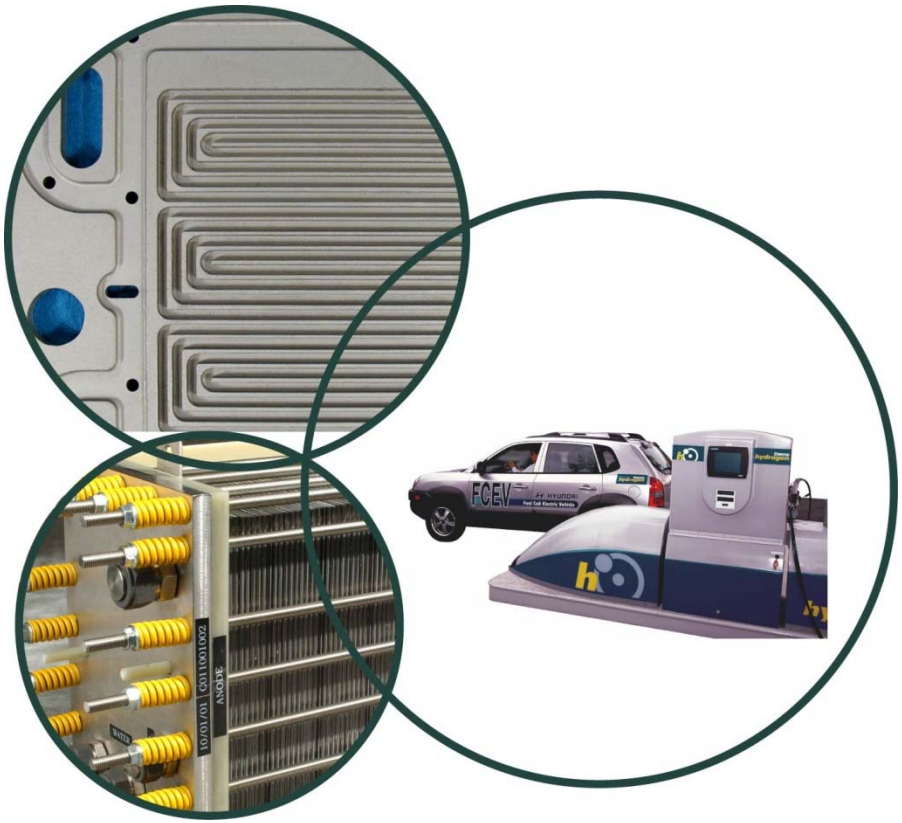
Composite Technology for Hydrogen Pipelines



Barton Smith, Barbara Frame, Lawrence Anovitz

Oak Ridge National Laboratory

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Overview

Timeline

- Start: Jan 2005
- Finish: Project continuation & direction determined annually by DOE

Budget

- Total project funding
  - DOE: $1.65M
- Funding received in FY 08
  - $600k
- Funding for FY 09
  - $0k

Barriers

- D. High Capital Cost and Hydrogen Embrittlement of pipelines
- Technical Targets on next slide

Partners & Collaborators

- Fiberspar, PolyFlow
- Arkema, Ticona, Fluoro-Seal
- 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%

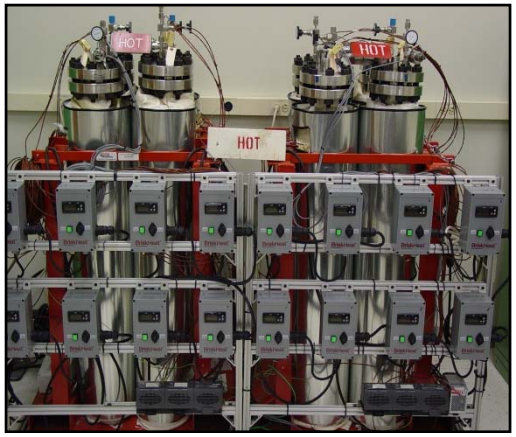
* Leakage targets are being reviewed by the Delivery Tech Team

Project Milestones

Month-Year	Milestone or Go/No-Go Decision
Sep 2008	Milestone: Survey of existing modifications and treatments available for reducing permeability in liner materials completed and reported (completed) Milestone: Recommendations for sensor integration, manufacturing and joining technologies completed and reported (50% complete)
May 2009	Milestone: Hydrogen compatibility evaluations of composite pipeline materials and construction completed (60% complete).

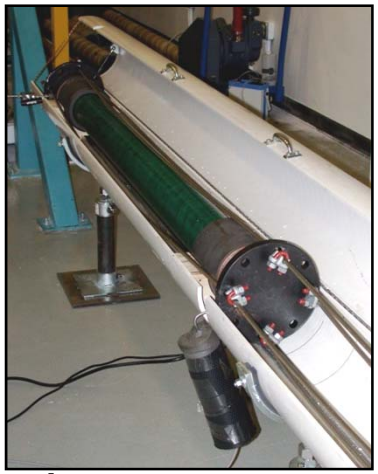
Technical Accomplishments-Initial Compatibility Testing Completed

- **Pipeline materials compatibility testing**
  - **Hydrogen compatibility testing following eight-month accelerated-aging protocol showed no quantifiable materials degradation**
  - **Hydrogen leakage measurements in Fiberspar pipeline yielded smaller than predicted leak rates (<0.02% per day); Leakage measurements on PolyFlow FRP pipeline are in progress**
  - **Fiberspar FRP pipeline specimen passed blowdown testing with hydrogen**



H_2 exposure station at SRNL

Pipeline test specimens



Leakage measurement at ORNL

Technical Accomplishments-Evaluation of Joining Technologies is Progressing

- **Joining and sensor technologies**
  - **Hydrogen leakage through Fiberspar LinePipe™ connectors is very low, <3x10^{-6} mol/s**
  - **Collaborative effort underway with SRNL to assess joint loading, pipeline flexure, and pressure/temperature cycling on hydrogen leakage for both Fiberspar and PolyFlow connectors**

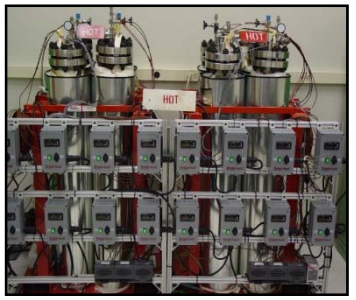
FiberSpar connector with compressive o-ring seals

PolyFlow swaged connector

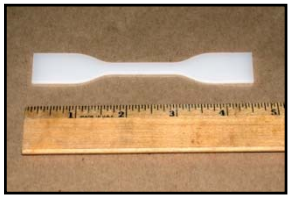
Completed H_2 compatibility screening of Fiberspar pipeline and materials

- **Accelerated aging procedure used to screen for long-term effects of hydrogen exposure on composite pipeline under normal-usage conditions**
- **Completed post-treatment tests of Fiberspar pipeline and constituent materials**
  - **Immersion in 1000 psi H_2**
  - **Accelerated aging at 60°C for 8 months (equivalent to 5+ years at RT)**
  - **No deleterious effects due to H_2 noted in qualification testing of pipelines or tensile and DMA testing of polymer and composite matrix resin specimens**

4-pt bending test specimen



SRNL H_2 exposure station



Liner test specimen

Compression test specimen

Glass filament specimen

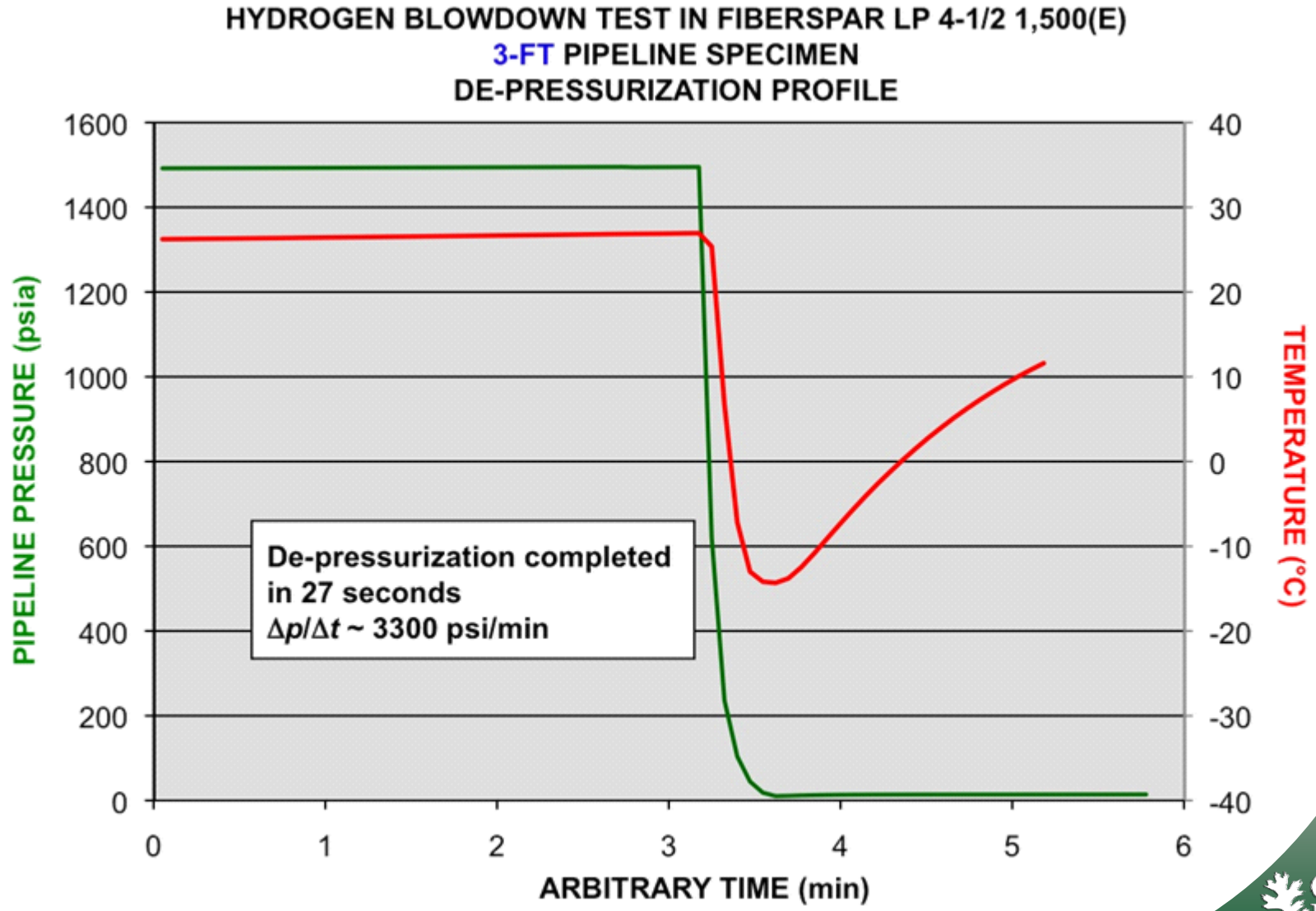
Hydrogen blowdown testing of composite pipeline

- **Guidance: API 15S - Qualification of Spoolable Reinforced Plastic Line Pipe, Appendix D**
  - **Specimen filled with hydrogen* to pressure rating, specimen heated to temperature rating, these conditions held until pipeline structure is saturated with gas**
  - **Following hold period, specimen de-pressurize at a rate greater than 1000 psi/min**
  - **Following blowdown, specimen liner was examined and no visual evidences of liner blistering or collapse**

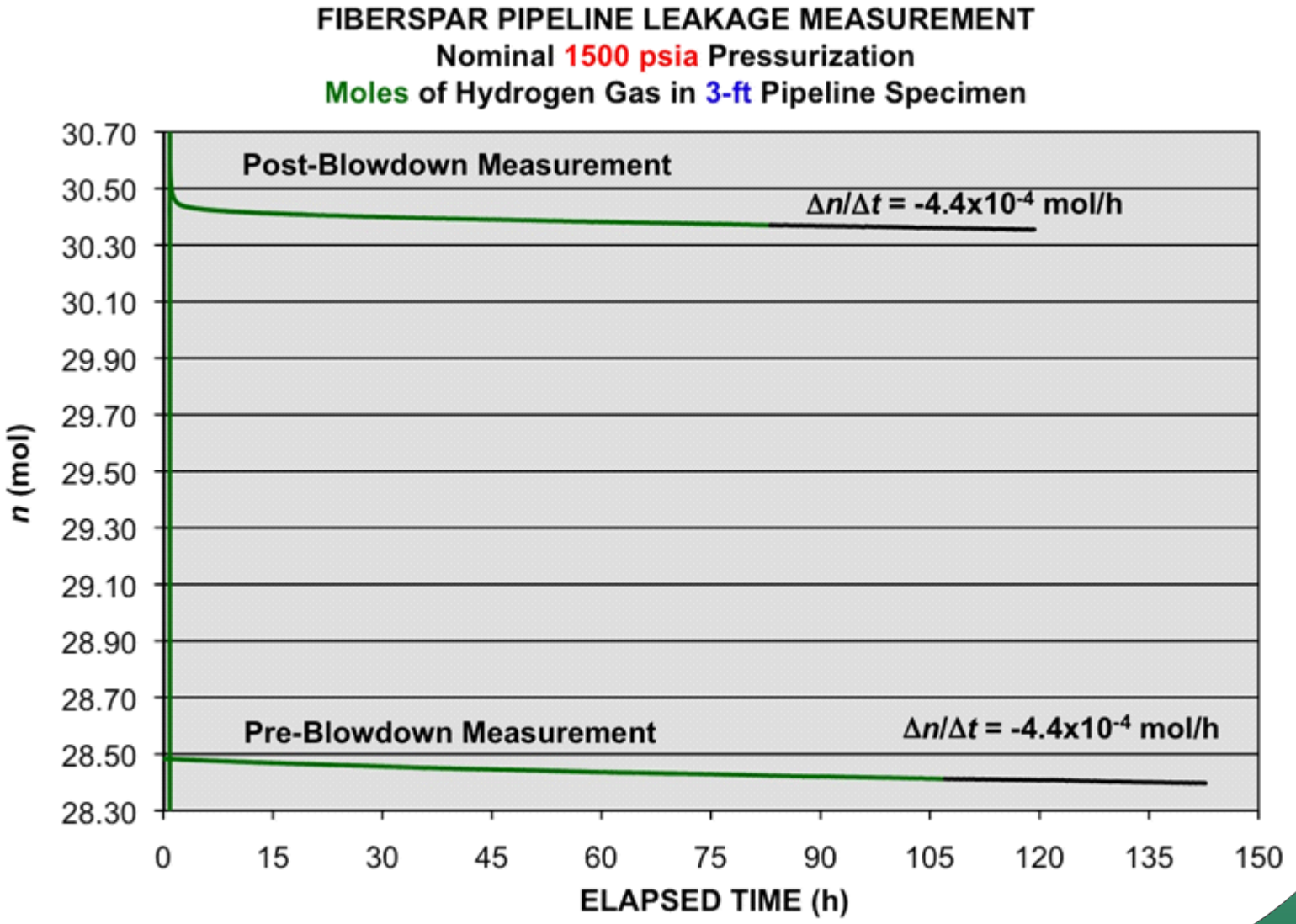
3-ft pipeline specimen being instrumented for blowdown testing

***API 15S specifies the use of supercritical CO_2 for blowdown testing**

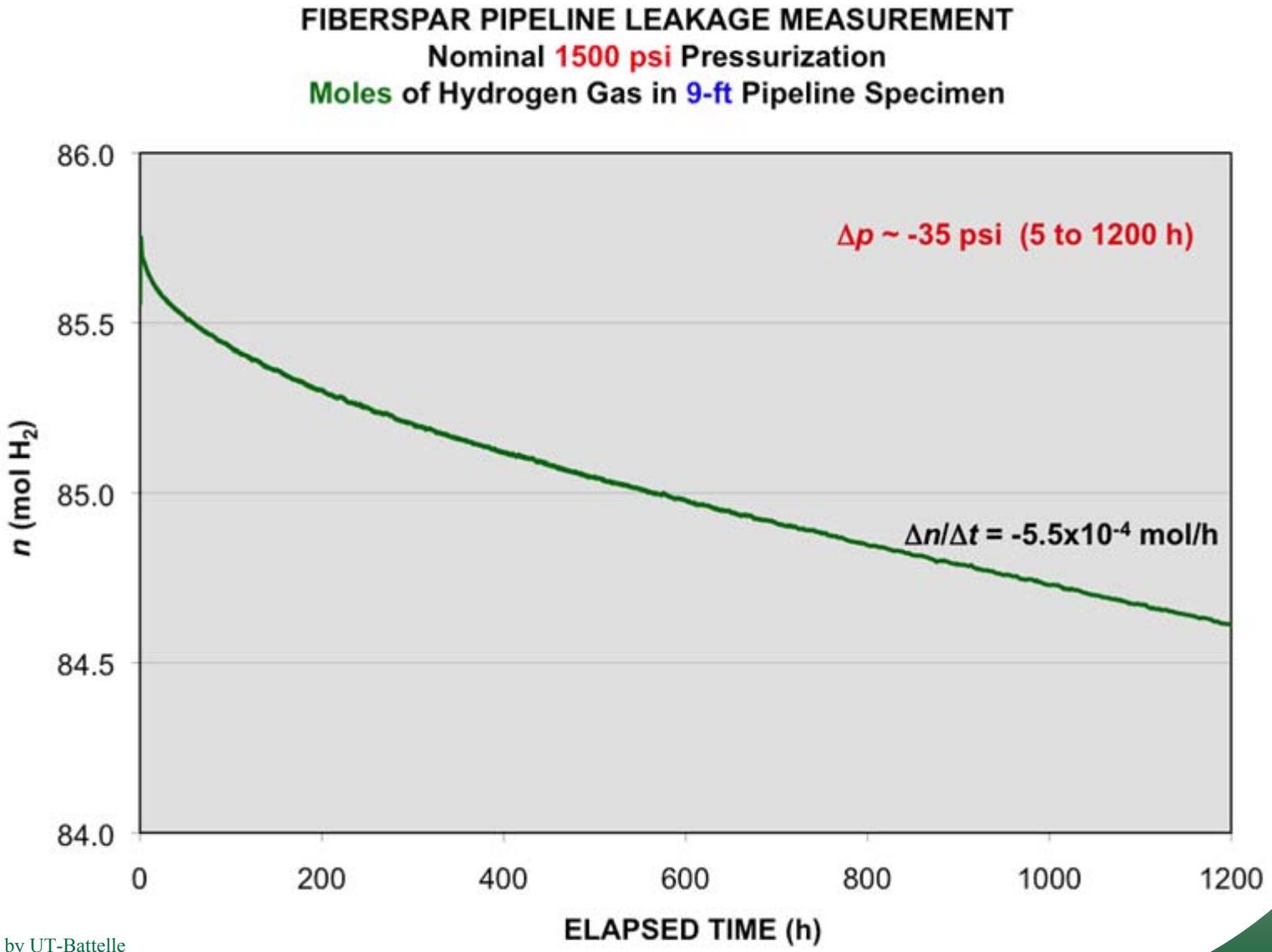
Blowdown de-pressurization rate was 3X specified minimum rate



Post-blowdown leakage rate was identical to pre-blowdown rate



Actual H_2 leakage rate is nearly 50X below predicted rate



Summary of H_2 leakage rate measurements for Fiberspar LinePipe™

Start Date	Specimen	Nominal Pressure	Leakage Rate (mol/h)
5/15/08	3-ft pre-blowdown	1500 psi	-4.4×10^{-4}
5/22/08	3-ft post-blowdown	1500	-4.4×10^{-4}
6/3/08	3-ft post-blowdown	500	$(+7.6 \times 10^{-5})$
3/26/08	6-ft	1500	-5.5×10^{-4}
4/7/08	6-ft	500	$(+3 \times 10^{-4})$
8/25/08	9-ft	1500	-5.5×10^{-4}

Summary of H_2 leakage rate measurements to date

Specimen Length	Nominal Pressure (psig)	Measured Leakage Rate (mol/h)	Predicted Leakage Rate (mol/h)
3-ft	1500	-4.4×10^{-4}	-8.2×10^{-3}
6-ft	1500	-5.5×10^{-4}	-1.6×10^{-2}
9-ft	1500	-5.5×10^{-4}	-2.5×10^{-2}

In most extensive test to-date, hydrogen lost due to permeation and leakage through end cap seals was less than 0.02% per day. The rate is 45 times below the predicted value for HDPE (PE-3408) liner.

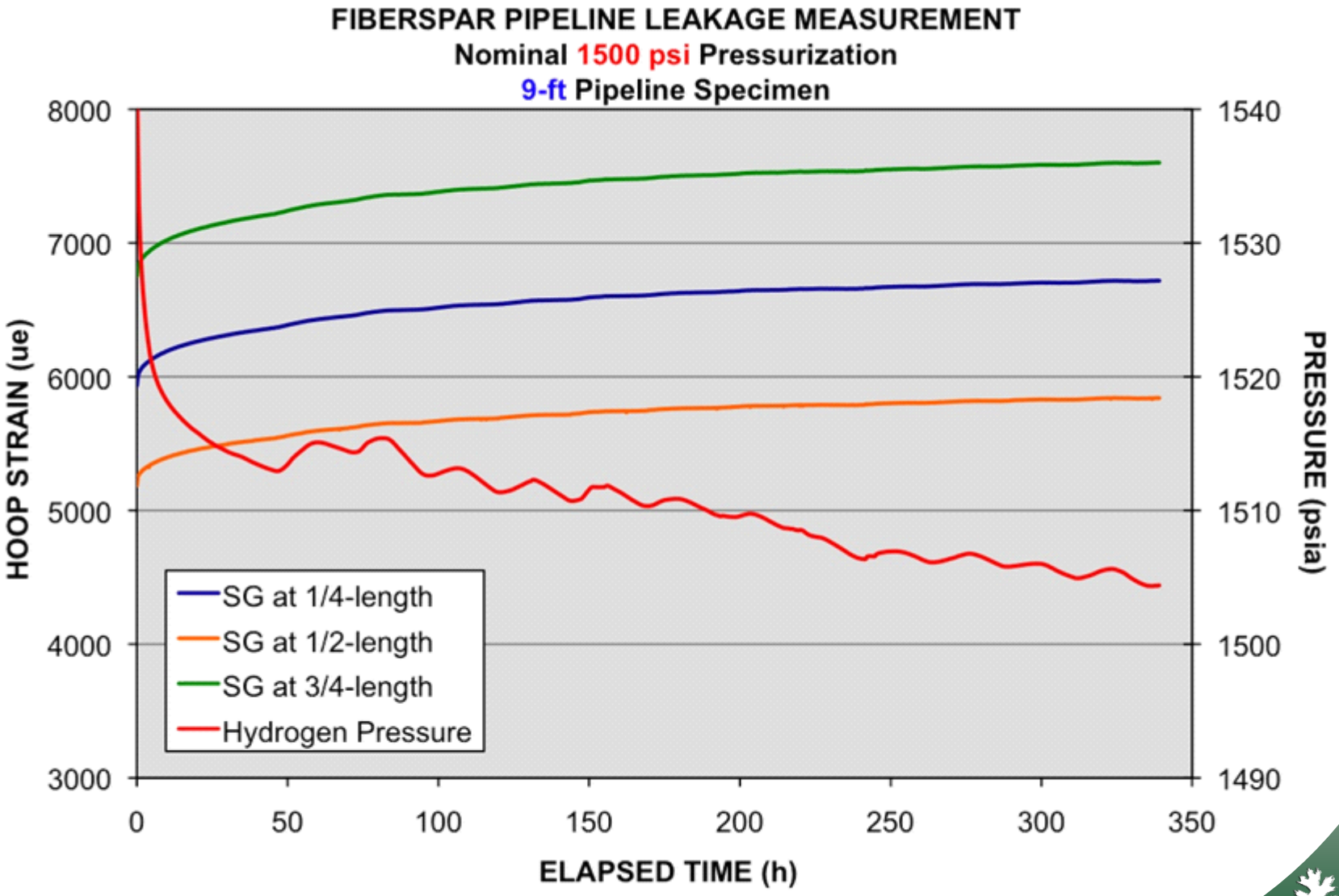
Summary of H_2 leakage rate measurements to date

- Loss due to leakage is much lower than expected (and might be good enough to meet leakage target)
- Reinforcement layer might be providing some gas barrier benefit but probably can't account for full extent of discrepancy between predicted and measured values
- Rapid decompression of pipeline is probably not going to be a failure mechanism for liner
- Joints with elastomeric seals have worked well (so far)

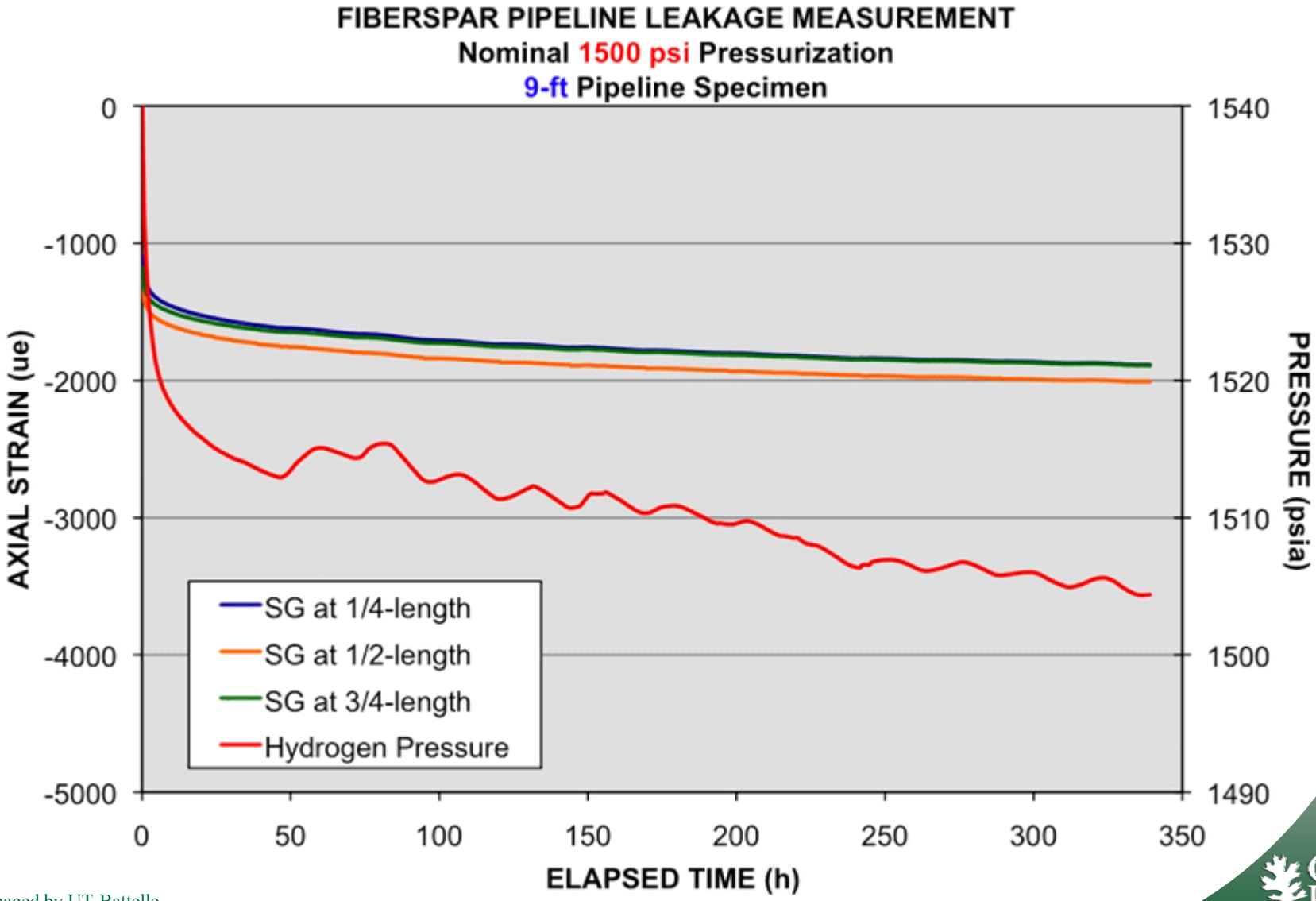
Future directions for H_2 leakage rate measurements in Fiberspar FRP pipeline

- Subject specimens to 4-pt bend testing to reveal the extent of how microcracking increases permeation and leakage
- Measure pressure as a function of depth in wall or within composite layers

Hoop strain in Fiberspar FRP pipeline during leakage measurements

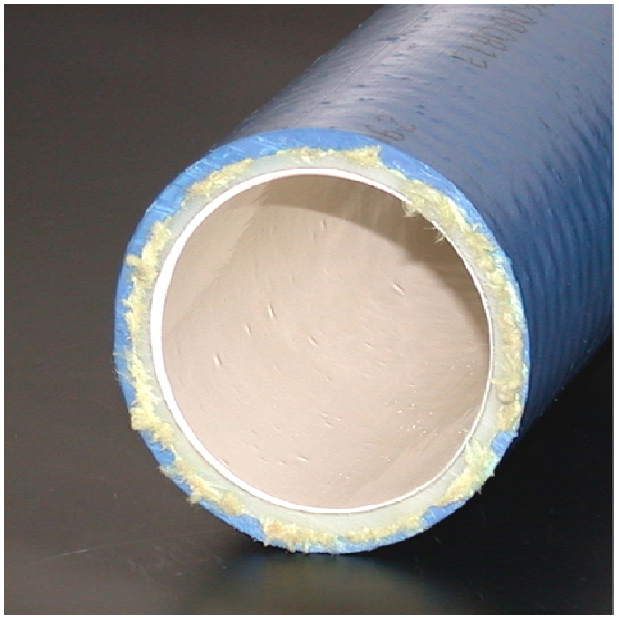


Axial strain in Fiberspar FRP pipeline during leakage measurements



H_2 leakage rate measurements in PolyFlow Thermoflex® Reinforced Pipe

- Liner: Coextruded PPS and PA-6
- Reinforcement: aramid fiber rovings braided on liner, laid over four longitudinal rovings
- Burst strength determined by braid angle, not by number of plies
- PP jacket with damage indicating colorant
- Couplings with swaged metal seals
- Leakage rate measurements in progress



Future Work

- **FY 2009**
  - Report test results from 8-month accelerated aging and hydrogen exposure of pipeline and material specimens
  - Continue measurements of liner materials, including measurements of surface fluorination samples, using new diffusion and permeation measurement apparatus for polymers with additional capabilities
  - Begin assessment of possible hydrogen-induced cracking in the reinforcement layers during cyclical strain, perform long-term stress rupture tests, perform high-pressure cyclical fatigue tests, assess joint sealing under cyclic loading
  - Collaborate on development of codes & standards for hydrogen-service FRP pipelines
- **FY 2010**
  - Coordinate initial field test of FRP pipeline for hydrogen service, providing springboard for commercially viable demonstration project

Project Summary

Relevance:	**Need viable alternative to metallic pipelines to achieve cost and performance targets for hydrogen transmission and distribution**
Approach:	**Investigate applicability of commercially available FRP polymer pipelines and develop path forward for hydrogen delivery**
Progress:	**Cost scenario shows composite pipelines can meet DOE 2012 goals and are close to 2017 goals; hydrogen compatibility of pipeline materials is acceptable; pipeline leakage rates are lower than predicted**
Collaborations:	**Pipeline and polymer industries, National Lab**
Future:	**Codes & standards; prototype FRP pipeline system for H_2 delivery; demonstration project**