UT-BATTELLE

# Fiber-Reinforced Polymer Pipelines for Hydrogen Delivery

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OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

# Overview

- **Timeline**
  - Start: Jan 2005
  - On standby in FY 2006
  - Restart: Nov 2006
  - Finish: Project continuation & direction determined annually by DOE
- **Budget**

| | |
|---|---|
| FY 2005 | $151k |
| FY 2006 | $17k |
| FY 2007 | $450k |

- **Barriers**
  - D. High Capital Cost and Hydrogen Embrittlement of pipelines
  - Technical Targets: see next slide
- **Partners & Collaborators**
  - Fiberspar LinePipe, LLC
  - University of Tennessee, Knoxville
  - SRNL
  - Pipeline Working Group

# Overview

- **Technical Targets**

| Category | 2005 Status | 2012 | 2017 |
|---|---|---|---|
| **Pipelines: Transmission** | | | |
| Total Capital Investment (16-in pipeline, $/mile) | $720k | $600k | $490k |
| **Pipelines: Distribution** | | | |
| Total Capital Investment (2-inch pipeline, $/mile) | $320k | $270k | $190k |
| **Pipelines: Transmission and Distribution** | | | |
| Reliability/Integrity (including 3rd-party damage issues) | Acceptable for current service | | Acceptable for $H_2$ as a major energy carrier |
| $H_2$ Leakage | Undefined | TBD | < 0.5% |

# Objectives

| | |
|---|---|
| **Overall** | • 2012: Reduce the cost of hydrogen transport from central and semi-central production facilities to the gate of refueling stations and other end users to <$0.90/gge.<br>• Investigate use of fiber-reinforced polymer (FRP) pipeline technology to transmit and distribute hydrogen and achieve reduced installation costs, improved reliability, and safer operation of hydrogen pipelines. |
| **FY 2005** | • Demonstrate feasibility of FRP pipelines for hydrogen delivery<br>• Demonstrate reduced hydrogen permeability in polymer containing nanostructured composites |
| **FY 2007** | • Demonstrate integrity of FRP pipeline during hydrogen exposure<br>• Assess hydrogen leakage in existing liner materials<br>• Assess joining methods for FRP pipelines<br>• Determine integrated sensing & data transmission needs |

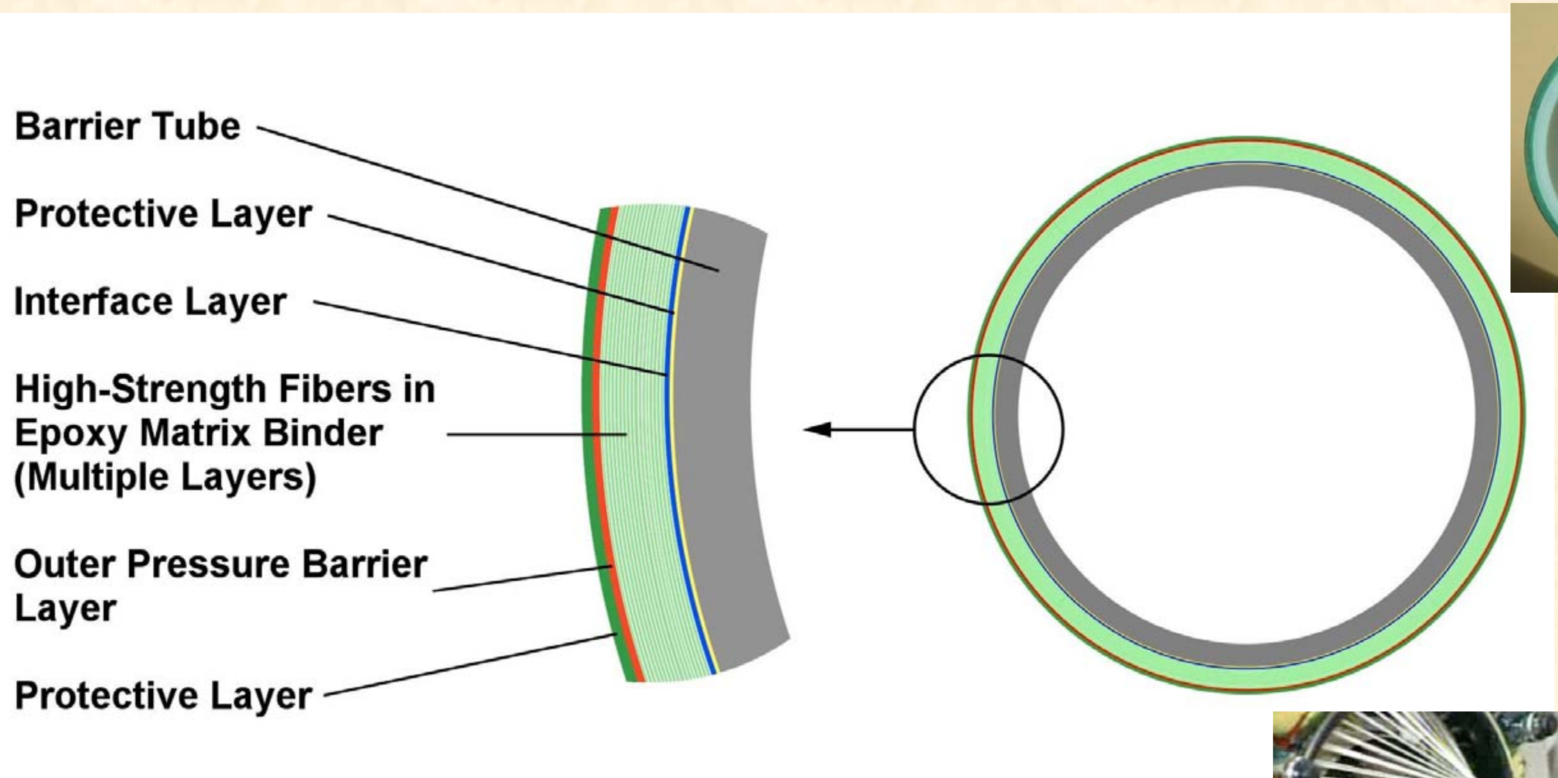
# Plan & Approach

- **Task 1: Evaluate FRP pipeline - 10% complete**
  - $H_2$ exposure testing of FRP pipeline specimens and constituent materials
- **Task 2: Evaluate FRP pipeline liner materials - 15% complete**
  - Tabulate $H_2$ permeabilities of pipeline liners
  - Measure $H_2$ permeabilities in OEM liners
  - Assess modification and treatment options
- **Task 3: Evaluate FRP pipeline joining and integrated sensor technologies - 0% complete**
  - Assess methods for joining during emplacement, joining FRP pipelines to other pipelines, and repairing FRP pipelines
  - Assess needs for structural health monitoring, leakage and gas property sensing
- **Task 4: Support Pipeline Working Group - 50% complete**

# The need for non-metallic pipelines

- Issues related to susceptibility of pipeline steels to hydrogen embrittlement
- Aggressive targets for reduction in capital costs
  - Welding is a major cost factor, and in some cases it can exacerbate hydrogen embrittlement
- Expectation that hydrogen delivery infrastructure will rely heavily on sensors and smart structure capabilities
- *Incremental improvements* to existing NG and $H_2$ pipeline materials, construction methods and monitoring or diagnostic systems might be inadequate to achieve the cost and performance goals
  - Major breakthroughs will be necessary

# Fiber-Reinforced Polymer (FRP) Pipeline Architecture




Inner thermoplastic pressure barrier is reinforced by helical windings of high-strength glass fiber yarns embedded in an epoxy thermoset resin matrix.

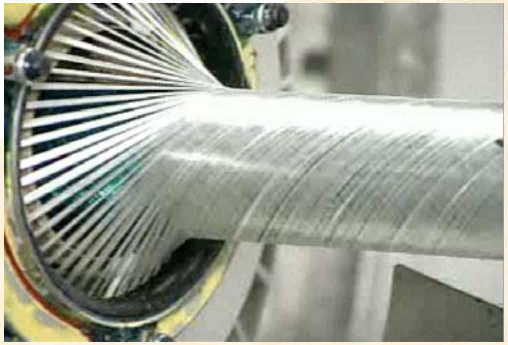


Photo provided by Fiberspar LinePipe, LLC

# Properties of FRP Pipelines

- **Construction provides anisotropic properties**
  – Hoop strength - extraordinary burst and collapse pressure ratings
  – Longitudinal strength - very high tensile and compressive strengths, up to 3% strain in service
- **Corrosion resistant and damage tolerant**
- **Sensors can be integrated into composite structure**
  – Real-time structural health monitoring
  – Real-time operational parameters
  – Reduce or eliminate need for pigging operations

# Properties of FRP Pipelines

- **No welding and minimal joining**
  - Many miles of pipeline can be emplaced as seamless monolith.
- **Emplacement requirements are less stringent than those for metal pipeline**
  - FRP pipeline can be installed in areas where right-of-way restrictions are severe.

# FRP Pipeline Installation

Video used with permission of Fiberspar LinePipe, LLC.

# Capital cost estimate for FRP hydrogen transmission pipelines

- **Compare today's FRP pipeline costs with capital cost target**
- **Employ Hydrogen Delivery Scenario Model (HDSAM version 1.0, 4/1/06) to calculate delivery criteria**
  - Model inputs and assumptions:
    - City populations: 200,000 and 1,000,000 people
    - Market penetration: 50% light-duty HFC vehicles
    - Distance from centralized production to city: 62 mi
    - $P_1$ = 1000 psi, $P_2$ = 700 psi
- **FRP pipeline**
  - Commercial, off-the-shelf linepipe for oil & gas market
  - 4.5-inch ID, 1500 PSI rating, PE liner

# Capital cost estimation for FRP hydrogen transmission pipelines

- Calculation of pipeline quantity and size (Panhandle B equation)

| City Size | Peak $H_2$ Demand (kg/d) | Daily $H_2$ Demand (kg/d) | 4.5-inch ID Pipelines Required | ID Required for Single Pipeline (inches) |
|---|---|---|---|---|
| 200,000 | 58,600 | 41,000 | **4** | 7.25 |
| 1,000,000 | 293,000 | 205,000 | **17** | 13.75 |

Photos provided by Fiberspar LinePipe, LLC

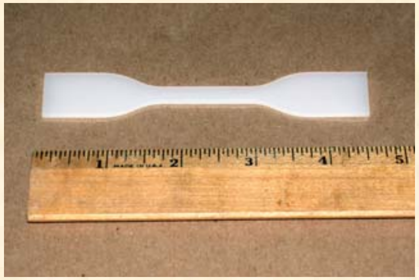
# Capital cost estimation for FRP hydrogen transmission pipelines

- Today's cost for 4.5-inch ID, 1500 psi-rated FRP pipeline (pipeline, connectors, transportation, installation) is approximately $80k per mile
- Installation of four 4.5-inch ID pipelines would require investment of approximately $331k to $346k per mile, excluding ROW and permitting costs.

| City Size | FRP Pipelines Installed ($k/mi) | Est'd ROW & Permitting ($k/mi) | Total Capital Investment ($k/mi) | 2017 Cost Target ($k/mi) | 16-inch ID Steel Pipeline ($k/mi) |
|---|---|---|---|---|---|
| 200,000 | 331 – 346 | 250 | 581 – 596 | 490 | 636 |

# Task 1: Evaluate FRP Pipeline Materials and Construction

- **No known hydrogen-related damage mechanisms in FRP pipelines or constituent materials**
- **ORNL, Fiberspar, and SRNL devised a screening procedure to assess effects of $H_2$ exposure on samples of commercially available FRP pipeline and constituent materials**
  - Immersion in 1500 psi $H_2$
  - Accelerated aging (60°C)
  - 1 wk, 1 mo, 1 yr exposures



# Task 1: Evaluate FRP Pipeline Materials and Construction

- **Post-exposure, perform standard test procedures to detect gross structural degradation**
  - *Hydrostatic burst pressure tests* to assess the overall integrity of the samples
  - *Compression tests* to determine the ultimate compressive strength of the laminates and determine any adverse effects on the polymer matrix
  - *Bend testing* to assess the integrity of the laminate
  - Test for conformance with API 15HR, ASTM D2996, ASTM D2517 specifications

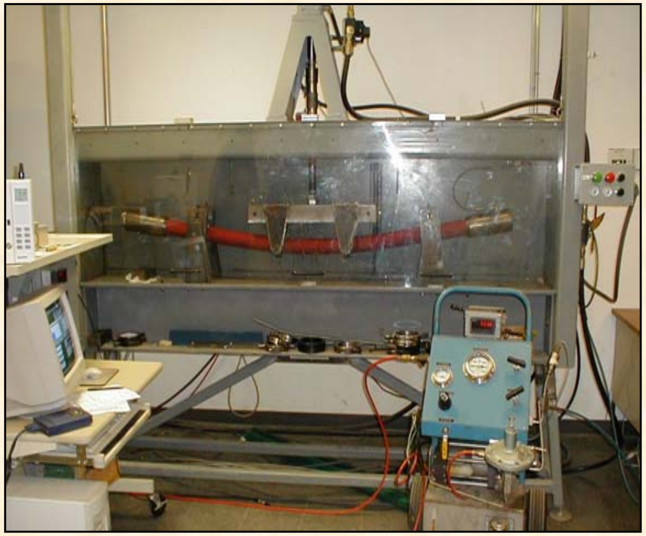


Photo provided by Fiberspar LinePipe, LLC

# Task 1: Evaluate FRP Pipeline Materials and Construction

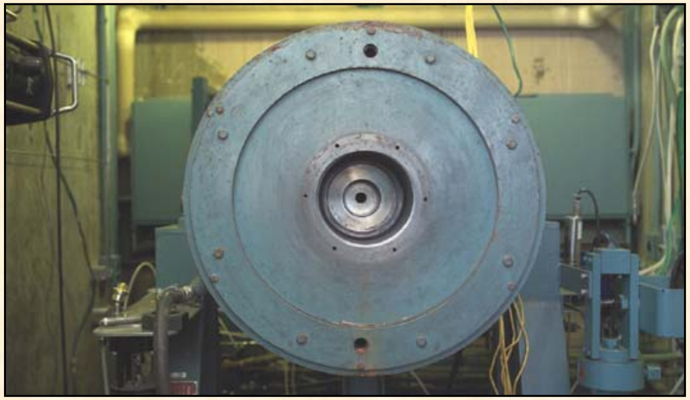
- **Post-exposure: perform bench-scale tests of constituent materials**
  - Dynamic mechanical analysis of polymer liner and epoxy-fiber matrix “dogbones” to measure changes in the dynamic modulus and the glass transition temperature
  - Pull-tests of glass fibers and yarns

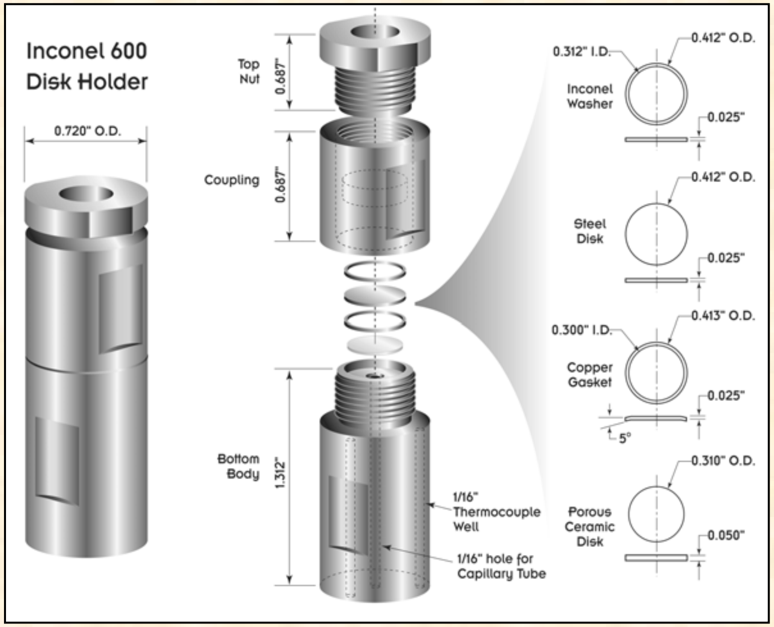
# Task 2: Evaluate FRP pipeline liner materials

- **Assess permeabilities of liner materials and determine improvement required**
  – Tabulate published data on diffusivities/permeabilities of liner materials (*e.g.* PE, PEX, HDPE, PA, PVDF)
  – Perform measurements of diffusivities/permeabilities in samples of OEM liner materials (unpublished data)
  – Evaluate applicability of existing modifications and treatments for reducing permeability in liner materials
  – Use the RD&D Plan, H2A model and other resources to quantify acceptable leak specifications
- **Use this information to propose path forward for liner development**

# Task 2: Evaluate FRP pipeline liner materials

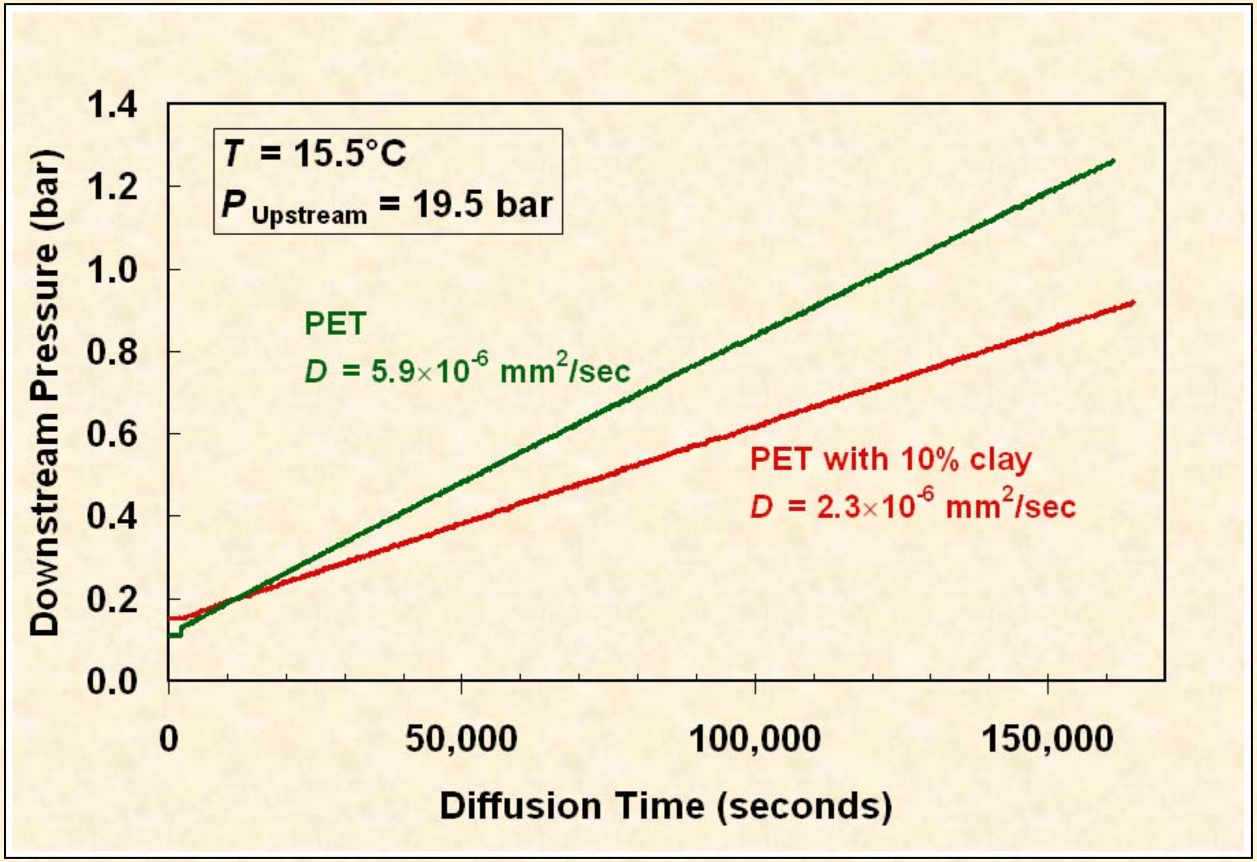
- **$H_2$ permeability & mechanical testing using ORNL hydrogen-service Internally Heated Pressure Vessel**
  - Test rig for automated measurements of diffusivity and permeability of metal and polymer films
  - Temperature range 5-1000ºC (±0.1°C in range 5-90°C) and $H_2$ pressures up to 40,000 psi





# Task 2: Evaluate FRP pipeline liner materials

- $H_2$ diffusion rate measurements for PET polymers



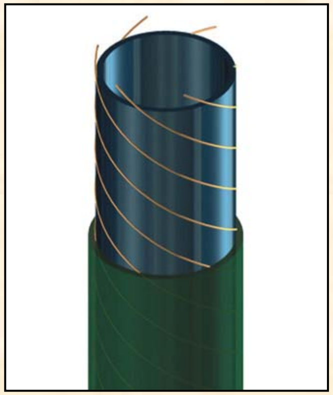

Temperature stabilization is essential for obtaining reproducible results.

# Task 3: Evaluate joining and integrated sensor technologies

- **FRP hydrogen pipelines will require methods for**
  - Joining pipeline during emplacement
  - Joining to pipelines of other materials
  - Repairing/replacing segments of pipeline
- **Current joining methods use mechanical compression and elastomeric seals and do not rely on adhesives or plastic welding**
  - Evaluate efficacy of methods for hydrogen service
  - Consider new methods of joining the pipelines, such as plastic and composite welding
- **Joining methods must withstand high pressures and exposure to harsh environments above & below ground.**

# Task 3: Evaluate joining and integrated sensor technologies

- **Integrated sensors & communication**
  - Leakage
  - Local strain
  - Pressure and temperature data
- **Predecessors**
  - “Smart” CNG tanks
  - ACPT “smart” composite drill pipe
  - Fiberspar SmartPipe™



# Future Work

- **FY 2007**
  - Report results from short- and medium-duration hydrogen exposure in pipeline specimens
  - Complete evaluation of liner materials and report results
- **Early FY 2008**
  - Complete assessment of joining and integrated sensor technologies and report results
  - Collaborate on development of codes & standards for hydrogen-service FRP pipelines

# Project Summary

**Relevance:** Need viable alternative to metallic pipelines to achieve cost and performance targets for hydrogen transmission and distribution

**Approach:** Investigate applicability of FRP pipelines being used for operations in oil & gas and develop path forward for hydrogen

**Progress:** Cost scenario shows FRP pipelines competitive; compatibility and permeation testing underway

**Collaborations:** Industry, university, national lab

**Future:** Codes & standards; prototype FRP pipeline system for $H_2$ delivery; demonstration project