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Fiber Reinforced Composite Pipelines

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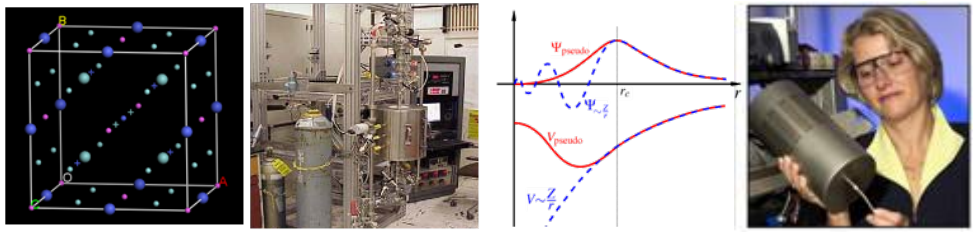


SRNL-STI-2009-00202

Project ID #: PD_42_ADAMS

Overview

Timeline

- Project start date:10/06
- Project end date:10/10
- Percent complete:60%

Budget

- Funding for FY08
  - FRP Pipeline: $200K
- Funding for FY09
  - FRP Pipeline $0K

Barriers

- Barriers Addressed
  - Hydrogen Leakage: <0.5%
  - $490K/mile and $190K/mile Transmission and Distribution Costs
  - Safe delivery of hydrogen of hydrogen at a cost target of $1.00/gge

Partners

- ORNL
- Polyflow
- Fiberspar
- ASME

Relevance – 2010 DOE Technical Targets

"***Develop hydrogen fuel delivery technologies that enable the introduction and long long-term viability of hydrogen as an energy carrier for transportation and stationary power***"

-DOE Hydrogen Delivery Goal

Target	Units	2012
Pipeline : Transmission	$/mile	$600,000
Pipeline : Distribution	$/mile	$270,000
Reliability/Integrity		Acceptable for H_2 as Energy Carrier (2017)
H_2 Leakage		<0.5% (2017)

Hydrogen Pipeline Delivery Targets

Objectives

Overall Project Scope:

- **Focused evaluation of fiber reinforced composite piping for hydrogen service applications.**
- **Assessment of the structural integrity of the FRP piping and leakage of existing commercial available FRP joint designs and joint components.**

Challenges:

- ***Reduced Installation Costs for FRP is an Attractive Attribute—One that Offers the Potential to Meet the Long Range (2017) Cost Targets for Installed Hydrogen Delivery Pipeline—Critical Issues That Need to be Addressed are as Follows: FRP Liner Hydrogen Embrittlement Susceptibility, FRP Liner Hydrogen Permeation, Qualification of Joint/Joint Components, and External Damage Robustness***

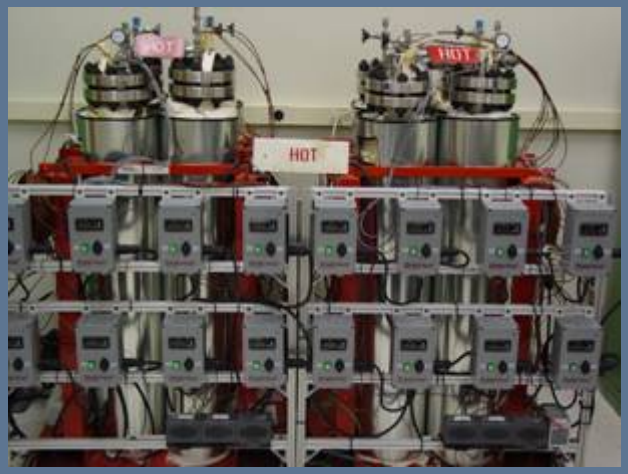
- ***To date Identification of a Gaseous Hydrogen Embrittlement Mechanism has not been Conclusively Identified—for FRP to Successfully Move Forward—this Issue must be Addressed—a Technical Basis Defining the Extent of FRP Susceptibility to Hydrogen Embrittlement must be Developed***

- ***Robustness with Respect to Leakage for Existing Commercially Available FRP Joint Components is a Concern—As Leak Testing Continues Should the Existing Joint Design Prove Unreliable—New Joint/Joining Technologies Will Need to Be Explored.***

Post FY08 AMR Project Scope

- **Complete Hydrogen Exposure of FRP Pipe Sections and Test Samples and Return to ORNL**
- **Complete Testing to Assess Impact of Joint Loading and Flexure on Commercial FRP Joint/joint Component Leakage**
  - **SRNL Fabricated a Simple Loading Rig to Place the Joint/Joint Components Under a Measured Flexural Load and Assess Changes in Leakage Rate**

Fiber Reinforced Composite Pipeline—H_2 Exposure



SRNL Hydrogen Exposure Station

4-Ft FRP Sections

Compression Samples

Tensile Samples

- **Hydrogen Exposure Test Matrix**
  - **1-Month & 1-year Exposures**
  - **2-FRP Pipe Section for Hydrostatic Burst**
    - 2-FRP Pipe Sections for Radius Bend Test
    - Glass Fiber, Resin, HDPE Liner Samples
    - 1000 psig @140°F
- **Control Sample Thermal Exposures**
  - **1-month and 1-year Exposures@ Temperature in Air**
- **Pipe Sections, Compression Samples, Tensile Dogbones, and DMA Samples**
- **7-month Exposure Completed in July/ 2008—Samples Shipped to ORNL for Testing and Evaluation**

Fiber Reinforced Composite Pipeline Leak Testing

- **DOT Gap Analysis Report Identifies 4 Major Needs for Composite FRP Piping**
  - Lack of Design Specifications
  - ***Qualified Joints/Joining***
  - Permeation
  - Robustness to External Damage

- **Performed Hydrogen Leak Testing Measurements Using H_2 @ 1000 psi Sensitivity of 10^{-9} cc/sec**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	$4.08X10^{-5}$
Poly 1	$5.5X10^{-2}$
Poly 1+	$4.67X10^{-2}$

Fiber Reinforced Composite Pipeline Test Under Applied Bending Load

- **DOT Gap Analysis Report Identifies 4 Major Needs for Composite FRP Piping**
  - Lack of Design Specifications
  - ***Qualified Joints/Joining***
  - Permeation
  - Robustness to External Damage

- **Performed Hydrogen Leak Testing Measurements Using H_2 @ 1000 Psi Sensitivity of 10^{-9} cc/sec**
- **Loaded in 3 Point Bending--2 Inch Displacement**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	$4.08X10^{-3}$
Poly 1+	$3.25X10^{-2}$

Fiber Reinforced Composite Pipeline Design Specification

• **ASME B31.12 Does not address non-metallic piping**

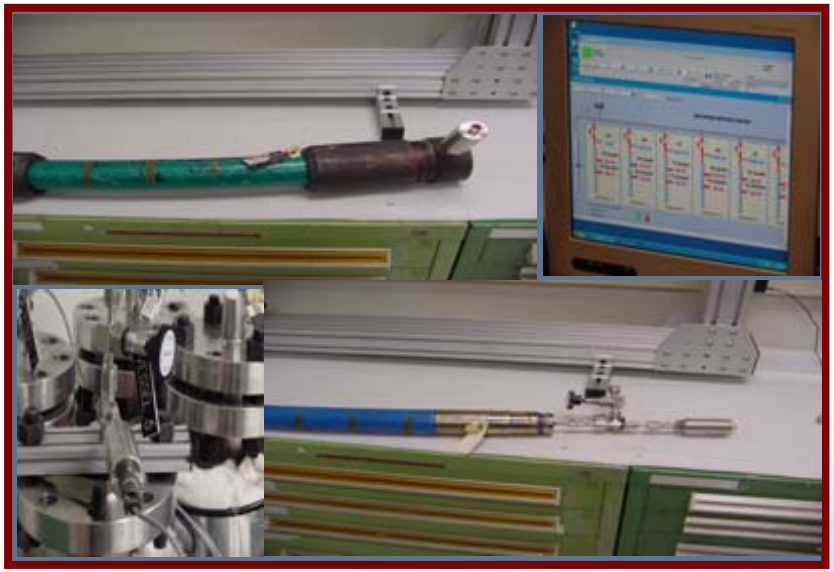
•**Technical basis is needed to provide direction to Users, Designers, and Manufactures to facilitate the application of FRP and non-metallic piping**

•**Performance based approach is proposed to address needed testing and acceptable criteria**

- **Design Pressure**
- **External Loads**
- **Permeation**
- **Leakage**

•**Hydrogen Specific Testing Techniques for Design Quality Data??**

- **DOT Gap Analysis Report Identifies 4 Major Needs for Composite FRP Piping**
  - ***Lack of Design Specifications***
  - **Qualified Joints/Joining**
  - **Permeation**
  - **Robustness to External Damage**



Fiber Reinforced Composite Pipeline Design Specification

- FRP Test Protocol Evaluations
  - FRP Pipe Fabricated to API 15HR and ASTM D2996 Code
- ASTM D2996 Requires:
  - D1598--Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
  - D638—Test Method for Tensile Properties of Plastics
  - D1599--Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
  - D2105--Test Method for Longitudinal Tensile Properties of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube
  - D2143--Test Method for Cyclic Pressure Strength of Reinforced, Thermosetting Plastic Pipe
  - D2412--Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- Fiberspar Tests for Product Quality
  - Radius Bend, Compression, Burst

- Parallels to Metallic Pipe Test
  - Tensile—ASTM E8
  - Fracture—K_{IH}, K_{IC}/J_{IC}--ASTM 1821/399/1681
  - Fatigue—ASTM E647
- Parallels to Composite Vessels
  - Burst
  - Pressure Cycling
  - Drop
  - Penetration (gunfire)

- Issue is How to Evaluate in Hydrogen and also how to use data for Engineering Design Purposes??

- New Tests/Codified Tests for Composite Fiber Reinforced Pipe in Hydrogen??

FRP Technology Gaps/Questions??

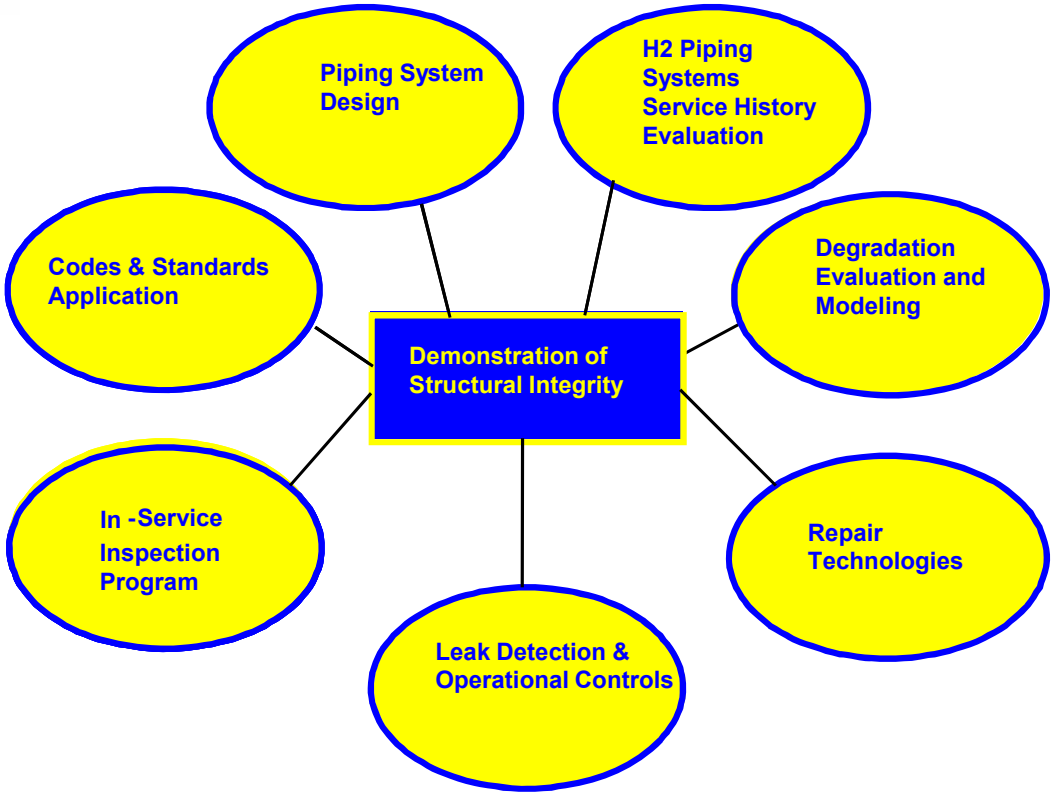
- **DOT Gap Analysis Report**
  - Lack of Design Specs
  - Joints/Joint Design
    - Leakage
    - Acceptance Criteria
    - Integrity of Metallic Joint Materials in Hydrogen
    - Needs for Alternate Designs
  - Permeation
    - Permeation vs Leakage
    - Permeation Acceptance Criteria
    - Standardized Test Technique??
  - Robustness—Third Party Damage
    - Repair vs Replace
- **Development of Suite of Standardized Test for Hydrogen Performance of FRP**
- **Development of Life Management Methodologies for FRP in Hydrogen**
  - Modifications/Amendments to B31.8S
- **Value of Sensored FRP Pipe**
  - Operation Procedures/Responses
  - Impact on Costs

Development of FRP Life Management

- A technical basis is needed for the design and life management of fiber reinforced piping
  - Need for Life Management program for FRP was introduced by SRNL at recent PWG and Hydrogen Delivery Tech. Team Meetings
- Detail investigation is needed in the following areas:
  - System Design and Applicable Codes and Standards
  - Service Degradation of FRP
  - Flaw Tolerance and Flaw Detection
  - Integrity Management Plan
  - Leak Detection and Operational Controls Evaluation
  - Repair Evaluation

Development of FRP Life Management

Life Management Program Elements



- A white paper prepared by SRNL and ASME has been developed that outlines the necessary elements for Design and Life Management for FRP for Hydrogen Service
- The execution of the plan will provide the needed technical basis to complete a:
  - FRP Design Section in B31.12
  - Structural Integrity standard for FRP (B31.8S)
- This technical basis is required to proceed with the ASME Code development of FRP for Hydrogen Service
- The work will be proposed as a joint industry and government project
  - Plan to discuss funding with DOE, DOT, FRP Manufacturers, Industrially Gas Suppliers, and Industrially Pipeline Constructors

SRNL FY09 Proposed AOP Scope

- **Continued Leakage Evaluation of FRP Commercial Joint Components—Long-Term Pressure Decay**
- **Hydrogen Absorption/Solubility Testing—Evaluation of the Long-Term Absorption/Solvation of Gaseous Hydrogen in Typical FRP Liner Materials—HDPE—Pressure Absorption and Thermal Desorption Experiments**
- **Structural Integrity—Hydrogen Embrittlement Susceptibility Evaluation (ASTM G142) of Metallic Commercial FRP Joint/Joint Component Materials**
- **Methodology for FRP Life Management**
- **Development of Design Specifications/Special Technical Report**

Summary

Fiber Reinforced Composite Pipeline

- ***Critical Issue for Demonstrating Feasibility of FRP Pipeline for Hydrogen Service is Development of the Technical Basis to Demonstrate Structural Integrity by Defining FRP Susceptibility to Hydrogen Embrittlement***
- ***Qualification of Existing Commercial FRP Joint Components With Respect to Leakage Identified in DOT Gap Analysis Report as 1 of 4 Major Needs for Demonstrating Composite FRP Piping Feasibility***
- ***Initial Leakage Results for FRP Commercial Joints Indicate Acceptable Leakage Rates***
  - ***Soil/Ground Movement/Relocation has Been Shown the Place Load on Pipeline Joint /Fittings and Can Exacerbate Leakage***
    - ***Joint Flexure Test Indicate Increased Leakage Rates***
  - ***Leakage Rate Values for This Research Would Translate to $\cong$ 0.5Kg H_2 /yr/joint***

- ***Critical to the Successful Implementation of FRP Pipelines is the Development of a Life Management Methodology that can Be Codified Through National Consensus Code Organizations***