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Fiber Reinforced Composite Pipelines

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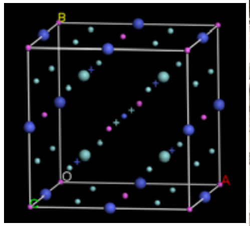
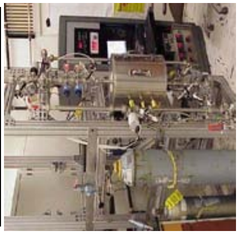




Project ID #: PD022

Overview

Timeline

- Project start date:10/06
- Project end date:10/13*
- Percent complete:50%

Budget

- Funding for FY10
  - FRP Pipeline $175K
- Funding for FY11
  - FRP Pipeline $150K

Barriers

- D. High Capital Cost and Hydrogen Embrittlement of Pipelines
  - $490K/mile and $190K/mile Transmission and Distribution Costs
- K. Safety, Codes and Standards, Permitting

Partners

- Commercial FRP Manufacturers
- ASME

* Project continuation and direction determined annually by DOE

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	2017
Pipeline : Transmission	$/mile	$490,000
Pipeline : Distribution	$/mile	$190,000
Reliability/Integrity		Acceptable for H_2 as Energy Carrier (2017)
H_2 Leakage		<0.5% (2017)

Hydrogen Pipeline Delivery Targets

Relevance – Objectives

Overall Project Scope:

- Development of Technical Basis for Life Management/Structural Integrity Methodology for Fiber Reinforced Composite Pipeline Materials
  - Environmental Effects
  - Flaw Tolerance Testing
  - Joint Integrity

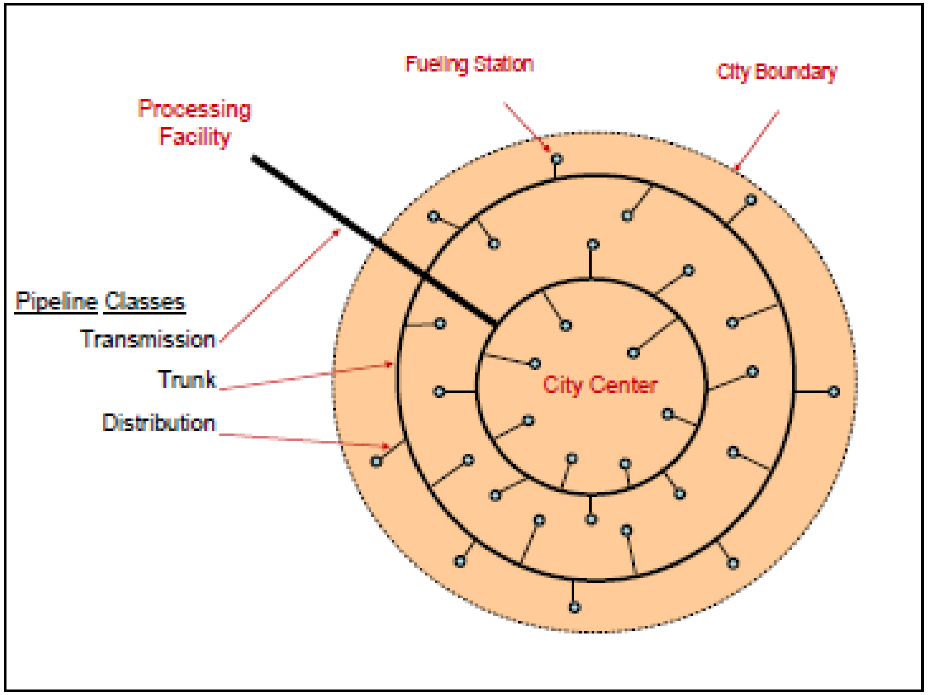
Challenges:

- 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

Targets:

- Implement Life Management Methodology Development
- Initiate Codification of FRP for Hydrogen Pipeline Service

Baseline Approach to Hydrogen Delivery



At Greater Than 5-10% Market Penetration in a Hydrogen Economy Hydrogen Delivery via Pipelines Becomes the Most Economical Option

Key Challenges for H_2 Delivery

Key Challenges

- Retro-fitting existing NG pipeline for hydrogen
- Utilizing existing NG pipeline for Mixed Gas Service
- New hydrogen pipeline: lower capital cost
- Leakage/Seals/Permeation
- Hydrogen Effects on Materials
- Lower cost and more energy efficient compression technology
- Lower cost and more energy efficient liquefaction technology
- Novel solid or liquid carriers

Comparison of Materials Options

Metallic Pipeline Materials

Carbon steel systems operating in hydrogen service with no history of failure that can be attributed to any of these factors. Generally the materials are low strength alloys.

Challenges for Carbon and low alloy steel :

- Affected by dry hydrogen gas service
- Show reduction in ductility, fatigue strength, burst strength
- Could be subject to sustained load cracking

Existing Technology Issues:

- Gaps in comprehensive material test data for carbon steel in a high pressure hydrogen environment. Additional design conservatism is utilized to account for these gaps
- Reduce conservatism may be possible when comprehensive test data is available
- Reduce Installation Cost Paramount for Meeting DOE Cost Targets

Fiber Reinforced Composite

Composite pipeline technology has the potential to reduce installation costs, improve reliability and provide safer operation of hydrogen pipelines.

Advantages to using FRP:

- Excellent burst and collapse pressure ratings
- Large tensile and compression strengths
- Superior chemical and corrosion resistance
- Long lengths can be spooled for delivery
- A few workers can install thousands of feet of pipeline per day

Existing Technology:

- FRP is an existing commercial technology currently employed in the oil & gas business—commercial product up to 4” diameter and 1500psig pressure rating

Economic Case Studies

Economic Advantage: Single Wrap Case Study

- 2.5 mile Gathering Line
  - Buried, Low Pressure

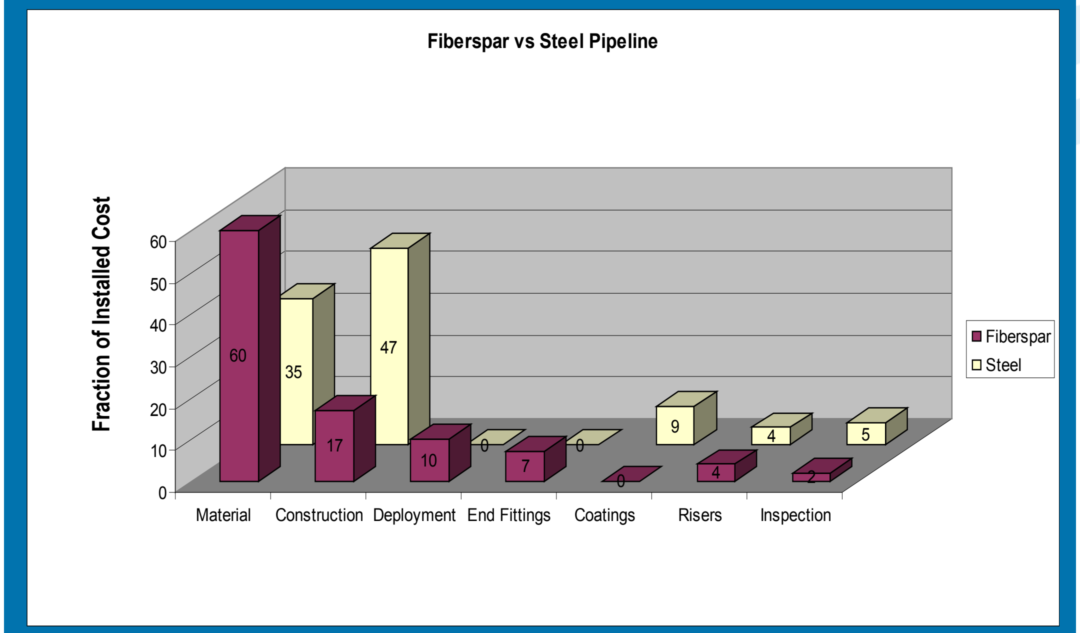
Welded Carbon Steel Construction

- Welded 2” Steel Line= $7/ft—labor, trenching, etc..
- Welded 2” Steel= $2.95/ft—materials cost

Single Wrap—4000ft Spool 1.75” ID

- Labor Cost—trenching, connections, etc..=$2/ft
- Materials Cost=$2/ft

Multi-Wrap Installed Cost 80% of Steel



- 1.5 Miles of 2.5” Flowline Installed and Operating in 8-hours
- 3.0 Miles of Saltwater Line Installed and Operating in 2.5 Days

Approximately 20-60% Cost Reduction for FRP vs Welded Steel Construction

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FRP Life Management

- SRNL in collaboration with ASME has developed an FRP Life Management Plan

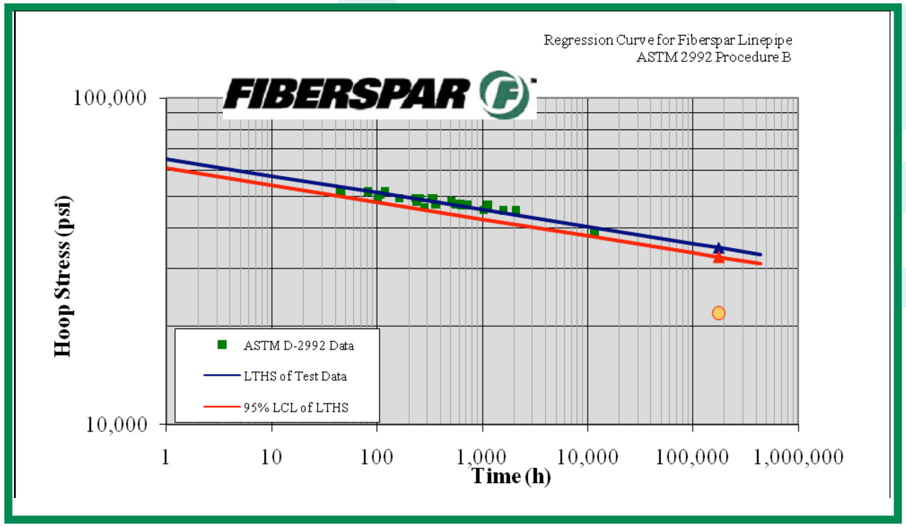
- Detail investigation is needed in the following areas:
  - System Design and Applicable Codes and Standards
  - Service Degradation of FRP
  - Flaw Tolerance and Flaw Detection
  - Integrity Management Plan
  - Leak Detection and Operational Controls Evaluation
  - Repair Evaluation

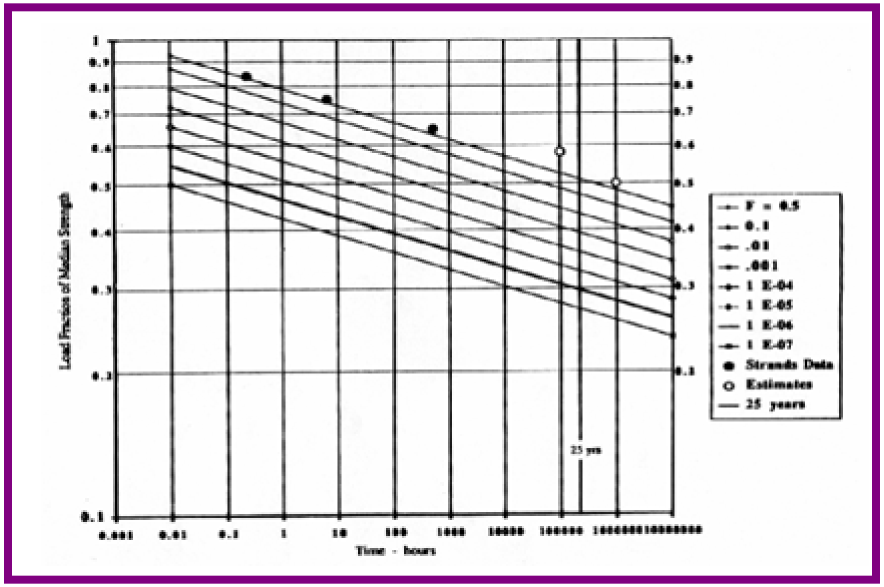
Design Margin for FRP

- Stress ratios are being set in newer standards to address reliability in regards to stress rupture as compared with the Hydrostatic Design Basis used in ASTM D2992.

- The date provided by Robinson, Aerospace Corporation has shown that a margin of 3.5 on the burst pressure (.28 Stress Ratio) will provide a creep rupture life of 25 years.

- Burst data for FRP Design to ASTM D2292 indicated that the margin on burst of 4.0 indicating that there is additional margin to address factors like third party damage, environment and additional service.





Robinson Aerospace Corporation

Experimental Testing

- Flaw Tolerance Testing
  - 40% Through Wall
  - 1-2” length
  - 0.125-0.25 “ width

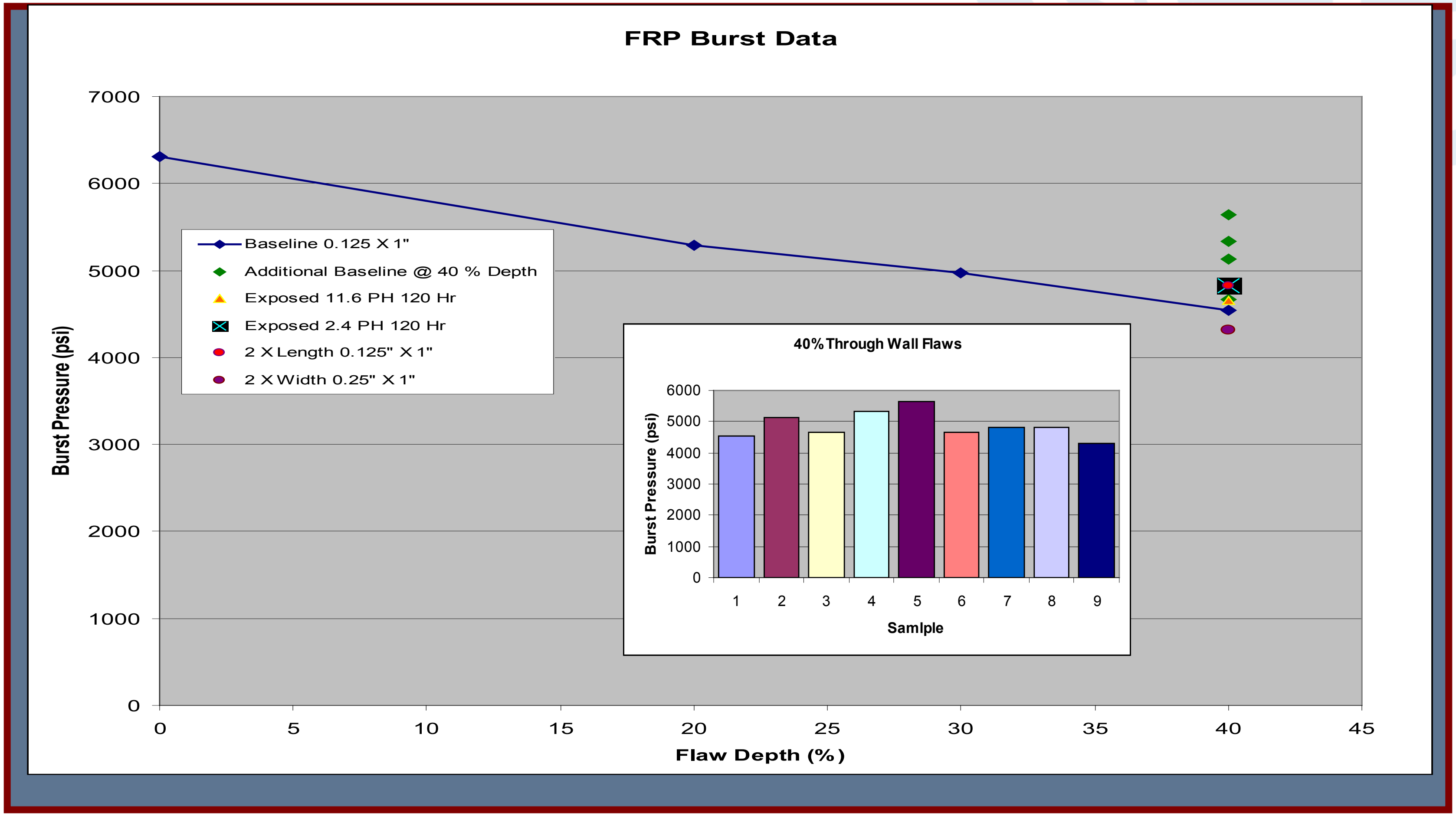
- Environmental Exposure Flaw Testing
  - 40% Through Wall
  - 1” length
  - 0.125” width
  - Exposure to pH 2.4 and 11.6@ 120 hrs

- Sustained Pressure Dimensional Stability
  - 1500psig (max rated pipe pressure)

- Joint Leakage
  - Bending Moment
  - Cyclic Load

Fiber Reinforced Composite Pipeline

Evaluation of Third Party Damage Multi - Layer Reinforcement



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Fiber Reinforced Composite Pipeline

Evaluation of Third Party Damage

Multi - Layer Reinforcement

Baseline Flaw

Width 1”x 0.125

40% Depth

- Reduction in Burst Pressure from unflawed condition to 40% through wall flaw of 28 % for short term burst and multiply layer reinforcement
- With the 40 % through wall flaw there is still a margin of approximately 3 above the rated pressure

Failure mode changes from global to local and then move back towards global as flaw depth increases

2 X Width 1”x 0.25

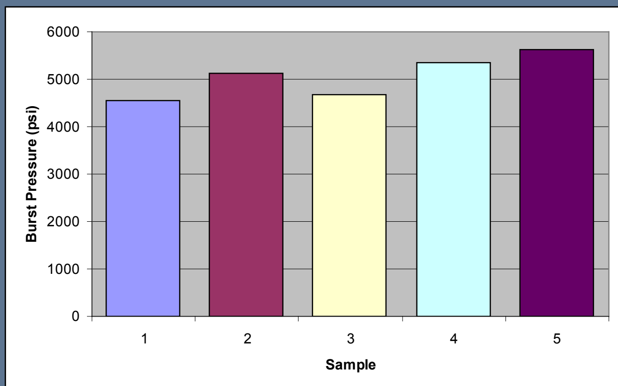
40% Depth

2 X Length 2”x 0.125

40% Depth

Fiber Reinforced Composite Pipeline

Evaluation of Third Party Damage Multi - Layer Reinforcement



Baseline Flaw

1”x 0.125

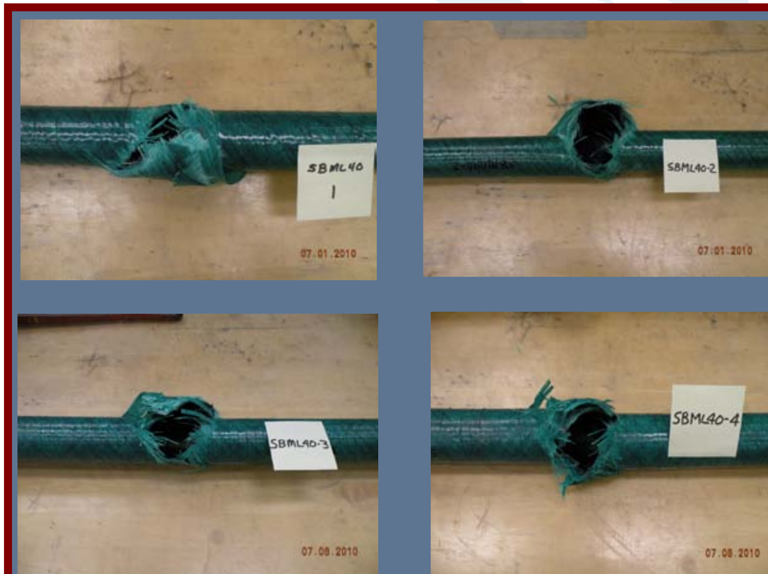
40% Depth

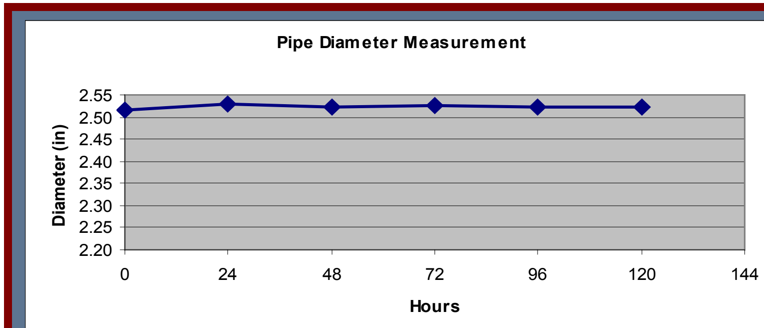
No Evidence of Bulging Under Sustained Pressure

Additional Baseline Flaw

1”x 0.125

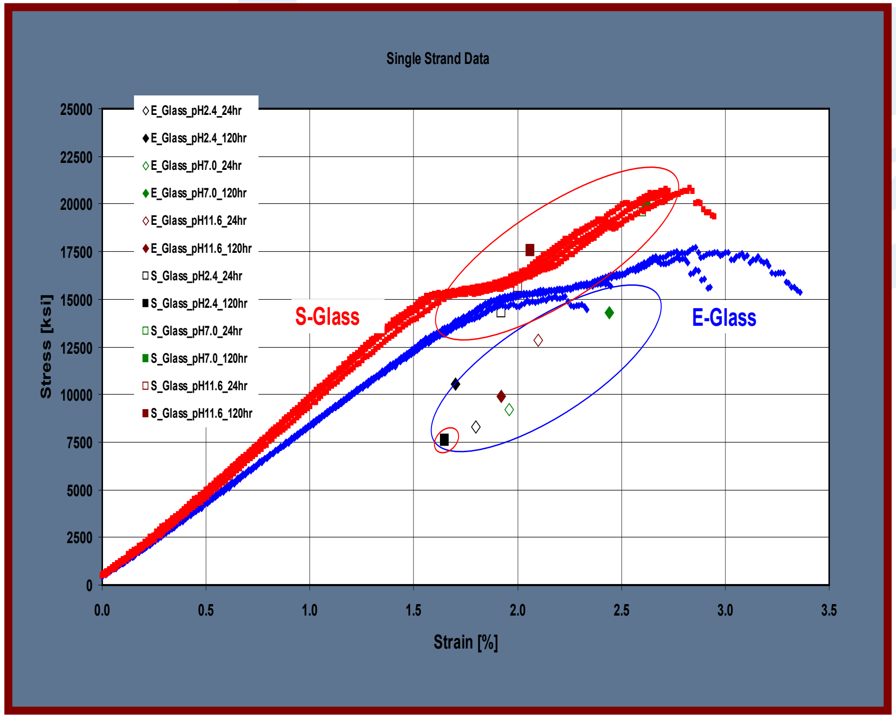
40% Depth

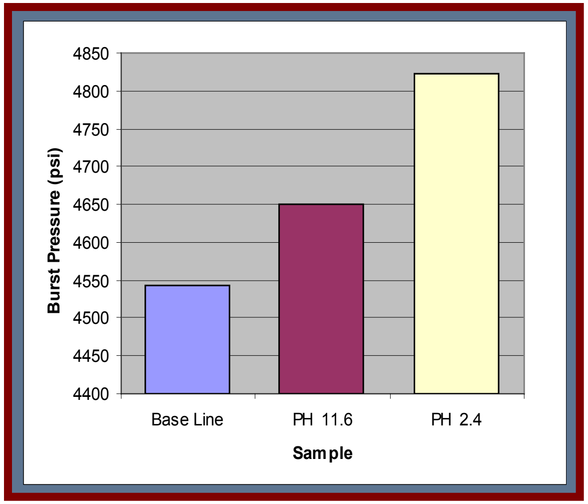




Chemical Exposure Tensile Strength Results

- The API 15HR Specification for High Pressure Fiberglass Line Pipe indicates the need to address an environmental service factor. But does not provide a methodology.
- A performance test as applied in pressure vessel standards may be a better option





1"x 0.25

40% Depth

PH 11.6 120 Hr

1"x 0.25

40% Depth

PH 2.4 120 Hr

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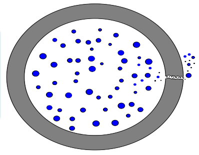
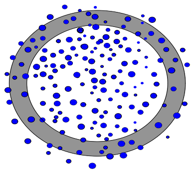
Fiber Reinforced Composite Pipeline Leak Testing



Physical Leak



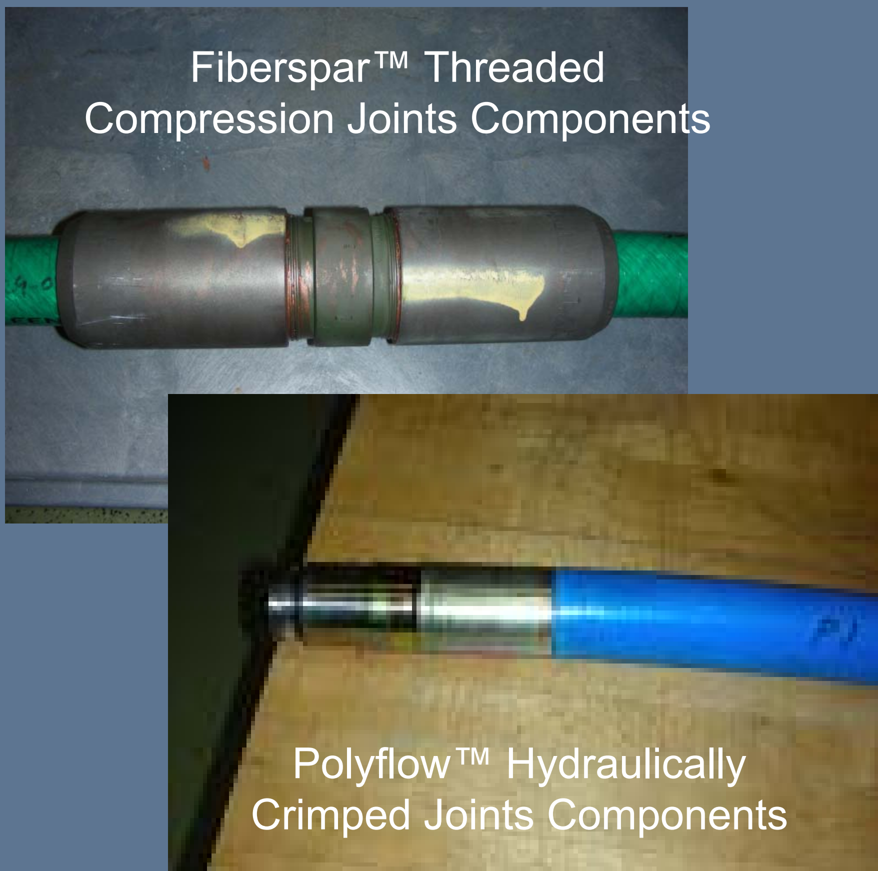
Permeation Leak

- **NASA Report NSS- 1740.16 Pressure boundary rupture only make up 14 percent of the hydrogen accidents. Accidents due to leakage and improper handling of hydrogen make up a greater percentage of the accident.**

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

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

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^{-5}-10^{-6} cc/sec**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	9.8×10^{-5}
Poly 1	9.5×10^{-3}
Poly 1+	5.0×10^{-2}

Standard Code Leak Testing Evaluates Leaks Rates on the Order of 10^{-2}-10^{-4}cc/sec of the fluid

Fiber Reinforced Composite Pipeline Test Under Applied Bending Load

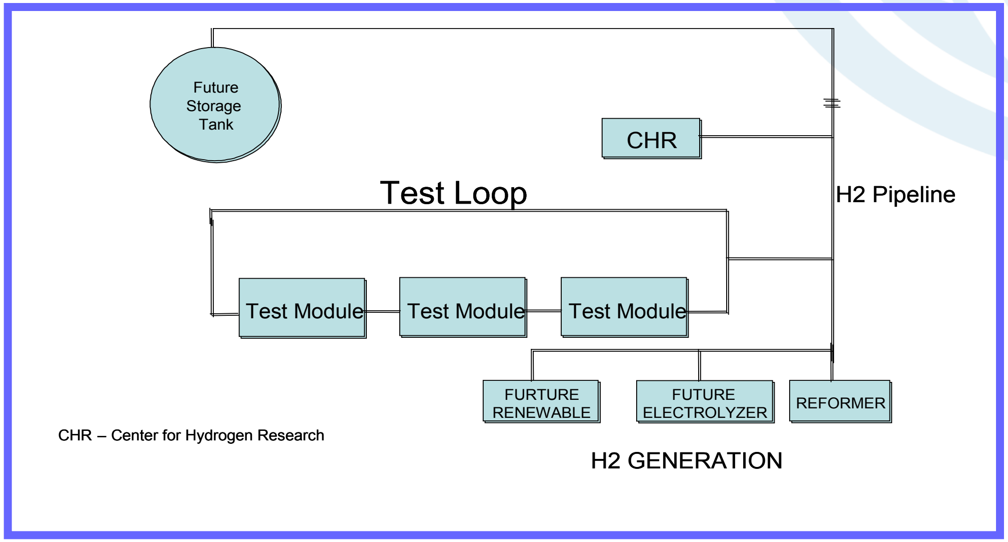
- **DOT Gap Analysis Report Identifies 4 Major Needs for Composite FRP Piping**
  - Lack of Design Specifications
  - ***Qualified Joints/Joining***
  - Permeation
  - Robustness to External Damage

- **Performed Hydrogen Leak Testing Measurements Using H_2 @ 1000 Psi Sensitivity of 10^{-5}-10^{-6} cc/sec**
- **Loaded in 3 Point Bending--2 Inch Displacement**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	1.4×10^{-4}
Poly 1 Cycled	8.9×10^{-4}
Poly 1+	8.1×10^{-4}

FRP Hydrogen Pipeline Demonstration Facility

Schematic of FRP Hydrogen Pipeline Demonstration Facility



- Proposed FRP Hydrogen Demonstration Loop between DOE, State of South Carolina
- Partners DOE, State of South Carolina, Aiken Country SRNL, ORNL, and ASME
- Workshop being planned for the summer 2012 to discuss path forward.

Summary

- FRP is an Attractive Technology with Potential to Reduce Overall Pipeline Installation Cost
    - Field Case Studies Indicate 20-60% Reduced Cost Over Steel Pipeline
- FRP Pipe Fabricated API 15HR is the most relevant Standard reviewed to date for the fabrication of FRP line pipe for hydrogen service. This standard can be tailored to address the need for hydrogen pipelines
- Flaw tolerance tests show that for flaws up 40% through-reinforcement and up to 2 " length and 0.25" width a factor of 3X margin is maintained on rated pressure
- Performance testing to evaluate both flaw tolerance and environmental effects has been conducted—integrated test better indicator of performance over previous testing of individual materials test
- The current recommendation is to develop a performance based design specification to be included in ASME B31.12
- Workshop to Discuss Next Steps Toward ASME Codification to be Held in FY11

Proposed Future Work – FY11-12 SRNL Scope for FRP

- Perform long term stress rupture test for flawed FRP samples
- Performed additional burst testing of flawed FRP samples on aged samples
- Recommend performance qualification tests for FRP in H2 service to ASME B31.12 Committee
- Evaluate B31.8S (Managing System Integrity of Gas Pipelines) for changes needed to address FRP in H2 service;
- Workshop with State of SC, ASME B31.12, and Key Technical Resources to Outline Plan for Inclusion of FRP in B31.12 Code