New Materials for Hydrogen Pipelines

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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

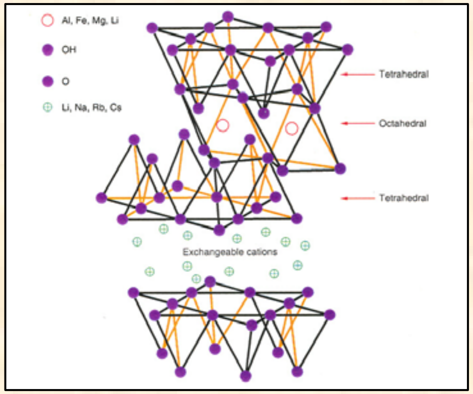
- **Fiber-reinforced polymer (FRP) pipeline for H_2**
  - Identify performance targets for H_2 pipelines as they relate to FRP technology.
  - Identity potential manufacturing options and joining/repair techniques.
  - Determine what is required to make the technology economically feasible.

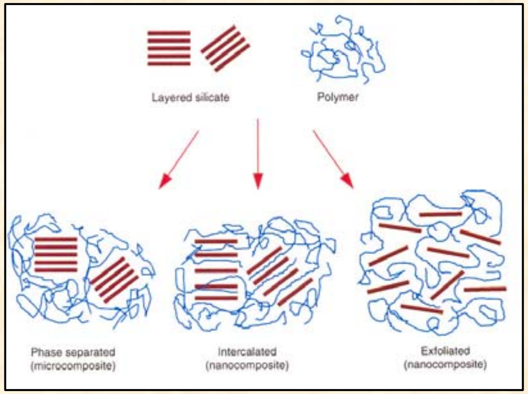
Picture provided courtesy of FiberSpar.

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

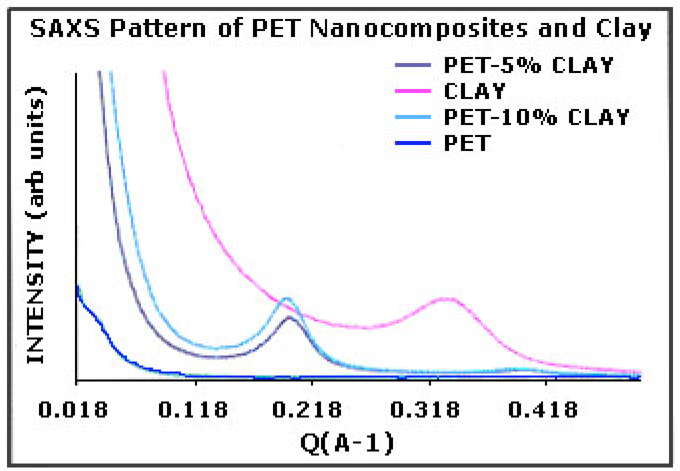
- **FRP Piping Feasibility Assessment (continued)**
  - Current capital cost (materials and installation) for 4-inch ID, 1000 PSI-rated fiber-reinforced polymer piping is $50K to $100K per mile.
  - Transmitting H_2 to a population of 100,000 would require five 4-inch ID pipelines, at an approximate 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.

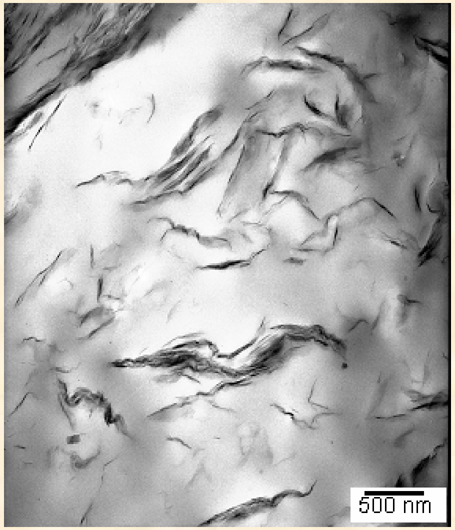
Technical Accomplishments

- **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

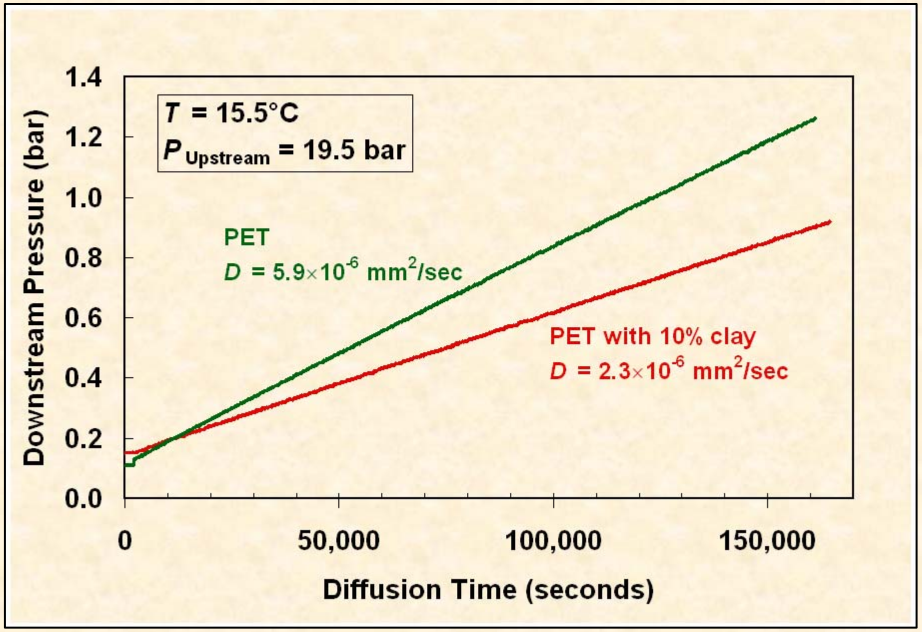


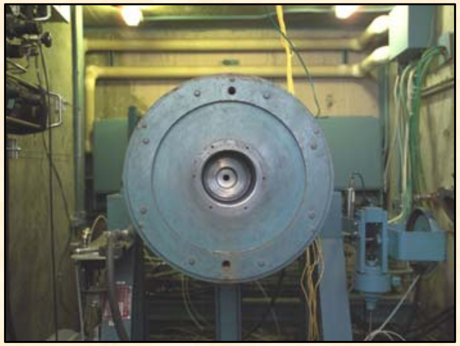


- **Transmission electron microscopy (TEM)**
  - Images of PET with 5% (left) and 10% (right) clay contents
  - Clay appears as dark lines
  - Most clay occurs as intercalated clusters with only partial exfoliation

Technical Accomplishments

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





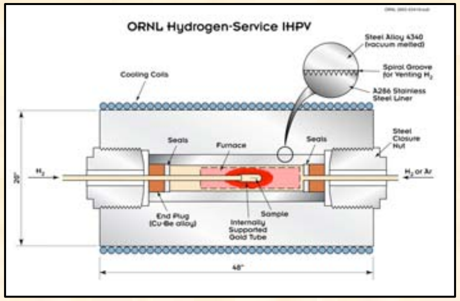


Photo and schematic of the internally heated high-pressure vessel.

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.