Pacific Northwest NATIONAL LABORATORY

Compatibility of Low Cost, High Pressure, Polymer H_2 Dispensing Hoses

Project ID# HD2030

PI-Kevin L Simmons, PNNL

Jennifer Lalli, NanoSonic

PNNL-Wenbin Kuang, Ken Johnson
Timothy Roosendaal
NanoSonic- William Harrison

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-142002

Pacific Northwest NATIONAL LABORATORY

NanoSonic Putting nanotechnology to work

Overview

Timeline

- Project Start Date: 1/15/2018
- Project End Date: 7/15/19
- % Completed: 75%

Budget

- Total Project Budget: $60K
  - Total Federal Share: 50%
  - Total DOE Funds Spent:

    $0K (DOE)

    $23K(cost share)

Barriers

A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis

I. Other Fueling Site/Terminal Operations

K. Safety, Codes and Standards, Permitting

Partners

- PNNL (Project Lab Lead)
- NanoSonic (PI)

Relevance

Objectives: To increase the safety and reliability of H_2 hoses while low H_2 permeation polymers and durable cryogenic composites to realize the H2@Scale objectives to reduce the cost of H_2

- Provide scientific and technical basis to enable full deployment of H_2 and fuel cell technologies by filling the critical knowledge gap for polymer performance in H_2 environments for dispensing hoses
- Develop standard test protocol for dispensing hose materials under high pressure hydrogen and sub ambient temperatures
- Develop a better understanding of material performance under extreme conditions for improved life cycle performance and costs

Barriers	Project Impact
A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis	Develop hose durability and reliability data for hydrogen compatibility guidance that will provide improved life-cycle costs for dispensing hoses
I. Other Fueling Site/Terminal Operations	Provide alternative dispensing hose options with lower costs and longer operational life
K. Safety, Codes and Standards, Permitting	Develop valuable test method that provide increased understanding of dispensing hose performance under extreme environmental conditions

Objectives

To determine the lifetime of NanoSonic H_2 hose polymer and composite constituents

- Testing material using time-temperature superposition (TTS) studies via dynamic mechanical analysis (DMA) under H_2
- Friction and wear resistance under in situ H_2 tribometry
- Multi-axis strain testing of composite materials under cryogenic conditions

Pacific Northwest
NATIONAL LABORATORY

Project Tasks

Task 1:

Technical Interchanges with NanoSonic

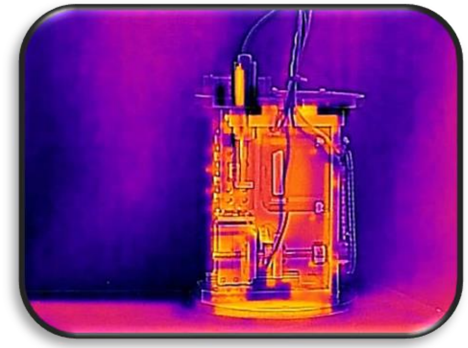
- Materials of interest developed by NanoSonic
- NanoSonic to provide PNNL with newly developed materials
- Interchange technical information

Task 2:

Cryogenic Multi-axis Strain Testing

Selection of relevant polymers

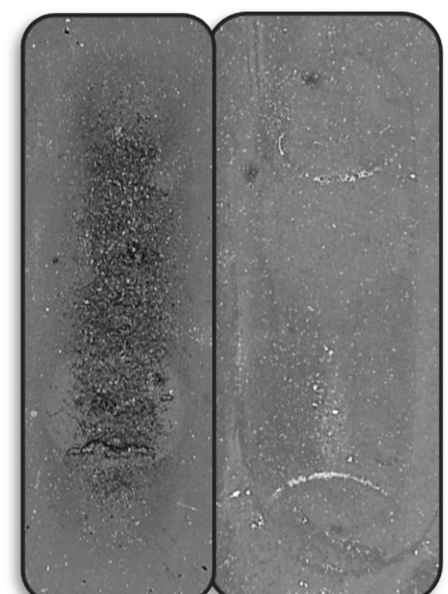
- Determining preliminary test parameters
- Conducting preliminary tests and establishing optimum conditions of operation



Task 3:

H_2 Tribology and H_2 DMA TTS for Polymer and Composite Lifetime Assessment

Baseline properties before and after exposure to H_2



Approach
In Situ Tribology Tester

PNNL Unique In situ Tribometer

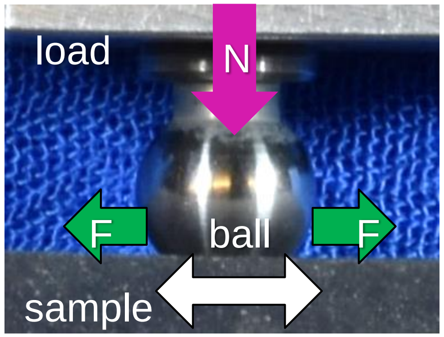
- Linear reciprocating adapted from ASTM G133
- Normal load (using weights) presses steel ball into moving sample
- Frictional force and vertical wear depth profiles measured in situ
- Pressures up to 5,000 psi hydrogen
- Ambient air and high-pressure argon tests run for comparison

Capabilities

- Produce abrasion, adhesion, displacement to target material
- Render coefficient of friction and wear rate
- Provide insights on tribological performance of materials
- Predict wear resistance of materials at various conditions and also useful in designing new materials with improved performance

Electrical Feedthroughs

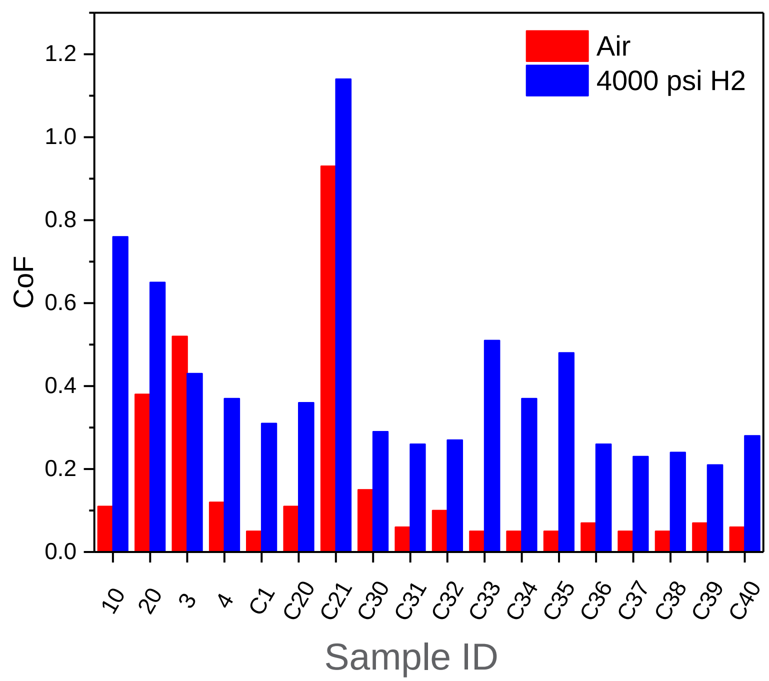
Tribometer



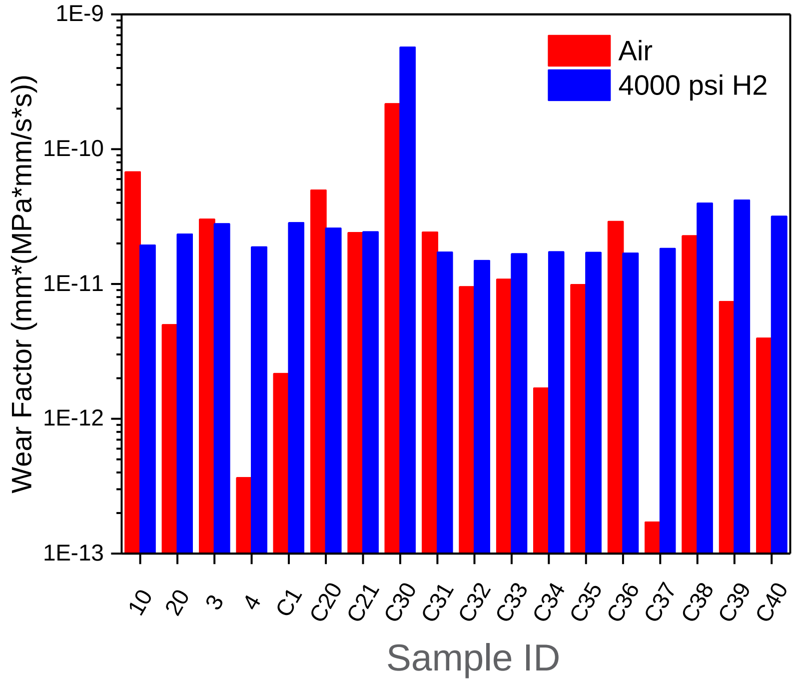
Accomplishments and Progress

Tribology Testing of NanoSonic hose barrier material at various conditions

High-pressure hydrogen effects on tribological performance investigated



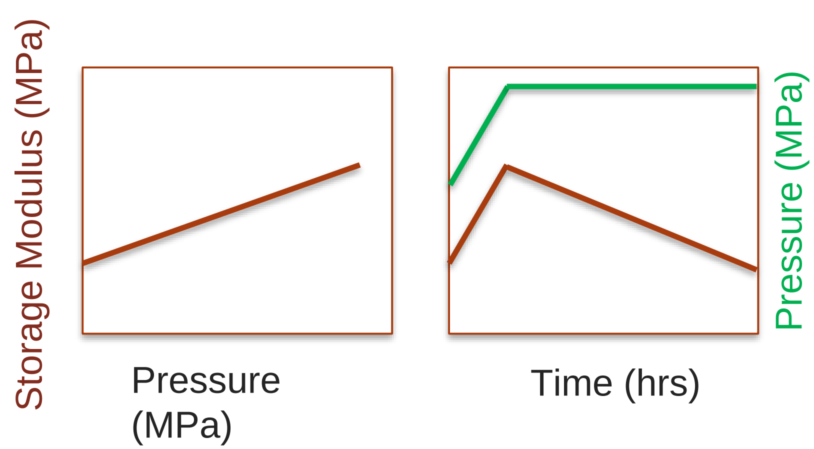
Examined in ambient air (red) and in 4000 psi hydrogen (blue)

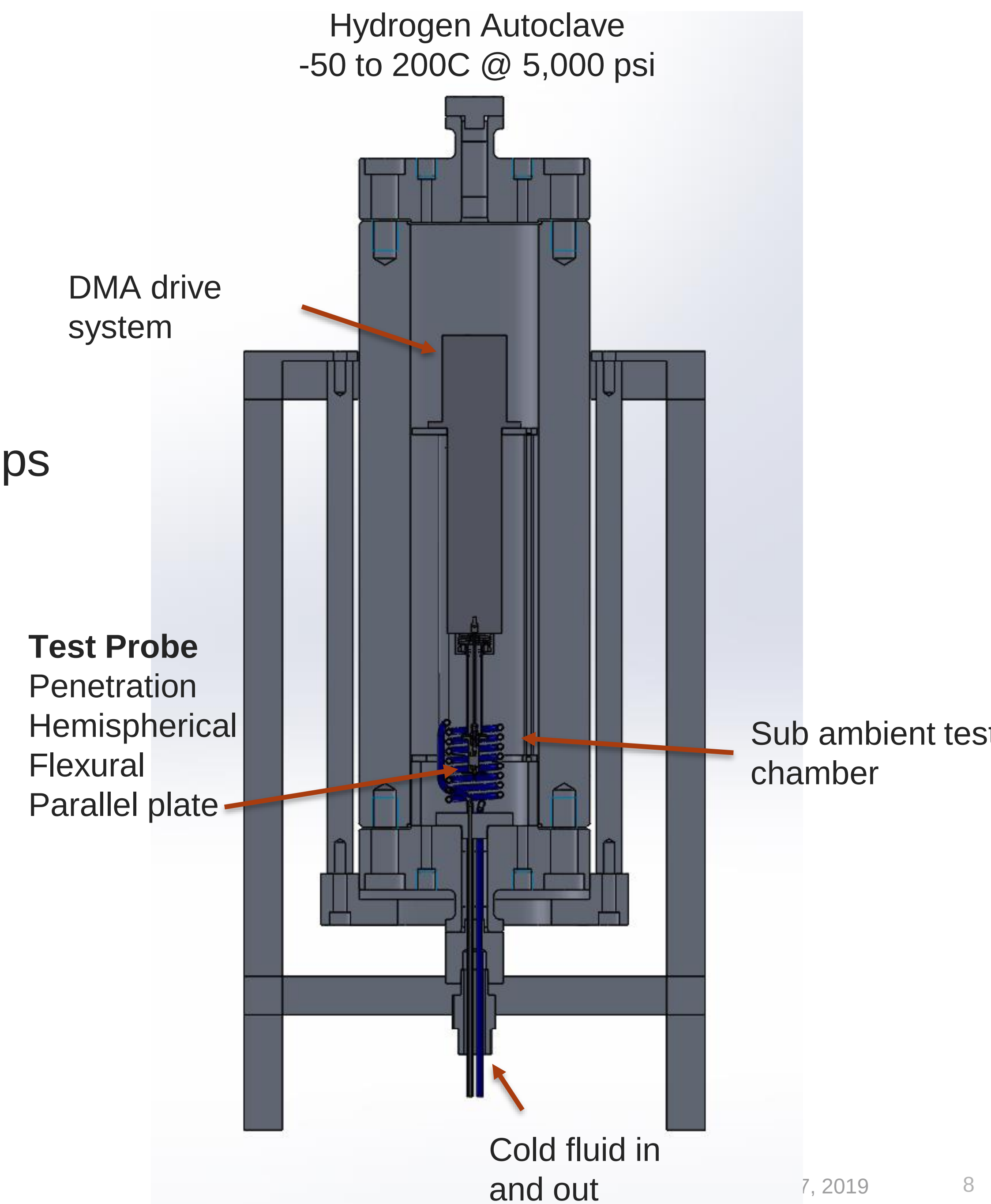


- Coefficient of Friction increases with high pressure hydrogen
- Wear factor increases, but is dependent on material type

Approach
In situ Dynamic Mechanical Analysis

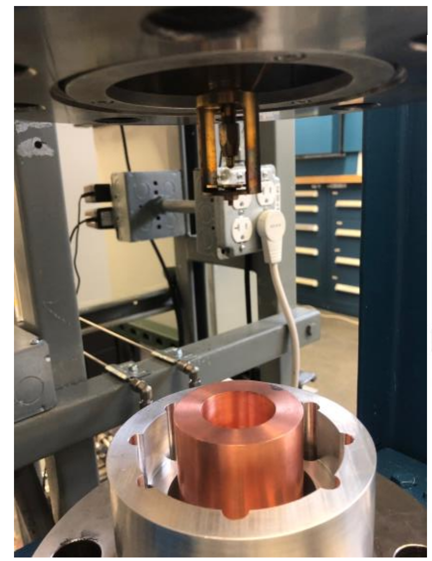
- Pressure range atmospheric to 30 MPa
- Frequency sweeps
- Creep and recovery
- Temperature range -50°C to 125°C
- Isothermal runs with pressure sweeps to investigate pressure effects on material with gas variable



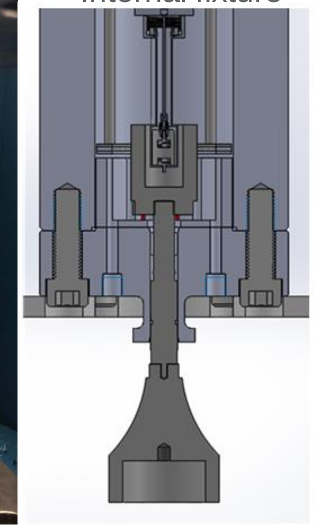


Accomplishments and Progress

In situ Dynamic Mechanical Analysis



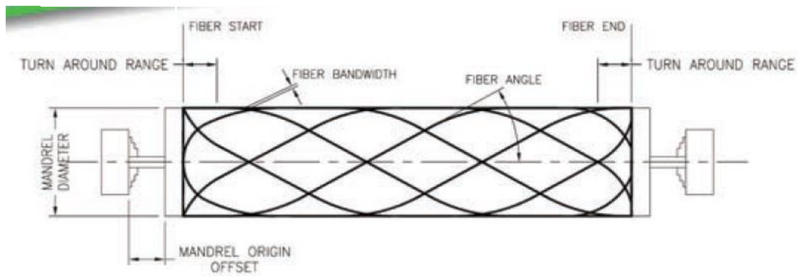
Internal fixture

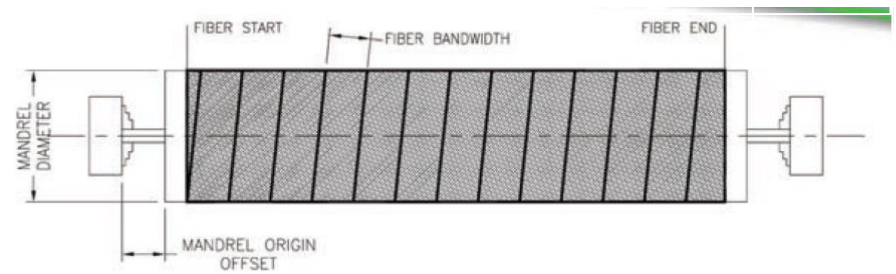


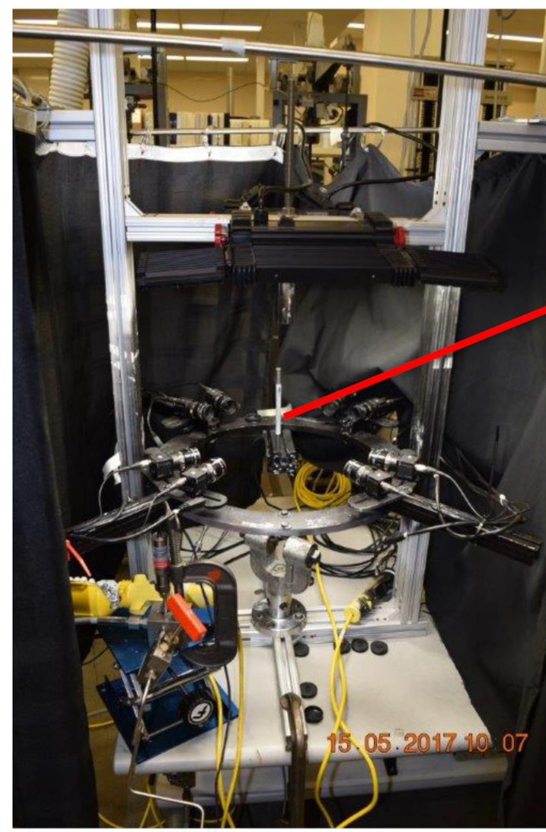
- In situ DMA is complete & baseline experiments ongoing isothermally with high-pressure helium
- Capable of measuring various mechanical property values (e.g. storage modulus) in situ on account of high pressure, gas species, and temperature
- Generate results for time-temperature superposition studies

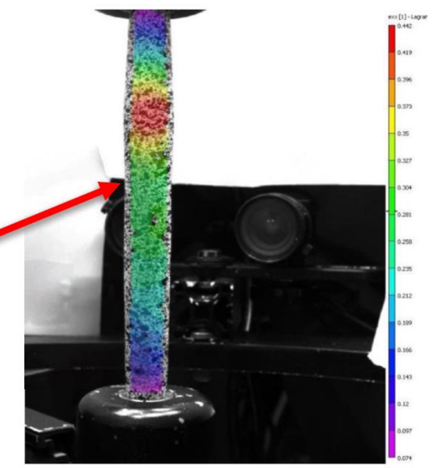
Approach

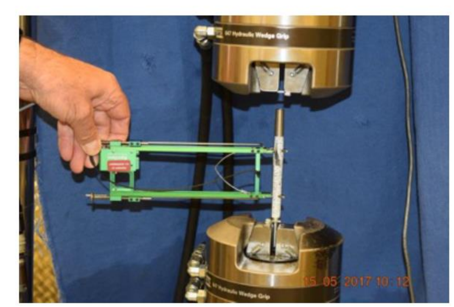
Composite Multiaxial Strain and Hose Testing







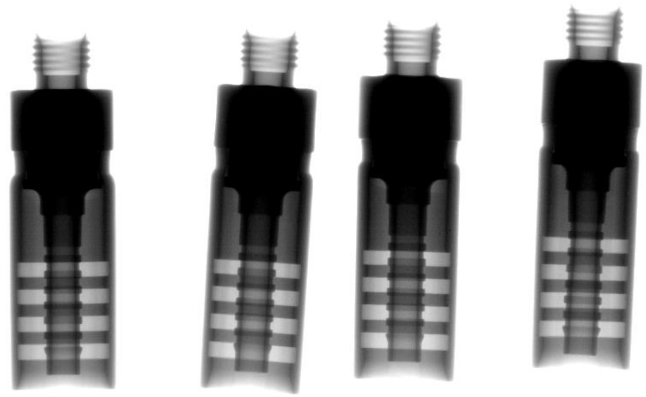


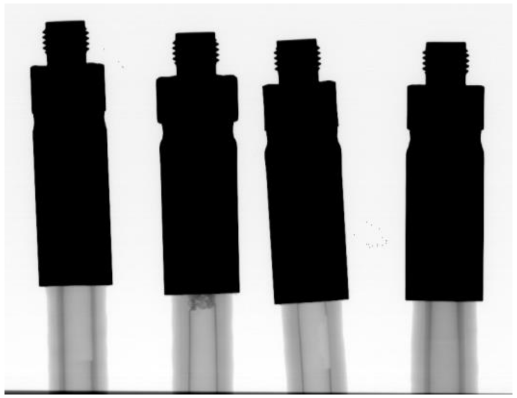


- Digital image correlation technique used to provide information on failure threshold during hose pressurization on where it fails and how it fails (strain analysis)

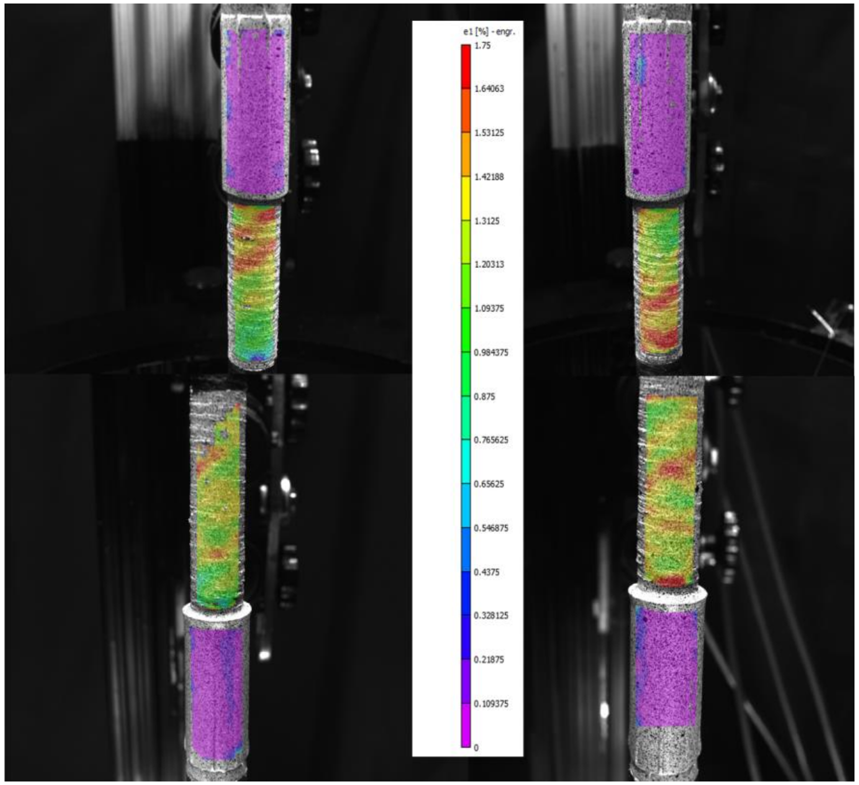
Accomplishments and Progress:

X-ray Examination and Hose Testing under 25,200 psi pressure





X-ray analysis pre-test



The strain in the tube portion was generally around 1% with spots up to 2%.

After pressure was released from the tube, there was approximately 0.1% residual strains in the tube.

The major strains in the tube are almost entirely in the axial direction.

Response to previous year's reviewers' comments

- Not previously reviewed

Collaborative Activities

Partner		Project Roles
Pacific Northwest NATIONAL LABORATORY	PNNL	Project Lead, Polymer Characterization, Wear and Tribological Studies, Mechanical Properties and High Pressure
NanoSonic Putting nanotechnology to work	NanoSonic	Project Manager, Principal Investigator, Material Development, Material Fabrication, and Polymer Characterization

Remaining Challenges and Barriers

Challenges and Barriers	Mitigation
Hose Connections	Testing to understand deficiency in hose connections that will allow for connector design changes
Hose Liner Barrier Cold Gas Properties	Testing to develop material properties in cold gas hydrogen that will provide insight on material deficiency
Composite in-plane Strain Understanding	Develop an understanding of the composite material limitations for hoses and tanks that will provide a more predictable understanding

Technology Transfer

- Industrial Collaborators
  - NanoSonic

Contacts

PNNL

Kevin Simmons (PI, PM)	☎: 509-375-3651	✉: kl.simmons@pnnl.gov
Wenbin Kuang	☎: 509-375-4338	✉: Wenbin.kuang@pnnl.gov
Ken Johnson	☎: 509-375-2241	✉: ki.johnson@pnnl.gov
Timothy Roosendaal	☎: 509-375-2743	✉: timothy.roosendaal@pnnl.gov

NanoSonic

Jennifer Lalli (PI)	☎: 540-626-6266	✉: jhlalli@NanoSonic.com
William Harrison (PM)	☎: 540-626-6266	✉: wharrison@NanoSonic.com

Summary

- Accomplishment:
  - Tribology testing completed on ambient air and 4000 psi hydrogen
  - Developed test method for strain measurement in hoses during burst testing
  - Pressure (burst) testing of sample hoses NanoSonic
  - High pressure in situ DMA in progress

- Future Work:
  - *In situ* Dynamic Mechanical Analysis (DMA) at 4000 psi in helium and argon
  - Sub-ambient testing at -40C in in-situ DMA at 4000 psi helium and argon
  - In-plane strain testing on composite plates
  - DIC burst testing of hoses
  - Recommendations to NanoSonic based on observations
  - Any proposed future is subject to change based on funding levels