Polymer and Composite Materials Used in Hydrogen Service

MEETING PROCEEDINGS

Polymer and Composite Materials Meeting
Fuel Cell Technologies Office
Office of Energy Efficiency and Renewable Energy (EERE)
U.S. Department of Energy (DOE)
Washington, D.C.
October 17-18, 2012

EXECUTIVE SUMMARY

This report[1] describes the results from an information-sharing meeting on the use of polymer and composite materials in hydrogen applications. The meeting, which was organized by the U.S. Department of Energy, *Office of Energy Efficiency and Renewable Energy (EERE)*, Fuel Cell Technologies (FCT) Office and Sandia National Laboratories staff along with consultant Jim Ohi, was held on October 17-18, 2012, in Washington, DC, at the U.S. Department of Energy's Forrestal Building. The meeting objectives were: 1) discuss knowledge gaps and data needs for using polymers and composite material systems in hydrogen service, particularly at high pressures (up to 100 MPa), demanding duty cycles, and long service life, and 2) provide important input to enable lower-cost, higher-performance systems through improved knowledge and revised codes and standards. Participants identified material knowledge gaps in six different topical areas, motivated by safety, performance, and reliability concerns.

The topical areas are:

- Thermal performance of polymers at service conditions and impact of thermal excursions
- Evaluation and minimization of gas permeation and absorption into polymers
- Polymer performance characterization tests considering significant material variability
- Characterization and performance of seals and O-rings
- Liner buckling in pressure systems
- Low cost composite material systems

Research and standards development activities that can help to close the knowledge gaps in the areas identified were suggested.

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[1] This meeting report was edited and issued by Sandia National Laboratories as SAND2012-10860P. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

1. MEETING PURPOSE

An information-sharing meeting was held on October 17-18, 2012, in Washington, DC through the U.S. Department of Energy, *Office of Energy Efficiency and Renewable Energy (EERE)*, Fuel Cell Technologies Office, to discuss issues associated with polymer and composite materials used for hydrogen applications. Participants included engineers and scientists from the hydrogen and fuel cell technology industries, standards development organizations, and federal and commercial laboratories. This meeting is the most recent in a series of discussions on material data needs for hydrogen-related codes and standards. Previous meetings[2] focused largely on either hydrogen compatibility with metals or pipeline applications using metals, composites, and polymers together. This information meeting was focused on polymer and composite materials in general.

While polymers and composites are currently used in fuel cell vehicle systems and fuel delivery and dispensing systems, designers and manufacturers continually look for ways to reduce costs through implementing new materials while improving safety, performance, and reliability. Designers and manufacturers typically seek chemical and mechanical characterization data for a material either to support direct implementation or to develop a more general performance-based standard that can then be used to qualify a class of materials. This meeting was designed to facilitate the discussion of gaps in data relative to the needs of industry and research. Specific objectives of the information exchange meeting were to:

- Discuss knowledge gaps and data needs for using polymers and composite material systems in hydrogen service, particularly at high pressures (up to 100 MPa), demanding duty cycles, and long service life
- Provide important input to enable lower-cost, higher-performance systems through improved knowledge and revised codes and standards
- Inform testing needs to better enable near-term applications of polymers and composite systems in hydrogen service, including components at high pressure and extreme temperatures

A list of invited meeting participants is shown in Appendix A. The meeting agenda is provided in Appendix B. The meeting consisted of background presentations, followed by systems-level break-out discussions and then focused topical discussions.

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[2] Examples of previous meetings where material data needs for codes and standards were discussed: Composites Conference, August 2012, Las Cruces, New Mexico; Hydrogen Compatible Materials Workshop, November 2010, Sandia National Laboratories, Livermore, California; Materials and Components for Hydrogen Infrastructure Codes and Standards Workshop, September 2007, Center for Hydrogen Research, Aiken, South Carolina; Hydrogen Pipeline Working Group Workshop, August 2005, Augusta, Georgia; Hydrogen Compatible Materials Workshop, December 2003, Sandia National Laboratories, Livermore, California.

On the first day of the meeting, participants identified material issues across automotive systems, dispensing, and the delivery infrastructure through facilitated discussion groups. From ideas gathered on the first day, the participants selected a few material issues to explore in more depth — issues for which they thought solutions would be particularly impactful to the widespread deployment of hydrogen fuel cell technology. On the second day, discussions focused on six topics: thermal performance of polymers at service conditions and impact of thermal excursions, evaluation and minimization of gas permeation and absorption into polymers, polymer performance characterization tests considering significant material variability, characterization and performance of seals and O-rings, liner buckling in pressure systems, and low-cost composite material options. Five of the six focused topic discussions are documented in this report.

2. Focused Discussions on Material Issues

The group identified six topics to explore. The participants self-assembled into topical discussion groups. For each topic, the discussion group was asked to consider the following questions:

- ***Problem Statement:*** *What is the problem statement (e.g. how is the material used; what is the performance, safety, or reliability concern)?*
- ***Information Gap:*** *What is the material data information gap?*
- ***Research Activity:*** *What research activity is needed to fill the knowledge gap?*
- ***Resource and schedule:*** *What resources are needed to execute the research and when is the information needed?*
- ***Stakeholders***: *Who are the stakeholders? Where are the data insertion opportunities? In which code, standard, database, or document would the information be most useful to stakeholders?*

The discussion groups provided answers to as many of the questions as they could address in the limited meeting time.

2.1 Thermal Performance of Polymers at Service Conditions and Impact of Thermal Excursions

Problem statement

The material properties of composites and polymers are not well understood when under the combined effects of low and high temperatures (-40^{o}C to 85^{o}C) with high pressures (700 bar service).

Information Gap

The effect of localized thermal excursions during refueling and/or defueling of the vehicles is not well understood. Information could be incorporated into fueling standards such as SAE J2601, SAE J2579/GTR, CSA HGV 4.3, CSA HGV 2, and ISO 15869.

Research Activities

Research is needed to characterize the thermal excursions and quantify the resulting material performance at the excursion temperatures and resulting material degradation as outlined below. Research would address the duration of the process that causes excursions, for example hot excursions due to fueling and cold excursions due to defueling or use.

Better correlations of material performance and degradation between certification testing at thermal soak and in-service temperature excursions are needed. During fueling there are temperature gradients that occur within and between the gas, the liner, and the composite wrapping. These differences must be properly quantified in order to correlate test results from the thermal soak to the in-service conditions.

Quantitatively characterizing the excursions during fueling, under the current "bulk gas" definition at 85^{o}C as well as other potential maximum-allowable temperatures, would provide data to fill the information gap. The key objective of this research is to understand the relationship between actual gas temperature and material temperatures.

Several key research steps are suggested for investigation:

- Determine the current status, or lack thereof, of test methods related to certification.
- Investigate the low and high temperature excursions that would occur if the temperature limitations were raised or exceeded.
- Determine the correlation between low and high temperature excursions and the qualification testing – soak conditions (static vs. dynamic effects).
- Research and understand the mechanisms that cause material degradation.
- Understand the effect of degradation on the integrity of the tank.
- Determine if the degradation has an effect on the fuel quality.
- Determine which properties of the material could be changed to make the material more robust.
- Identify improved performance-based test methods based on the knowledge of the current test methods, the actual gas temperatures, and the factors that affect tank integrity.
- Perform cyclic pressure and temperature testing as well as creep rupture testing at the combined conditions on full scale tanks, laboratory scale composite samples, and material coupons to determine the correlation between them and thereby the suitability of coupon level material testing.

Stakeholders

Original equipment manufacturers (OEM) and industrial gas companies (IGC) involved in fueling on-road vehicles using these tanks.

Time Frame

There is an immediate need for this information in the near term (months to 1 year).

2.2 EVALUATION AND MINIMIZATION OF GAS PERMEATION AND ABSORPTION INTO POLYMERS

Problem Statement

Prevention of gas permeation and absorption, specifically hydrogen, is a key design challenge for polymer containment and transmission systems.

Information Gap

Permeation and absorption into polymer systems are not understood or evaluated in standardized manner for service conditions. As a result, there is a need to:

- Develop, optimize and use standard methodologies (e.g., ASTM) and tests to evaluate gas permeation, with emphasis given to high-pressure hydrogen, on polymer based systems.
- Collect and document the effects of temperature and pressure on permeation and adsorption of gases on polymers in a public database format. Study the effects of pressure change rates on polymer materials with regards to gas permeation and absorption.
- Develop new materials and new processing methodologies of existing materials, which reduces permeation and absorption of hydrogen into polymers compared to what currently exists -- this includes the use of additives and polymer blends.
- Determine new engineering design processes that reduce gas permeation and absorption into polymer materials.

Research Activity

Characterization of the polymeric material could include measurements of

- Crystallinity (amorphous versus semi-crystalline versus crystalline)
- Degree of polymerization
- Crosslink density
- Outgassing and desorption of chemical species
- Permeation/sorption of hydrogen into polymers
- Gas exposure time, temperature, pressure, etc. (e.g., H_2 soak time as a function of temperature, hydrogen, pressure and time)

- Pressurization/depressurization rates
- Durability (which includes aging and temperature cycling)
- Correlation of bench-scale (coupon) versus full-scale materials characteristics

2.3 Polymer Performance Characterization Tests Considering Significant Material Variability

Problem Statement Standardized qualification of polymeric materials for hydrogen service is not established.

Information Gap

The gaps in understanding are a result of application-specific requirements of polymers in hydrogen service, including:

- The requirements for each application are not broadly recognized
- It is unknown if test methods exist that cover each requirement
- It is unknown if existing test methods are adequate
- Correlation between coupon tests results and component level test results is not established
- Degradation of material performance (e.g. loss of mechanical performance) due to gaseous hydrogen permeation (exposure) is not established

The following table relates material properties and test methods needed to support a specific application:

	Tank liner	Pipe liner	O-rings	Hose
Permeability	X	X	X	X
Hydrogen aging	X	X	X	X
Explosive decompression	X	?	X	X
Fatigue	X		X	X
Low temp ductility	X		X	X
Change in modulus	X		X	X
Thermal shock	X		X	X

Research Activities

The following are areas in which research is needed:

- Effects of hydrogen, temperature, and pressure on "creep" and "strength"
- Degradation of polymers by hydrogen "plasticization effects" such as change in ductility
- Supercritical properties of hydrogen as a solvent and its effect on polymers
- Leaching of polymeric components into hydrogen and subsequent transport into the fuel cell with potential for platinum damage; R&D activities for leaching cover a range of needs including quantitative understanding of the leachant process, understanding process variable effects, developing mechanistic/predictive models, longer term durability testing and further material screening
- Development of new test methods to evaluate hydrogen permeability

Stakeholders

- Material suppliers who need to obtain certifications for polymer materials
- Component suppliers who need to know which polymers are acceptable for component service conditions
- Certification agencies (i.e. CSA) who need a scientific basis for testing and performance boundaries
- Industrial companies and others involved in hydrogen applications who need standardized test methods

2.4 CHARACTERIZATION AND PERFORMANCE OF SEALS AND O-RINGS

Problem Statement

O-rings (elastomeric) leak at critical interfaces within hydrogen systems. Such interfaces include the on-board tank systems, the dispenser-vehicle interface, and the supply systems. O-rings are used in both static designs and dynamic designs:

- Static seal designs: The leaks are transient events, for example, during fueling. Rapid pressure/temperature changes can result in a temporary leak. After conditions equilibrate sufficiently, the elastomeric material will reseal. Performance specifications must consider transient conditions.
- Dynamic seal designs: In valves and pressure regulators, for example during motion between a shaft and the elastomeric material a temporary leak can occur.

A clarification is noted: There is a difference between rapid changes in pressure and temperature, transient effects, and "dynamic" effects that refer to seals in which there is motion, relative motion between O-ring and seating surface.

Information Gap

In the case of static seal designs, there is lack of "best practices" for O-ring interface designs with regard to localized service conditions (rapid changes in temperature and pressure) for O-ring sealing materials and groove design.

In the case of dynamic seal designs, the following issues can result in a temporary leak during movement between the sealing surfaces:

- Material decomposition or degradation
- pressure, thermal and chemical effects
- friction/wear

Research Activities

Evaluation and development of performance-based qualifications for static and dynamic seals, including:

- An understanding of what particular conditions/parameters define a given seal application
  - The effects of hydrogen exposure and compatibility
  - The effects of compression and decompression
  - The role of elastomeric "glass" temperature transition due to fluid pressure or temperature change
- Geometry and seal design
- Location and temperature effects

Research findings should directly support standards development. For a given sealing application and conventional (state-of-the-art) designs, demonstration of transient conditions that cause leakage and an understanding of the causes of a leak are necessary to improving design standards.

Stakeholders

The observation was made that the new Compressed Hydrogen Material Compatibility (CHMC 1) Phase II standard under development would be a good basis for developing a standard for elastomeric materials.

2.5 Liner Buckling in Pressure Systems

Problem statement

Polymer lined pressurized structures, for example, pipes and tanks, may exhibit liner buckling in certain operating conditions.

Information Gap

The limits of the speed at which composite tanks can be depressurized are not well understood. Other information gaps include:

- The cause and effect of liner buckling for existing and new polymers
- The response of the pressurized structures to the operating conditions (rate of change between the extreme values of temperature and pressure, normal or abnormal defueling operations or other environmental effects) and the resulting influence on the propensity of liner buckling
- Related failure modes of buckling and how they might affect cylinder performance

Research Activities

The following areas have been identified:

- Determine the severity of liner buckling (*cylinder performance*)
- Evidence liner separation from composite wrapping through field-deployable NDE techniques (*buckling mechanisms and cylinder performance*)
- Create sampling and measurement protocols related to buckling mechanisms (*buckling mechanisms*)
- Create structural response modeling techniques
- Determine the effects of aging on buckling behavior (*buckling mechanisms*)
- Configure liner shell (*buckling mechanisms*)
- Optimize design of liner materials to minimize buckling
- Develop a performance-based qualification test to demonstrate that buckling will not occur in operating conditions

2.6 Low Cost Composite Material Systems

Problem Statement

The cost of the composite overwrap in pressurized structures (namely high pressure tanks) is the dominant cost of the structure.

Information Gap

Inexpensive piping and storage vessels for compressed hydrogen gas are critical to the widespread commercialization of hydrogen fuel cells especially for light-duty vehicle applications. Currently high-pressure (i.e., 350 to 700 bar) storage vessels are constructed using expensive high-strength carbon fiber, such as aerospace-grade Toray T700, in a composite matrix as an overwrap to contain the stress.[1-2] In fact, cost analyses have predicted that carbon

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[1] *Technical Assessment of Compressed Hydrogen Storage Tank Systems for Automotive Applications*, September 2010, published on the DOE/FCT website: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/compressedtank_storage.pdf.

[2] T. Q. Hua, R. K. Ahluwalia, J. -K. Peng, M. Kromer, S. Lasher, K. McKenney, K. Law, and J. Sinha, "Technical assessment of compressed hydrogen storage tank systems for automotive applications," Int. J. Hydrogen Energy, 36 (2011): 3037-3049.

fiber can account for up to approximately 80% of the cost of high pressure storage vessels.[3-4] Low-cost carbon fiber precursors, low-cost carbon fiber manufacturing processes or process optimization, alternative structural materials such as glass or other inexpensive fibers, advanced fiber material characterization and modified epoxy resins for load sharing are all potential solutions to reducing the cost of carbon fiber and composite overwraps. Before compressed hydrogen gas storage vessel technology can move forward to widespread applications, solutions must be developed to achieve substantial cost reductions. Many of these solutions would also benefit low cost potions for compressed natural gas systems.

Research Activities

The following are areas in need of further research:

- Identify key fiber properties and requirements such as ultimate tensile strength, and tensile modulus for the application
- Perform parallel efforts to identify existing lower cost precursors that could successfully be made into fibers and develop new low-cost precursors to meet the application specifications
- OEMs would benefit greatly by having a rapid method for determining mechanical properties of received carbon fiber since they get limited data from carbon fiber manufacturers.
- Carbon fiber manufacturers need inexpensive, advanced material characterization methods for in-line monitoring of key performance properties including:
  - density during oxidation
  - defect structure
  - resistivity before/after carbonization
- A multi-fiber (carbon fibers with different tensile strengths or different fibers) approach could take advantage of the different translational forces observed by the fibers to increase the fiber usage efficiency and reduce the cost of the fiber overwrap.
- It would be useful to screen alternative fibers that have potential application in filament winding. The outcome would likely demonstrate multiple lower strength and cost fibers that could be used to replace current high strength carbon fibers. Some significant variables would be durability, strain/strength, resin compatibility and interfacial adhesion, etc. Suggested fibers for screening include:
  - PAN-based carbon fiber 34 to 67 Msi
  - Pitch-based carbon fiber 90 to 125 Msi or higher

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2 R.K. Ahluwalia, T.Q. Hua, J.K. Peng, "On-board and Off-board performance of hydrogen storage options for light-duty vehicles", Int. J. Hydrogen Energy **37** (2012) 2891-210.

3 *Technical Assessment of Compressed Hydrogen Storage Tank Systems for Automotive Applications*, September 2010, published on the DOE/FCT website: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/compressedtank_storage.pdf.

5 T. Q. Hua, R. K. Ahluwalia, J. -K. Peng, M. Kromer, S. Lasher, K. McKenney, K. Law, and J. Sinha, "Technical assessment of compressed hydrogen storage tank systems for automotive applications," Int. J. Hydrogen Energy, 36 (2011): 3037-3049.

4 R.K. Ahluwalia, T.Q. Hua, J.K. Peng, "On-board and Off-board performance of hydrogen storage options for light-duty vehicles", Int. J. Hydrogen Energy **37** (2012) 2891-210.

    - metal coated CF of all modulus (Cu, Ni, Fe, Ag, etc.)
    - fiber glass Type E,A, C, AR and S
    - metal coated fiberglass of all types (Al, Cu, Ni, etc.)
    - basalt fiber
    - quartz fiber
    - aramid type 29, 49 and generic
    - zylon fiber of various modulus
    - polyethylene fiber
    - polyester fiber
    - metal wire
- Transferring the load from fiber-to-fiber or fiber-to-resin in composite systems could minimize the mass of fiber used thus reducing the cost composite while maintaining strength properties. However, research is needed to understand the mechanisms involved and proper low-cost additives.

APPENDIX A: MEETING PARTICIPANTS

Name	Affiliation
Beatriz Acosta	Joint Research Centre
Dan Andrei	ASME Standards Technology, LLC
Bob Boyd	Boyd Hydrogen, LLC
Darren Cone	NASA/White Sands Test Facility
Donald Baird	Virginia Polytechnic Institute and State University
Rob Burgess	National Renewable Energy Laboratory
Stuart Chambers	Powertech Labs Inc.
Clemence Devilliers	Air Liquide
Peter Ehlers	CSA Group
Jim Fekete	National Institute of Standards and Technology
Aaron Harris	Sandia National Laboratory
Will James	US Department of Energy
Axel Junge	General Motors
Satoshi Kawasaki	Honda R&D Ltd.
Wei-Yang Lu	Sandia National Laboratory
Arnold Lustiger	ExxonMobil R&D
Steve Mathison	Honda R&D America's, Inc.
Dave McColskey	National Institute of Standards and Technology
Scott McWhorter	US Department of Energy
Chris Moen	Sandia National Laboratory
Norm Newhouse	Lincoln Composites, Inc.
Nha Nguyen	US Department of Transportation/NHTSA
Jim Ohi	Consultant/US Department of Energy
George Rawls	Savannah River National Laboratory

Kevin Simmons	Pacific Northwest National Laboratory
Barton Smith	Oak Ridge National Laboratory
Erika Sutherland	Department of Energy
Takanori Suzuki	Honda R&D Ltd.
Mike Veenstra	Ford

Appendix B: Meeting agenda

Automotive and infrastructure applications of polymer and composite material systems require additional research and testing. While existing standards and protocols like SAE J2579, SAE J2601, and CSA HGV4.3, address the use of carbon fiber tanks in automotive applications, there is potential to lower cost and enable higher performance systems. Therefore, the meeting discussions were structured around a few codes and standards use-cases.

The state of knowledge, anticipated failure modes, and performance issues differ substantially for polymer materials and composite material systems, so material issues were separated into polymers or composites as they were identified. Polymer material issues may exist for Type IV pressure vessel liners, fiber-reinforced piping, low-pressure fuel systems, and seals and valves in hydrogen components. Composite material and mechanical issues may involve known and potential failure modes under pressure and temperature regimes, permeation, and other key issues anticipated under near-term applications.

There has been significant input over the years on research needs for polymer materials. Ideas about polymer research were collected from open literature and circulated among the invitees prior to the meeting. The desired meeting outcome was a draft work plan that had been vetted by the participants so that a second draft can be circulated for comment among a wider segment of the community.

For composite systems, the discussion was focused around specific, near-term needs to refine requirements for codes and standards that, in turn, can be used to illuminate the critical R&D gaps and needs for composite systems in hydrogen service. The focus was issues that impact fast-fill protocol development and Type IV tank qualification or composite delivery systems.

The information exchange meeting occurred over two days.

Day 1 (all times in Eastern Time Zone)

Start	End	Activity	POC
08:00	08:45	Reception and badging	DOE
08:45	09:00	Welcome and meeting objectives / expectations / time horizon for research activities (targets)	Erika Sutherland, Sunita Satyapal
09:00	10:00	Polymer/elastomer and composite material science: key issues, knowledge gaps, R&D/testing data needs (40 min speaking, 20 min Q&A)	Kevin Simmons
10:00	10:30	Codes and standards requirements – SAE J2579, SAE J2601: knowledge gaps, R&D data/testing needs	Mike Veenstra
10:30	11:00	Break	
11:00	11:30	Codes and standards requirements –CSA HGV 4, ASME X and B31: knowledge gaps, R&D data/testing needs	Aaron Harris
11:30	12:00	Polymer/elastomer Draft R&D Work Plan ideas / Describe the plan for the afternoon / Describe break-out group framing questions and roadmap template and content	Chris Moen
12:00	13:30	Lunch	DOE Cafeteria
13:30	15:30	Identify polymer and composite material issues, knowledge gaps, and R&D/testing data needs, focusing on a different part of the vehicle and delivery system, loosely delineated by a standard.	Three assigned break-out groups with facilitators
15:30	16:00	Break	
16:00	17:00	Break-out groups reconvene and refine polymer and composite issues and prepare written outline of work plan items (one flip-chart sheet per item); flip-chart pages due to meeting planners by end of first day for use on second day	Three assigned break-out groups with facilitators: Veenstra, Sutherland, Harris
17:00	17:15	Close-out for day 1	DOE/SNL
		Adjourn; no-host, group dinner	

Day 2 (all times in Eastern Time Zone)

Start	End	Activity	POC
08:30	10:00	Each break-out group provides report-out of their R&D Work Plan items: key issues, gaps, resources, timing; group Q&A; introduce balloting exercise for group to collectively assess and select topics for further discussion and analysis	Breakout session chairs Facilitators
10:00	10:30	Balloting + break	
10:30	11:30	Results of balloting; Group selects sub-set of priority issues that will proposed for Tech Team R&D Roadmaps	Chris Moen
11:30	12:30	Lunch	DOE cafeteria
12:30	14:00	Create the R&D Work Plan – divide up the topics and assign to new self-assembled break-out groups; address Roadmap framing questions	New break-out groups
14:00	14:30	Meeting close-out, action items	DOE
14:30		Adjourn	

APPENDIX C: MEETING ORGANIZATION DETAILS

Day 1 break-out groups and focus areas:

- Materials within the vehicle system; facilitator – Mike Veenstra; scribe – Will James
- Materials used within the fuel distribution system and the fueling station; facilitator – Erika Sutherland; scribe – Jim Ohi
- Materials used within the vehicle and dispensing interface; facilitator – Aaron Harris; scribe – Rob Burgess

Day 1 framing questions to identify material issues:

- What is the motivation or driver for the issue / what is the problem statement?
- What specific information is needed? What is the research question? If it is not a specific material, how broad is the material class?
- How would the information be used?
- What would the materials research, characterization, or testing activity look like to address the information needs? What resources are required?
- Who are the stakeholders/partners that would make use of the information (e.g. is the information for a particular standard that is broadly used or for a specific component or system manufacturing sector)
- What is the relative rank-order priority amongst all your issues?
- Considering the scope of the proposed activity and the priority, when would the information need to be completed?

Questions for which we desire written answers by end of meeting (Day 2):

- Descriptive title
- Problem statement (How is the material used? What is the performance, safety, or reliability concern?)
- Information gap (What do we not know? What do we need to know?)
- Research activity (How do we fill the knowledge gap?)

- Resources and schedule (What will it take to fill the gap and when do we need it?)
- Stakeholders and data insertion opportunities (In what code or standard or database should the information go to be most useful?)

Preliminary polymer material research topics

The following polymer-related material issues where posed to the meeting participants in order to generate discussion:

- Hydrogen Permeability Characterization
- Permeability Reduction
- Contamination Characterization
- Polymer Degradation by Chemical Means
- Polymer Degradation by Mechanical Means
- Coordination of Testing Methods