partners

- High Energy Coil Reservoirs, LLC
- University of Texas – Center for Electromechanics

Relevance

Purpose: to develop game changing storage for compressed hydrogen gas that will provide a cost-effective and conformable storage solution for hydrogen vehicles

- Conformable, lightweight 700 bar gaseous hydrogen storage
- Storage system can be extended once proven at smaller sizes
- Continuous production processes
- Expect around 10% gravimetric capacity

Initial two segment test vessels

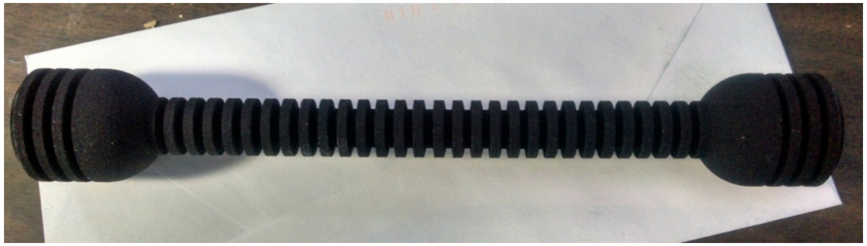
Relevance

- Final vessel ~10% gravimetric capacity
  - 5.6 kg H_2 storage has expected ~50 kg storage system mass
  - Exceeds DOE Ultimate target

- Cost target near DOE ultimate target
  - ~$280/kg H_2 stored at low production volumes
  - Based on conceptual 5.6 kg system

Pressure Vessel Process Background

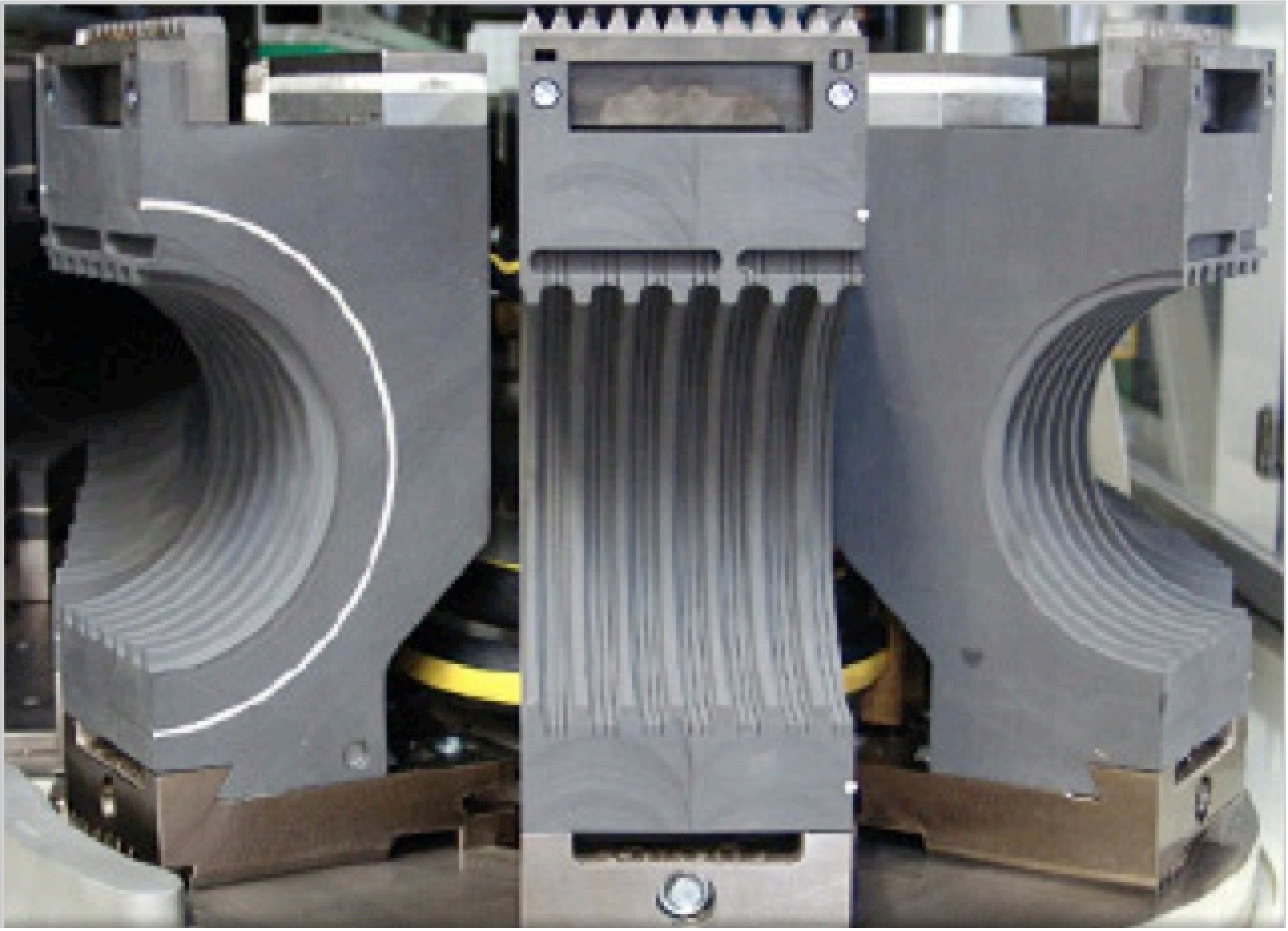
Pressure vessel is extruded resin liner with Kevlar overbraid – both <u>continuous processes</u>



Prototype sample of 700 bar corrugated core ~1.2” diameter

48” spool of continuous pressure vessels

Plastic Tube Corrugation Process



Plastic Tube Corrugation Process

Kevlar Overbraiding

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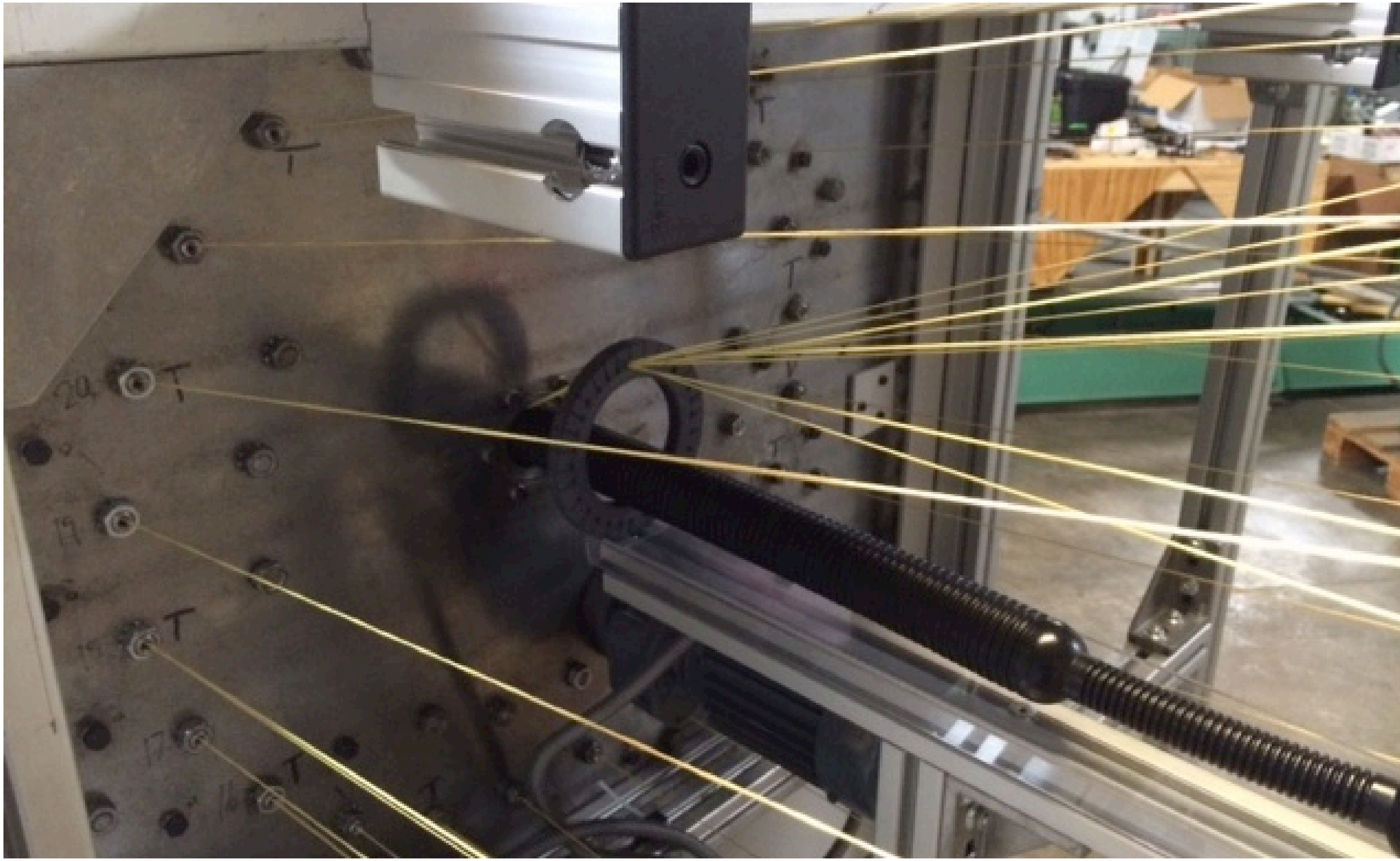


Kevlar Overbraiding

Approach – Key Steps

Complete

Resin selection
Order new corrugation tooling
Thermodynamic model of vessel filling
Design, build safety containment vessel

On going

Preliminary testing - existing vessel

Upcoming

Prototype cores with new tooling
Achieve 3.1X 700 bar burst pressure
Permeability testing 700 bar vessels
- baseline resin, new resin

Approach: Resin Selection

Key Material Requirements for successful prototype

- ***Hydrogen Leakage (< 0.05 g/hr/kg H_2 stored at 700 bar).***
- ***Operational Temperature Limit (-40°C ≤T≤ 85°C).***
- ***Corrugation Process Compatibility.***
  - Needs process compatible range of viscosity, melt temperature, and durometer.

Resin Selection - Accomplishments

A resin will be selected that offers:

- Superior resistance to hydrogen (low permeability)
- Compatibility with extrusion/corrugation process
- Compatibility with temperature extremes during H_2 fills

Most promising resins for prototype vessel permeability testing with are:

- Dupont Delrin (acetal)
- EVAL M100
- EVAL F101

Delrin granules

Resin permeability data at high pressure or with hydrogen is difficult to find, or non-existent

Resin Selection - Accomplishments

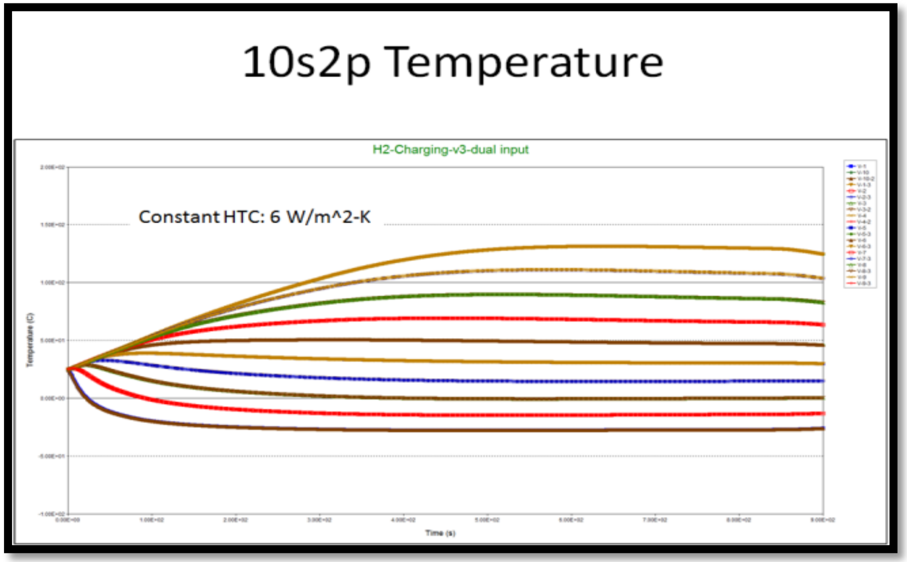
- **No clear trends observed to extrapolate permeability of different gases to predict hydrogen permeability**
- **Acetal and EVAL resins have an acceptable predicted thickness (<0.060”) and acceptable process properties**

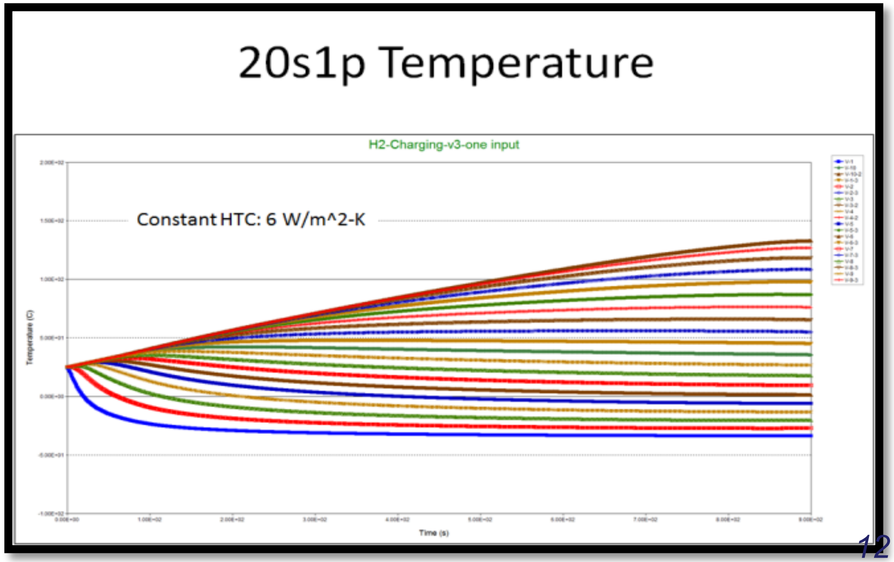
Resin / Polymer	Permeability (cm³ (cm)/ atm sec cm²)				Required thickness to meet 0.05 g/hr-kg H2 stored @ 700 bar	
	H_2	CO_2	He	N_2	*(cm)*	*(in)*
Hytrel 5556	na	1.80E-07	9.90E-08	1.40E-08	na	na
Acetal	1.50E-10	2.30E-09	na	na	0.0192	0.049 ★
EVALM100	1.62E-11	na	na	na	0.0021	0.005 ★
EVAL F101	1.30E-11	1.90E-12	3.70E-10	3.94E-14	0.0017	0.004 ★

Accomplishments and Progress

Thermodynamic Model:

- Filling rate does not seem restricted by smaller vessel connecting end sections
- Temperature rise in end vessels gets well above 85C in initial models
  - Used -40C hydrogen fill temperature
  - Affected by low heat transfer of dry weave and plastic liner
  - Last vessel in string is isolated and heats due to compression
  - Model not yet considering heat transfer between pressure vessel sections
  - Further refinement will continue in Q2

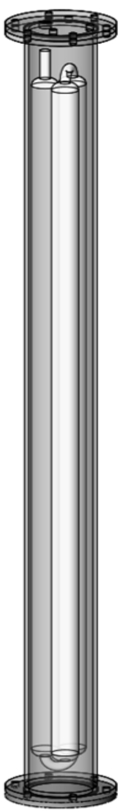




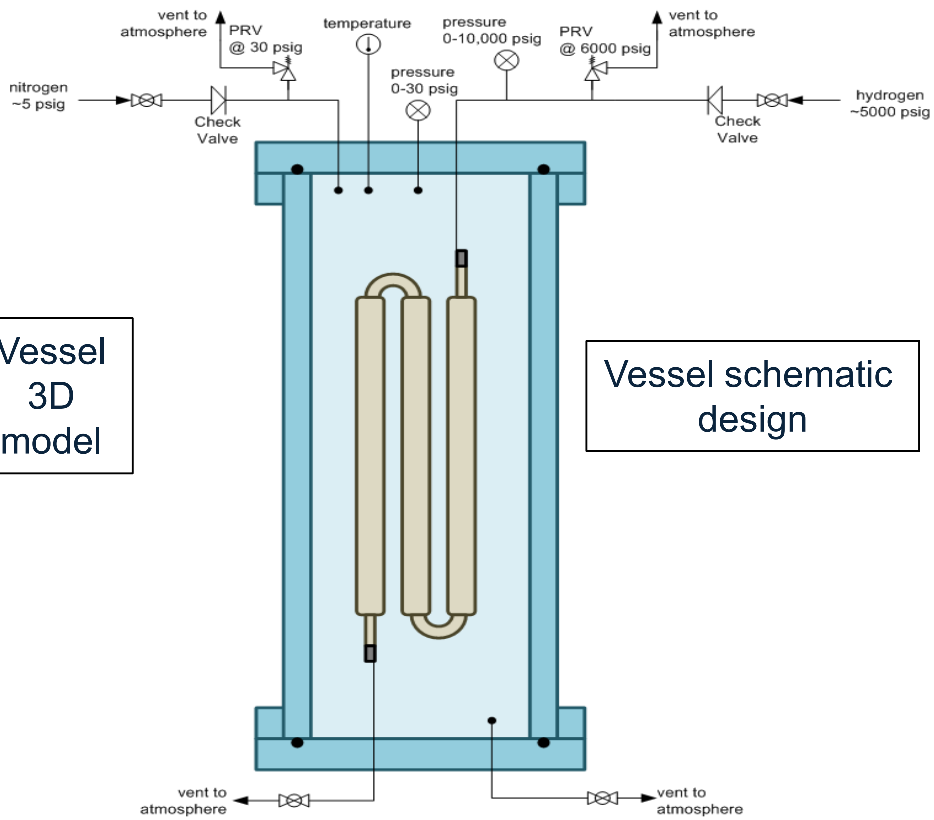
Accomplishments and Progress

Test Safety Containment Vessel

- Fabrication complete, all stainless steel components
- Designed to withstand 5,000 psi



Vessel 3D model

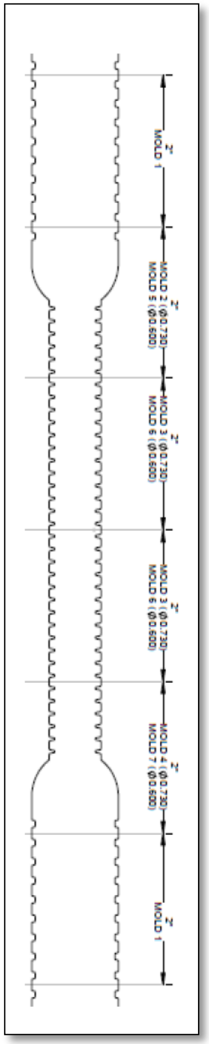


Vessel schematic design

Actual safety containment vessel with stand

Accomplishments and Progress

1. Hydrogen vessel tooling order completed
2. Resin selection completed for permeability testing
3. Add testing with existing pressure vessel design
4. Preliminary Thermodynamic modeling completed
5. Safety Containment Test Vessel complete
6. Hydrogen Safety Plan complete and approved
7. HECR current production pressure vessels built
8. Initial hydrogen permeability testing with current production HECR vessel (*estimated complete by AMR presentation)



Final resin core tool drawing

Collaborations: Project Possibilities

National Renewable Energy Laboratory

Investigating small project to utilize NREL programmable J2601 compliant station to test actual fills to 700 bar at -40C to validate and enhance thermodynamic model of vessel filling. Will use either reallocated internal project funds, or potentially Small Business Voucher to HECR.

CSA Group

We have a quote for a 3rd party 500 hour, 700 bar hydrogen permeability test at CSA's new hydrogen test facility. With successful internal project testing, the project team would like to pursue a 3rd party test to provide confirmation of extrapolated results from our 400 bar permeability testing.

Kuraray Group

Manufacturer of EVAL resins. Indicated interest in conducting initial permeability tests specifically with hydrogen if data is not otherwise available.

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Remaining Barriers and Challenges

Risks	Mitigation
Meeting hydrogen containment requirement - resin liner selection, limited real life data to support decision	• Comprehensive search of available resins • Detailed decision matrix to decide most promising candidates • Build and test several of most promising design alternatives
Prototype vessel design – reaching full required burst pressure	• HECR experience achieving similar burst pressures • New overbraid fiber identified which has better tensile properties than Kevlar
Prototype vessel production difficulty with new corrugation tooling design	• HECR will start with familiar, incumbent resin • Decision matrix has selected resins with similar processing properties

Proposed Future Work

- Task 1: Vessel Design and Validation
  - 1.1 Vessel Thermodynamic Modeling – Expected complete 4/30
  - 1.2 Resin Identification – Complete
  - 1.3 Procure Corrugation Equipment – Tooling expected mid July
  - 1.4 Test Vessel Design - Complete
  - 1.5 Test Vessel Fabrication
  - 1.6 Test Vessel Pressure Testing
  - 1.7 Design and Build H_2 Test Cell – Complete
  - 1.8 Test Vessel H_2 Leakage Testing
  - 1.9 Test Vessel Thermodynamic Model Validation
  - 1.10 Down-select Final Pressure Vessel Design
- Go/No-Go Decision Point

A Go/No-Go decision point follows the initial vessel testing after achieving the required burst pressure of 2170 bar and proving the hydrogen permeation is extrapolated below 0.05 g/hr/kg H_2 at 700 bar. Following this initial testing, the team will design an 1 kg, 700 bar complete storage system.

Proposed Future Work

- Task 2: H_2 Storage System Design, Fabrication and Testing
  - 2.1 Pressure Vessel Layout and Design
  - 2.2 Pressure Vessel Fabrication
  - 2.3 Pressure Vessel Burst Testing
  - 2.4 H_2 Storage System Design
  - 2.5 H_2 Storage System Fabrication and Inspection
  - 2.6 Preliminary Cost Model
  - 2.7 H_2 Storage System Assembly and Inspection
- Task 3: H_2 Storage System Demonstration
  - 3.1 Cyclic Pressure Demonstration
  - 3.2 Update Thermodynamic Model
- Task 4: Project Management and Reporting
  - 4.1 Project Kickoff
  - 4.2 1st Year Quarterly Reporting and Project Management
  - 4.3 2nd Year Quarterly Reporting and Project Management
  - 4.4 Project Closeout

Technology Transfer Activities

- HECR has established pathways to commercialize conformable fuel tanks via partnerships and industry connections.
- HECR is currently working on final testing for a commercially available conformable CNG storage vessel.

Testing of 5 DGE CNG tank system

Summary

- This project aims to reduce the cost, weight and difficult fit of conventional hydrogen tanks by developing a conformable 700 bar H_2 storage vessel.
- Three workable candidate resins identified
- Test cell and safety plan complete
- Preliminary large format testing underway

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