New Materials for Hydrogen Pipelines

Barton Smith, Barbara Frame, Cliff Eberle, James Blencoe,
Larry Anovitz and Tim Armstrong
Oak Ridge National Laboratory

Jimmy Mays
University of Tennessee, Knoxville

2005 DOE Hydrogen Program Annual Review

May 25, 2005

Poster Presentation PDP 51

This presentation does not contain proprietary or confidential information.

Overview – Barriers and Technical Targets

- **Barriers to Hydrogen Delivery**
  - Existing steel pipelines are subject to hydrogen embrittlement and are inadequate for widespread H_2 distribution.
  - Current joining technology (welding) for steel pipelines is major cost factor and can exacerbate hydrogen embrittlement issues.
  - New H_2 pipelines will require large capital investments for materials, installation, and right-of-way costs.
  - H_2 leakage and permeation pose significant challenges for designing pipeline equipment, materials, seals, valves and fittings.
  - H_2 delivery infrastructure will rely heavily on sensors and robust designs and engineering.

Alternatives to metallic pipelines - pipelines constructed entirely from polymeric composites and engineered plastics – could enable reductions in capital costs and provide safer, more reliable H_2 delivery.

Overview – Barriers and Technical Targets

- **Hydrogen Delivery Technical Targets (2015)**
  - Total capital cost of transmission pipelines: $800K/mile
  - Total capital cost of distribution pipelines: $200K/mile
  - High pipeline reliability: equivalent to today's natural gas pipeline infrastructure
  - Loss due to leakage and permeation: < 0.5% of H_2 put through pipeline

Objectives

- **Investigate feasibility of using fiber-reinforced polymer (FRP) pipeline for transmission and distribution of hydrogen to provide reduced installation costs, improved reliability, and safe operation.**

- **Develop nanostructured plastic with dramatically reduced hydrogen permeance for use as the barrier/liner in non-metallic H_2 pipelines.**

Advantages of Continuous FRP Piping

- Anisotropic characteristics of FRP piping provide extraordinary burst and collapse pressure ratings, increased tensile and compression strengths, and increased load carrying capacities.
- No welding.
- Nearly jointless - many miles of continuous pipe can be installed as a seamless monolith.
- Placement requirements could be dramatically less than those for metal pipe, enabling the pipe to be installed in areas where right-of-way restrictions are severe.
- Corrosion resistant and damage tolerant.
- Structurally integrated sensors will provide real-time structural health monitoring and could reduce need for “pigging”.

Approach

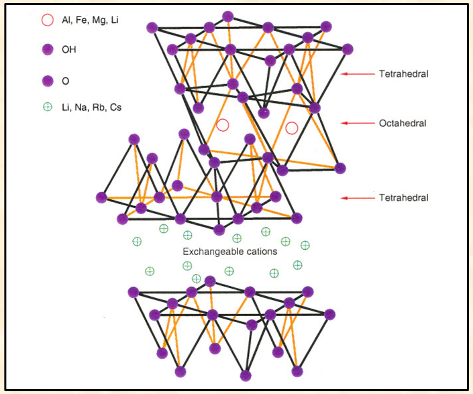
- **Fiber-reinforced polymer (FRP) pipeline for H_2**
  - Identify performance targets for H_2 pipelines as they relate to FRP technology.
  - Identity potential manufacturing options and joining/repair techniques.
  - Determine what is required to make the technology economically feasible.

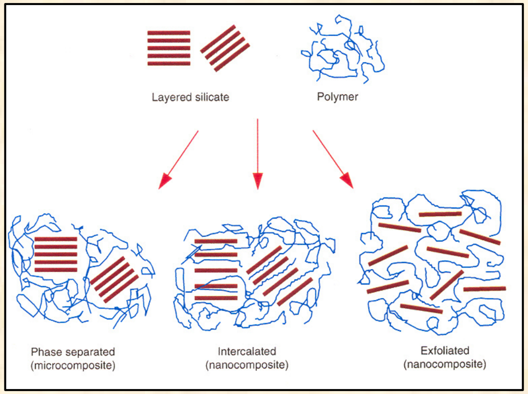
Picture provided courtesy of FiberSpar.

Picture provided courtesy of Ameron International.

Approach

- **Nanostructured plastic with reduced H_2 permeance**
  - Synthesize nanocomposites in polyethylene terephthalate (PET) using layered organo-modified nanostructured montmorillonite (clay).
  - Evaluate hydrogen permeability and mechanical properties of sample coupons of modified PET.
  - Optimize permeance of modified PET by adjusting organo-modifier, montmorillonite loading, and extrusion conditions.





Overview – Project Timeline

Task 1: Investigate feasibility of FRP pipeline for H_2 transmission and distribution

FY 2005	FY 2006	FY 2007
1 2 3	4 5	6

- New start – project began January 2005
- Subtasks
  - **FY 2005**
    1 – Identify pipeline requirements
    2 – Perform point design
    3 – Identify advantages and challenges of manufacturing methods
    4 – Assess feasibility of technology
  - **FY 2006**
    5 – Perform bench-scale tests of integrated modified-PET liner and FRP pipe
    6 – Develop sensor integration, manufacturing, joining technologies
  - **FY 2007**
    7 – Demonstrate larger scale pipe with industry
    8 – Recommend best manufacturing and placement methods

Overview – Project Timeline

Task 2: Develop nanostructured plastic barrier material

FY 2005	FY 2006	FY 2007
1 2 3	4 5	6

- New start – project began January 2005
- Subtasks
  - **FY 2005**
    1 – Synthesize clay nanocomposites in PET
    2 – Extrude modified PET
    3 – Test extruded samples for H2 permeability and mechanical properties
  - **FY 2006**
    4 – Optimize non-permeability of modified PET
    5 – Extrude liner for bench scale tests of FRP pipe
  - **FY 2007**
    6 – Commercialize technology

Overview – Budget

Task	FY 2005
1. Investigate feasibility of using fiber-reinforced polymer pipeline for H_2 transmission and distribution	$80K
2. Develop nanostructured plastic for use as non-permeable liner in H_2 pipelines	$80K
Total	**$160K**

Interactions and Collaborations

- **Existing**
  - Hydrogen Pipeline Working Group
  - Extrusion of modified PET: University of Tennessee Textiles and Nonwovens Development Center (TANDEC)
- **Pending**
  - Fiber-reinforced polymer piping: U.S. manufacturers of composite piping and storage tanks
  - Pipeline infrastructure: Natural gas industries
  - Pipeline materials qualification: Savannah River National Laboratory
  - Others

Technical Accomplishments

- **Plastic non-permeable liner**
  - Synthesize nanocomposites in PET using layered organo-modified nanostructured clay (montmorillonite)
  - Evaluate hydrogen permeability and mechanical properties of sample coupons of modified PET
  - Optimize non-permeability by adjusting organo-modifier, montmorillonite loading, and extrusion conditions
- **Fiber-reinforced polymer H_2 pipeline**
  - Identify performance targets for H_2 pipeline transmission as they relate to FRP technology
  - Identity potential manufacturing options and joining/repair techniques
  - Report on requirements to make the technology economically feasible.

Technical Accomplishments

- **FRP Piping Feasibility Assessment**
  - Assume H_2 production plant 200 miles from population center.
  - Estimate per capita H_2 demand of 0.5 kg/day for transportation use.

	Pipeline Requirements for H_2 Delivery Assuming 1,000 PSI Source Pressure and 300 PSI Pressure Drop				
Population Served	**Peak H_2 Demand (kg/h)**	**No. 4-inch Pipelines Req'd**	**No. 8-inch Pipelines Req'd**	**No. 12-inch Pipelines Req'd**	**I.D. for Single Pipeline (inches)**
100,000	3,000	5	1	n.a.	8
1,000,000	30,000	50	9	3	18
10,000,000	300,000	500	90	30	44

Technical Accomplishments

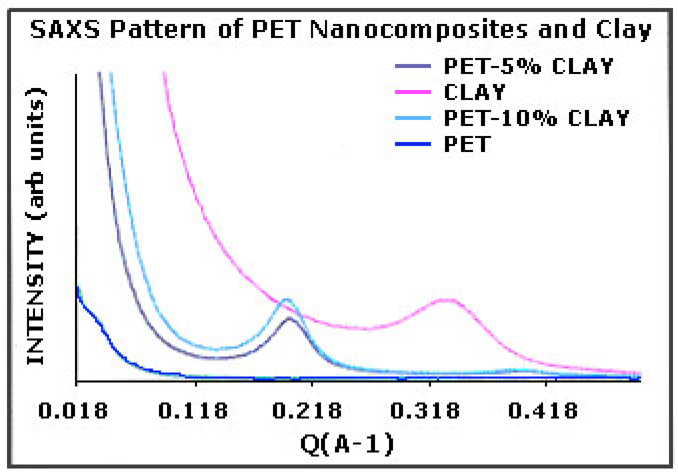
- **FRP Piping Feasibility Assessment (continued)**
  - Current capital cost (materials and installation) for 4-inch ID, 1000 PSI-rated fiber-reinforced polymer piping is $50K to $100K per mile.
  - Transmitting H_2 to a population of 100,000 would require five 4-inch ID pipelines, at an approximate capital cost of $250K to $500K per mile.
  - This estimate is well below the DOE 2015 target for hydrogen delivery ($800K per mile).
  - However, current fiber-reinforced piping needs liner with acceptably low hydrogen permeation and needs qualification for high-pressure H_2 service.

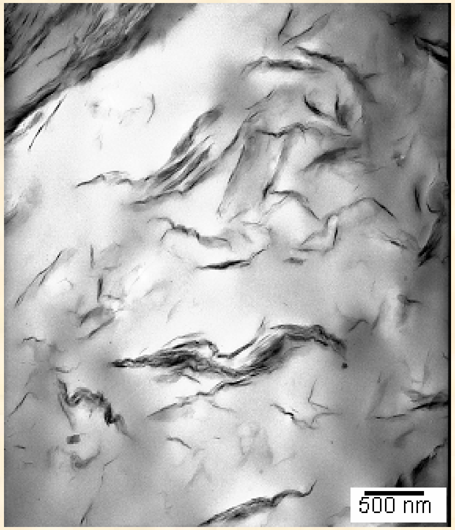
Technical Accomplishments

- **Preparation and evaluation of PET/clay nanocomposites**
  - Synthesized nanocomposites by solution mixing PET and organo-modified clay in phenol/chloroform solvent
  - Prepared PET nanocomposites with clay contents of 5 and 10 wt%
  - Modified PET films prepared for analysis and testing by pressing dried mixtures of PET/clay into thin membranes
  - Evaluated nanostructure of films using SAXS and TEM
  - Evaluated hydrogen permeability using ORNL hydrogen service IHPV test facility

Technical Accomplishments

- **Small-angle x-ray scattering (SAXS)**
  - Intercalation of PET chains increases interlayer spacing, shifting peak to lower Q values
  - Exfoliation of PET/clay would be evidenced by broadening of peak

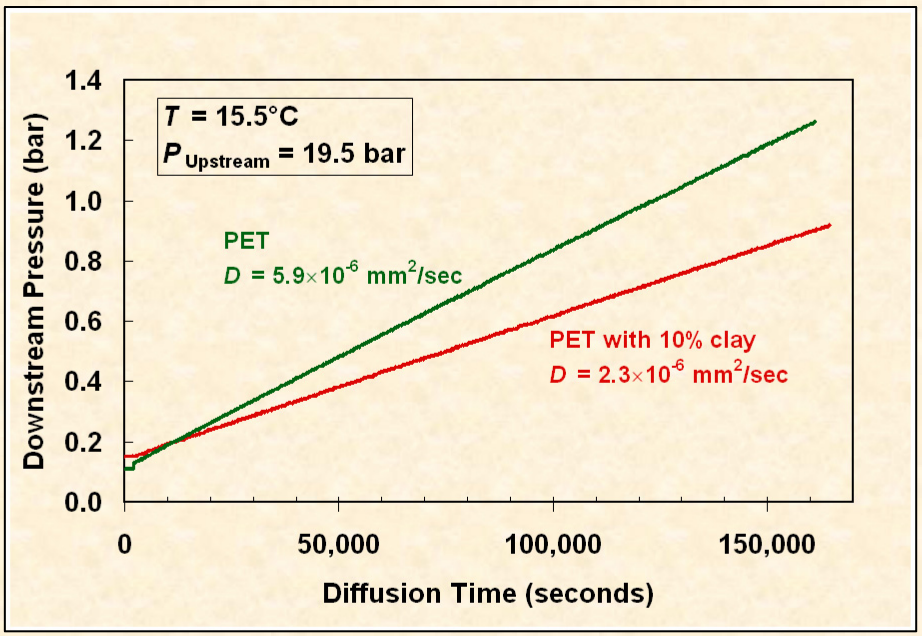


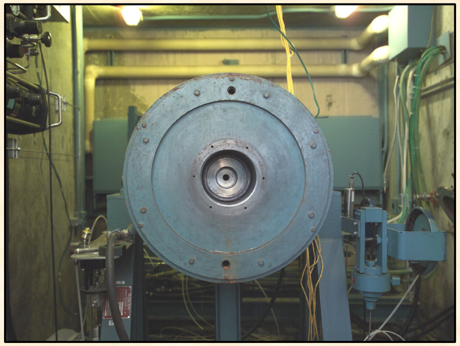


- **Transmission electron microscopy (TEM)**
  - Images of PET with 5% (left) and 10% (right) clay contents
  - Clay appears as dark lines
  - Most clay occurs as intercalated clusters with only partial exfoliation

Technical Accomplishments

- **H_2 permeation measurements in ORNL IHPV**
  - Initial modified PET sample exhibited 60% decrease in diffusion rate coefficient





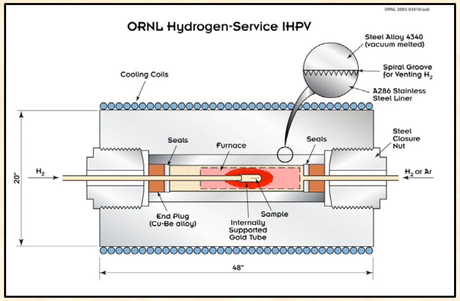


Photo and schematic of the internally heated high-pressure vessel.

Future Work – Milestones

- **Remainder of FY 2005**
  - On schedule to complete milestones
    - May 2005 - PET-based polymer-layered silicate composite barrier materials prepared and ready for permeability testing.
    - Sep 2005 - Report on FRP pipeline feasibility and recommendations completed.
    - Sep 2005 - Assessment of hydrogen permeability in barrier material coupons completed and reported.
- **For FY 2006**
  - Optimize synthesis of modified PET for minimal permeance.
  - Extrude liner for bench scale tests of FRP pipe.
  - Perform bench-scale tests of integrated modified-PET liner and FRP pipe.
  - Develop sensor integration, manufacturing, joining technologies.

Hydrogen Safety

- The most significant hydrogen hazard associated with this project is the potential leakage of H_2 during permeation measurements in the IHPV (internally heated high-pressure vessel).
- All project activities, including the permeation measurements, are covered by a formal, integrated work control process for each practice/facility.
- Each work process is authorized on the basis of a Research Safety Summary (RSS) review by ES&H subject matter experts and approval by PI's and cognizant managers.
- The RSS is reviewed/revised annually or whenever a change in work is needed.
- Staff with approved training and experience are authorized through the RSS.