the Energy to Lead

FINAL REPORT

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Feasibility of Using Plastic Pipe for Ethanol Gathering

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Prepared For:
Mr. James Merritt
Program Manager
U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety
793 Countrybriar Lane
Highlands Ranch, CO 80129
Telephone: (303) 683-3117
Fax: (303) 346-9192
james.merritt@dot.gov

Prepared By:

Mr. Andy Hammerschmidt, GTI
Team Project Manager
andrew.hammerschmidt@gastechnology.org
847-768-0686

Mr. Daniel Ersoy
Team Technical Coordinator
daniel.ersoy@gastechnology.org
847-768-0663

Additional Members of GTI Project Team:
Julie Maupin, Engineer
Karen Crippen, R&D Manager
Mike Miller, Principal Engineer

Gas Technology Institute
1700 S. Mount Prospect Rd.
Des Plaines, Illinois 60018
www.gastechnology.org

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Executive Summary

This USDOT PHMSA sponsored research project addressed and successfully determined the initial feasibility of using new materials, both polymeric and composites, as low-cost alternatives to specially designed metallic gathering pipelines. The project focused on the potential integrity effects of using such polymer based pipes when used with typical feed stocks (for ethanol production) at common temperatures and pressures. The work also included designing an ethanol pipe system for gathering to determine both engineering and economic feasibility of polymer pipe system use. Finally, the research effort provided the direction for subsequent relevant research in this area as well as a foundation for developing a program to evaluate future biofuels. To ensure relevancy, an industry based steering committee was formed and consulted throughout the effort. This was comprised of organizations such as the Renewable Fuels Association, Archer Daniels Midland, Poet, Illinois Corn Growers Association, and USDOT PHMSA representation.

Ethanol production world-wide was studied, including first generation and second generation ethanol production. First generation corn ethanol production provided a typical configuration for ethanol plant spacing and distance from a clean-up or transportation hub, as well as typical requirements for gathering pipeline systems. A summary list of all known feedstocks was compiled for both domestic and non-U.S. ethanol is included in this report.

Current ethanol transportation methods were studied and supplemented with information from the project steering committee. Most large corn farms are between 10 to 15 miles from an ethanol plant. From the production centers, about 60 percent of ethanol is shipped by rail, 30% by truck and 10% by barges. There is only one recently commissioned U.S. steel pipeline that is transporting fuel grade ethanol blended with gasoline.

A material compatibility analysis was performed requiring chemical analysis of Ethanol. An industry survey was developed to capture this information, as well as operational parameters in ethanol production. The largest constituent identified was the denaturing agent, usually gasoline, which is added prior to shipping. The survey, literature review, and detailed analysis of Ethanol constituents and impurities are included in the report.

The project steering committee requested GTI focus on the bulk thermoplastic pipe for the materials selection and compatibility analysis. However, a small work effort was completed to list out all the current joining practices and with which thermoplastic resins that can and are being used today. The advantages and disadvantages of all joining methods were studied in detail and summarized.

All commercially available thermoplastic, composite, and fiberglass reinforced pipe products were investigated for chemical compatibility with ethanol and solvents in general, and their subsequent fundamental chemistry reviewed. This included researching the literature and contacting the relevant material manufacturers. Chemistry, structure, and availability (in pipe form) were all researched and summarized.

GTI worked closely with the manufacturers to collect all relevant information and data on materials of interest for a ranking process. The rating system was set up from "1-Cannot be used" to "4 - Can be used", where a rating of 3 is more likely to be compatible with ethanol than a product rated 2.

Ethanol compatibility data gaps were also documented and summarized into three areas where very limited to no direct data could be found:

- Long term strength testing with ethanol,
- Permeability testing at operating pressures, and
- Erosion resistance with ethanol flow.

To fully evaluate the feasibility of utilizing these prioritized materials for ethanol gathering lines, a theoretical gathering system was created with the assistance of the steering committee. This pipeline system was designed to transport ethanol from several production plants to a class 1 railroad. Based on the research, four pipe systems were selected for operation and economic comparison:

- High Density Polyethylene (HDPE),
- Polyamides (PA12),
- Epoxy Resin Pipe (Red Thread II), and
- Composite Pipe (Flexpipe).

With all assumptions taken into account, all four systems produced a theoretical system that could gather/transport ethanol as desired.

Four systems were further explored for economic viability with Carbon Steel as a baseline material of construction. Flexpipe economic analysis was not fully pursued due to pipe diameter restrictions requiring numerous pumping stations based on the theoretical gathering system development. To ensure a relative economic comparison and minimize operational related cost variability, two test case scenarios were developed: a simplified single pipeline segment and a full gathering system scenario. The segment test case exhibited a 7% increase in cost (from steel) when PA12 was used and 64% reduction in cost when HDPE was used.

A second test case scenario was developed utilizing the same materials of construction with the addition of RED THREAD II and designed around operational and economical requirements of the theoretical ethanol gathering pipeline system. Using the cost of a carbon steel system as the baseline, this test case scenario resulted in:

- A 61% reduction in total cost when using HDPE,
- A 43% reduction in total cost when using RED THREAD II, and
- A 41% increase in total cost when using PA12.

The materials compatibility, manufacturing testing to date, and theoretical gathering system and associated economic analysis undertaken in this project has initially demonstrated that polymer pipe is a feasible and potential very attractive choice for ethanol gathering lines. However, as the gap analysis also indicated, full-size and pressurized testing of this concept is recommended as the next step to validate/substantiate the findings for this report.

U.S. Challenge - The Shipment of Ethanol

With the U.S. moving towards an annual production goal of 50 billion gallons of biofuels, identification of lower-cost gathering, production and transportation options are critical. U.S. ethanol production from renewable sources was over ten billion gallons in 2009, and projections continue to increase as new conventional fermentation projects come on-line and cellulosic processes are commercialized. However, a recent Congressional Research Service report noted that the distribution of ethanol, particularly from the Midwest production sites to the population centers on the coasts, may constrain expanded production. Ethanol is currently shipped in rail cars, tanker trucks, and barges, all of which are relatively expensive. In addition, although rail transportation has tripled between 2001 and 2006, there may be insufficient rail capacity for the continued expected increases.

Necessity of This Research Effort

The Congressional Research Service report concluded that expansion of ethanol production will require investment in new distribution infrastructure and gathering lines to support its collection. Pipeline transportation, a lower-cost option, accounts for only a small fraction of current ethanol shipment. An Oak Ridge study[1] identified several potential issues that could limit use of the current pipeline infrastructure for fuel ethanol, including pipeline corrosion, absorption of water (yielding off-specification product or phase separation issues for fuel/ethanol blends); and the possibility that ethanol could dissolve impurities in multi-use pipelines, leading to engine damage.

Even if these technical issues are resolved, the existing fuel pipeline network runs in the opposite direction required for ethanol distribution. Consequently, new pipelines are required to connect the Midwest production areas with the country’s coastal population centers. Part of this new and comprehensive construction would include gathering lines to collect and transport ethanol to central distribution hubs.

Polymeric materials have largely displaced steel pipelines in the natural gas industry due to their lower cost, ease of installation, outstanding corrosion resistance, and excellent service record. If ethanol gathering lines could be constructed from polymer materials instead of steel a substantial benefit to all stakeholders might be realized.

A leading ethanol/biofuels industry collaboration organization, Renewable Fuels Association (RFA), has identified and expressed that one of the most significant challenges in expanding the biofuels market is product distribution and how to integrate an economical and robust transport system. Use of non-metallic materials compatible with ethanol/biofuel blends will address these challenges and eliminate significant concerns, such as corrosion and other related damage, as well as provide a generational technology “leap” in ethanol/biofuel gathering collection and transportation.

Project Objectives

This project researched and determined the feasibility of using new materials, both polymeric and composites, as low-cost alternatives to specially designed metallic gathering pipelines. The project focused on what the short and long term effect would be on the integrity of a polymer based pipe when used with the ethanol at typical temperatures and pressures. It included an economic analysis to validate that polymer pipes are also economically feasible for gathering use. This research effort will provide the direction for subsequent relevant research in this area as well as provide a foundation for developing a program to evaluate future biofuels.

Anticipated Project Benefits

It is anticipated that results of this initial research will be the first step in the safe utilization of polymer based pipelines for ethanol/biofuel gathering and transportation. Benefits of polymer based gathering lines could include lower cost, ease of installation, outstanding corrosion resistance, and provide a generational technology "leap" in ethanol/biofuel gathering collection and transportation.

Research Method / Scope

A short description of each of the research tasks is provided below to explain the methodology and reasoning behind the approach.

Task 1: Identify Expected Ethanol (and other new liquid) Feed Stocks

To ensure relevance to the industry, GTI worked with the Renewable Fuels Association (RFA) and ethanol producers to obtain representative samples or test results of ethanol stocks. A survey was developed and issued to the RFA, their representative technical committee, ethanol producers, and pipeline operators for industry guidance. Special attention was placed on the specific chemistry of the feed stocks, including trace items and additives that could have a large effect on material stability and integrity over the age of a gathering line.

Task 2: Identify Candidate Polymer and/or Composite Pipeline Materials

GTI identified commercially available, candidate *polymer/composite pipeline materials* that could be used for ethanol gathering lines (i.e., the actual material layer in contact with the ethanol). The polymer *in contact* with the fuel was the focus in order to determine the potential resistance to various fuels and thus its resultant lifetime stability and integrity. Examples of candidate materials include: thermoplastic polymers, thermoset polymers, fiberglass reinforced thermosets, thermoplastic/fiberglass hybrids, carbon fiber reinforced composites, thermoset/thermoplastic hybrid composites, thermoset/elastomeric hybrid composites, and thermoplastic/metallic reinforced composites. Special considerations in bonding or joining zones in contact with the fuel were also considered in this task.

Task 3: Conduct Materials Compatibility Analysis and Testing Data Literature Search

Once all fuel blends and materials of interest were identified in Tasks 1 and 2, GTI conducted a detailed literature search to collect any prior, published testing data to determine if and how the alcohols and other chemical constituents of the fuels interact with the polymer/plastic in contact with them. Previous work related to non-metallic issues with ethanol service was reviewed to prevent duplication of research effort.

The materials, including bulk pipe and relevant bonding/joining zones, in contact with these fuels identified in Task 2 formed the other half of the compatibility research effort. All major resin manufactures were contacted and chemical compatibility data was requested, received, reviewed, and incorporated into this report. The literature review and data included the identification of any known short or long-term performance/stability issues of the polymer/composite pipe when exposed to the ethanol or similar alcohol (when ethanol data was not available) liquid fuels stocks.

Task 4: Evaluate Pipe System Materials/Products for Gathering Applications

With the information from Tasks 1-3, GTI evaluated and selected several promising candidate polymer/composite *pipeline systems*. The focus was placed on those pipe systems for which fabrication techniques already exist and have compatible polymer materials in contact with the fuel streams. Flow and pressure design calculations were conducted and the system was designed based on extensive input from typical service parameters and needs in the ethanol industry.

Task 5: Economic Analysis of Potential Use of Candidate Polymer/Composite Systems

Those materials and pipe systems made from the materials which were identified in Task 4 were analyzed for economic feasibility. The RFA and its partners shared logistical information such as projected ethanol gathering sites, possible routing/gathering options, and anticipated ethanol/biofuel transportation volumes to facilitate GTI's economic analysis for optimal pipeline strategies.

Task 1 - Identify Expected Ethanol Feed Stocks

General Ethanol Production Background Information

First Generation Ethanol

First generation bioethanol is produced by fermenting plant-derived sugars to ethanol, using a similar process to that used in beer and winemaking. This requires the use of 'food' crops such as sugar cane, corn, wheat, and sugar beet. These crops are required for food, so if too much biofuel is made from them, food prices could rise and shortages might be experienced in some countries. Corn, wheat and sugar beet also require high agricultural inputs in the form of fertilizers, which limit the greenhouse gas reductions that can be achieved.

The ethanol production process involves milling, slurrying, fermenting, distilling, and purifying in a systematic manner to maximize production. At the present time, most ethanol in the U.S. is produced from corn by either dry milling or wet milling processes. The U.S. is the top ethanol producer using corn as the feedstock and Brazil is the world's top ethanol producer using sugar cane as the feedstock. Vehicles in Brazil have been using 100 percent ethanol for decades.

The complete processing of corn to ethanol is generally done at a single facility. Most of these ethanol plants are sited in Midwestern states, close to the farms where the corn is grown. Because of this close proximity, trucks are the predominate mode for the transportation of corn to ethanol plants. Once the corn is received at the plant it is stored in silos for up to 10 days until needed for ethanol production. Liquid transportation lines within the plant are usually above ground and are constructed from low alloy steel or stainless steel.

The dry milling process reduces the particle size of the corn using a hammer mill. The particle size of the grain can influence ethanol yield so finely ground corn (1/8 to 3/16 inch) is used to maximize ethanol yield. Water is added to start leaching soluble protein, sugars, and non-starch bound liquids. Ammonia may be added to control pH.

Wet milling is different in that the corn kernel is separated into various fractions allowing production of other products besides ethanol. The cleaned kernel is soaked in water containing sulfur dioxide and lactic acid. After soaking, the germ is removed and the starch and protein are separated by filtration and centrifugation. The starch is further purified by washing to remove protein.

After milling and slurrying, starches from the corn are converted into fermentable sugars (glucose) by amylolytic enzymes (enzymes capable of denaturing starch molecules) and heat. The fermentation is continued by the addition of Saccharomyces cerevisiae yeasts to produce low-grade ethanol. One by-product of the fermentation process is glycerol. Contamination by wild yeasts and microbes can be a problem, resulting in undesirable by-products such as lactic or acetic acid.

The low grade ethanol is refined by fractional distillation to produce ethanol that is 95.6% by volume (89.5 mole% or 190-proof). This mixture is an azeotrope with a boiling point of 78.1 °C and cannot be further purified by normal distillation. Desiccation, purification using molecular sieves, or azeotropic distillation is generally used to remove the remaining water.

Second Generation Ethanol

The goal of second generation biofuel processes is to extend the amount of biofuel that can be produced sustainably by using cellulosic or biomass comprised of the residual non-food parts of current crops. This includes stems, leaves and husks that are left behind once the food crop has been extracted, as well as other crops that are not used for food purposes, such as switch grass and cereals that bear little grain. Industry waste such as wood chips, skins and pulp from fruit pressing, and municipal solid waste (MSW) are also used.

The major component of these cellulose-bearing materials is the fibrous material consisting of cellulose, hemicellulose, lignin, and other polysaccharides. While the refining process for cellulosic ethanol is more complex than that of corn-based ethanol, cellulosic ethanol yields a greater net energy and is reported to result in lower greenhouse gas emissions.

The process to make ethanol from cellulosic material is not yet commercially viable from a economic perspective. Cellulose is very difficult to hydrolyze and the five-carbon sugars (pentoses) it produces are not fermentable with the yeasts normally used in ethanol production. Lignin, a partially polymerized phenolic resin, is a very undesirable contaminant.

One firm is working on techniques to make fermentation of cellulosic ethanol viable. Iogen Corporation is a privately held company, based in Ottawa, Ontario, Canada. Established in the 1970s, Iogen is one of Canada's leading biotechnology firms. They are an industrial manufacturer of enzyme products with a focus on products for use by the pulp and paper, textile and animal feed industries. Their specialty with respect to ethanol production is enzymatic fermentation. They are partnered with Shell, Goldman Sachs, Petro-Canada, and the Canadian government. With a $15.8 million investment from Petro-Canada, Iogen built a pre-commercial demonstration plant located in Ottawa, ON Canada. The company has been producing cellulosic ethanol at its demonstration plant since 2004.

Other firms are developing very different techniques to make ethanol. Coskata headquartered in Warrenville, IL is producing ethanol via the fermentation of synthesis gas, or ‘syngas’ mainly made up of carbon monoxide and hydrogen. Their process uses proprietary microorganisms to convert the syngas to ethanol. Syntec Biofuel also uses syngas as their feedstock, but produces ethanol by passing the gas over the catalysts in a fixed bed reactor, similar to the production process for methanol. The syngas used in both processes is generated through gasification of a variety of feedstocks.

Other ongoing research is focused on developing alternatives to the costly enzyme and yeast multi-step process. Mascoma Corporation in Lebanon, N.H., is working with a thermophilic bacterium. Oak Ridge National Laboratory researchers are studying Clostridium thermocellum which can both degrade the cellulose and ferment the resulting sugar. BC International is building a plant in Jennings, LA that uses genetically engineered E. coli bacteria to convert all forms of sugar.

Summary - Current Feedstocks Used to Make Common Liquid Fuels

The common feedstocks for ethanol were investigated and are summarized in Table 1 and Table 2 below. Note, biobutanol can be made from the same feedstocks as ethanol.

Table 1. Ethanol Feed Stocks (U.S. Production)

Ethanol (currently in production in U.S.)
Crops
Corn
Corn/barley
Corn/milo
Corn/wheat starch
Milo/wheat starch
Pearl millet (potential - SE. U.S.)
Waste Products
Cheese whey
Potato Waste
Wood waste
Waste beer
Beverage waste
Sugar cane bagasse
Brewery waste

Table 2. Ethanol Feed Stocks (Non-U.S.)

Ethanol (non-U.S.)
Sugarcane (Brazil)
Sugar beet
Wine (France/Italy)
Sake (rice wine - Japan)
Cassava (highest energy/acre - tropical areas)
Cellulosic Biomass
Residues & Waste Products
Non-edible plant parts
MSW
Pulp/Paper industry waste
Wood waste
Forest residues
Dedicated crops
Grass
Short rotation trees

Biodiesel feedstocks currently in production in the U.S. are listed in Table 3.

Table 3. Biodiesel (in U.S. Production)

Biodiesel (currently in production U.S.)
Oils
Soy
Canola
Cottonseed/soy
Cottonseed/soy/canola
Palm
Animal Products
Yellow grease
Animal Fat
Recycled oils and grease
Recycled cooking oil
Waste vegetable oil
Multi Feedstock
Tallow/yellow grease/soy/poultry fat
Soy/animal fats
Soy/choice white grease
Cottonseed/animal fats
Plant oils/animal fats
Soy/poultry fat

Overview of Current Transportation Methods for Ethanol

Historically, ethanol has been shipped to markets via truck, rail and barge. It is stored at fuel terminals and blended with gasoline at or near the point of retail distribution. To sustain the market growth needed to meet the current suggested targets, infrastructure improvements should be considered for transporting biofuel and co-products to market.

Most ethanol is currently produced in the Midwest, but 80 percent of the U.S. population (and therefore implied ethanol demand) lives along coastlines. Transportation factors to consider as ethanol production continues to expand include:

1. The capacity of the Nation's transportation system to move ethanol, feedstock, and co-products produced from ethanol.
2. The availability of corn close to ethanol plants (~ 10-15 miles).
3. The location of feedlots for use of co-products relative to ethanol producing areas.

In 2005, rail was the primary transportation mode for ethanol, shipping 60 percent of ethanol production (approximately 2.9 billion gallons of ethanol). Trucks shipped 30 percent and barges 10 percent. To date, the growth of ethanol production and the construction and expansion of new plants have not been hampered by logistical concerns. Railroads kept up with ethanol growth in 2006. As ethanol production grew by 26 percent in 2006, railroad shipments of alcohols (most of which is ethanol) increased by 28 percent.

This may not be the case in the future. All three modes used to transport ethanol—rail, barge, and truck—are at or near capacity. Total rail freight is forecast to increase from 1,879 million tons in 2002 to 3,525 million tons by 2035, an increase of nearly 88 percent.

Ethanol is shipped in the following containers:

1. Standard rail tank cars (approved for flammable liquids) - DOT 111A rail cars.
2. Standard gasoline tanker trucks (DOT MC306 Bulk Fuel Haulers). Truck drivers must have HAZMAT certification.
3. The main terminals served by barge include New York Harbor, Philadelphia, Baltimore, Providence, Chicago, New Orleans, Houston, Albany, and many others. Ethanol is typically shipped in 10,000–15,000 barrel tank barges. The number of ethanol plants located near a river facility, however, is relatively small.

There is one recently commissioned U.S. steel pipeline (Kinder Morgan) that is transporting fuel grade ethanol blended with gasoline from Tampa to Orlando.

The presence of water (as a contaminant) is a primary concern in the transportation of ethanol. A large investment in dehydrating and filtration/coalescing equipment would be required for any alcohol transportation by pipeline. There is evidence that ethanol can induce stress corrosion cracking, especially at untreated weld joints. Liners, weld treatments, or coatings could help alleviate this. Ethanol can also strip impurities present inside multi-product pipeline systems resulting in undesirable contaminants.

The high polarity of ethanol causes problems with certain elastomers also containing polar components. Nylon swells and loses tensile strength, similar to its behavior in water. Polybutene terephthalate also exhibits significant changes. *ASTM D5798 - Standard Specification for Fuel Ethanol* specifies that unprotected aluminum must not be used as it will introduce insoluble aluminum compounds into the fuel. The effect is exaggerated by elevated fuel conductivity due to contact with nitrile rubber.

A detailed materials compatibility study for ethanol gathering lines was completed as part of Task 3 of this project.

Ethanol Contaminant Information

To prevent diversion for human consumption, federal regulations require ethanol produced for fuel use to have a denaturant (usually gasoline) added before shipping. This is the source of the largest contaminant found in ethanol. The second largest are the inhibitors added to limit corrosion. These include ethyl tertiary butyl ether (ETBE), methyl tertiary butyl ether (MTBE), and various aliphatic ethers.

Other potential contaminants could be by-products of the production process and chemicals added to assist in milling, slurrying, and fermentation. Some of these are mentioned in the previous sections on ethanol production. Other chemical reactions with deleterious effects are reactions of ethanol with phosphoric and sulfuric acid to form phosphate and sulfate esters. A complete dehydration with sulfuric acid could produce diethyl ether or ethylene.

The chemical structure of ethanol also offers some potential incompatibilities with other materials. Ethanol is made up of carbon, hydrogen and oxygen. The oxygen content provides no BTU value. But it is this oxygen content that imparts very different properties to an alcohol, when compared to gasoline. The oxygen is present as a hydroxyl group (-OH), the same functional group found in water. Since the hydroxyl group is attached to the end of the molecule, it makes the alcohol molecule very polar. This also results in a high heat of vaporization as the molecule is very susceptible to hydrogen bonding, as opposed to very volatile gasoline. A multi-reference summary of common impurity specifications is presented in Table 4.

Combustion of ethanol in air is presented in Equation 1 below.

$$C_2H_5OH + 3O_2 \rightarrow 2(CO_2) + 3(H_2O) \qquad \text{[Eqn. 1]}$$

Representatives from the U.S., Brazil and EU (Tripartite Task Force) met in 2007 to write a white paper on "Internationally Compatible Biofuel Standards". The purpose was to compare biodiesel and biomethane standards from the three regions. An attempt was made to negotiate a harmonization of standards for future trade considerations.

The following conclusions were made:

1. Ethanol purity would be defined by the ethanol and water content.
2. Brazil and the U.S. would define a minimum ethanol content of 98.0% by volume. The EU would use a lower limit of 96.8 %. The task force was hopeful that after further negotiations the EU would agree to the 98.0 % limit.
3. The EU limit for water content was more conservative than found in the U.S. or Brazil.
4. Brazil has the lowest chloride limit. Inorganic chlorides contribute to fuel corrosiveness.
5. The EU is the only region having a phosphorus limit, based on data obtained from ethanol producers. Phosphorus may be more of an issue in cellulosic produced ethanol rather than corn produced ethanol. Phosphorus is a catalyst in the production of ethanol from petrochemical feedstocks.

6. Three parameters could not be compared because different test methodologies are used. These are residue by evaporation (gum), acidity, and pHe. It is hoped that an effort could be made that would lead to an agreement to standardizing test methods.
7. Brazil includes a specification for electrical conductivity (EC). It is felt that EC would be a quick test for purity.

Table 4. Common Impurity Specifications

Parameter	Recommended Value	Notes
Color	Dyes Permitted	Ethanol may have a yellow color due to the presence of proteins
Heavier (C3-C5) alcohols	2% (ASTM, EU)	No Brazilian limit
Methanol	0.5% (U.S.), 1.0% (EU)	No Brazilian limit
Hydrocarbons	3% (B)	Not specified in U.S. and EU because it is a common denaturant.
Benzene	0.06% (CARB)	Denatured ethanol
Olefins	0.05% (CARB)	Denatured ethanol
Aromatics	1.7% (CARB)	Denatured ethanol
Gum or Residue from Evaporation	5 mg/100ml (U.S., B), 10 mg/100 ml (EU)	Consensus needed on technique
Sulfate	4 ppmw (U.S., B)	Problems of sulfate deposits. EU expected to harmonize
Total Sulfur	10 ppmw (U.S., EU)	Brazil to harmonize. Low level amounts of sulfur in all plant based materials.
Chloride	1 ppmw (ASTM), 25 ppmw (EU), 1 ppmw (B)	Very aggressive corrosion inducing contaminant. Auto industry wants 1 ppmw limit.
Phosphorus	1.3 mg/L (ASTM), 0.5 mg/l (EU)	Possible contaminant from fertilizer and nutrients used in growing or fermentation.
Copper	0.1 ppmw (EU), 0.07 (ASTM, B)	Intended to prevent contamination from Cu tubes and stills. Cu is an oxidation catalyst and will increase oxidation rates.
Lead	13 mg/L (ASTM)	
Sodium	2 ppmw (B)	Feedstock contamination
Iron	5 ppmw (B)	Feedstock contamination
Electrical conductivity	500 uS/m	Brazil feels this is a quick test for purity
Acidity	50 ppmw (ASTM), 70 ppmw (EU), 38 ppmw (B)	Complex acids may be produced from certain feedstocks. WU and Brazil feel parameter is important from a corrosion standpoint (specifically acetic acid).
pHe	6.5 – 9.0 (U.S.), 6.0 – 8.0 (B)	Special meters and probes needed to be able to correlate data.

Notes: (1) U.S. - United States; EU - European Union; B - Brazil
(2) Condensed from Dec 2008 white paper[2], CARB ethanol standards, and ASTM D5798 specifications.

Because there was an additional large body of knowledge of material (plastic) compatibility with gasoline it was evaluated based on similarities between gasoline and ethanol. The results are presented below in Table 5.

Table 5. Properties of Ethanol versus Gasoline

	Ethanol	Gasoline
Molecular weight	46.07	100-105
Composition, by weight %		
Carbon	52.2	85-88
Hydrogen	13.1	12-15
Oxygen	34.7	0
Relative Density, 60/60°F	0.794	0.69-0.793
Density, lb/gal @ 60°F	6.61	5.8-6.63
Lower Heating Value		
BTU/lb	11,500	18.000-19,000
BTU/gal @ 60°F	76,000	109,000-119,000
Boiling point, °F	173	80-437
Freezing point, °F	-173.4	-40
Vapor pressure, psi	2.3	7-15
Water solubility, @70°F		
Fuel in water, volume %	100	negligible
Water in fuel, volume %	100	negligible
Viscosity		
@ 68°F	1.50	0.5-0.6
@ -4°F	3.435	0.8-1.0
Flash point, closed cup, °F	55	-45
Auto ignition temperature, °F	~793	~495
Flammability limits, volume @		
Lower	4.3	1.4
Upper	19.0	7.6
Latent heat of vaporization		
BTU/lb @ 60°F	396	~150
BTU/gal @ 60°F	2,378	~900
Stoichiometric air/fuel, weight	9.00	14.7
Moles product / moles charge	1.07	1.06
Moles product / moles $O_2 + N_2$	1.14	1.08

Ethanol Standards of Interest for Fuel Quality/Makeup

The primary standards related to ethanol fuel, quality, vehicle use, piping, and storage are listed below in Table 6. The "parent" standards (e.g., ASTM D4806) are highlighted in orange and drive many of the requirements for ethanol fuel and the components used in contact with it. The information in these standards are coupled with the reference material presented above, the survey results, and testing of submitted samples to establish the boundaries of the constituent make-up of the ethanol fuel that would flow through gathering lines.

Table 6. Ethanol Related Standards of Interest (Fuel Quality/Makeup)

Ethanol Fuel - General Standards/Specifications			
	ASTM		
		D4806	Standard Specification for Denatured Fuel Ethanol for Blending with Gasolines for Use as Automotive Spark-Ignition Engine Fuel
		D4814	Standard Specification for Automotive Spark-Ignition Engine Fuel
		D5798	Standard Specification for Fuel Ethanol (Ed75-Ed85) for Automotive Spark-Ignition Engines
		WK 18986	New (in development) Specification for International Specification for un-denatured Fuel Grade Ethanol
		RFG Research Report D02: 1347	Research Report on Reformulated Spark Ignition Fuel
	EU		
		pr EN 15376	Bioethanol - Auto-motive fuels - Ethanol as a blending component for petrol - Requirements and test methods
	RFA		
		NACE TM-01-77	RFA recommends corrosion inhibitors and criteria falls to NACE standard
Engine Fuel Quality			
	NIST		
		Handbook 130	Uniform Laws and Regulations in the Areas of Legal Metrology and Engine Fuel Quality
Vehicular Fuel Systems			
	SAE		
		J1681	Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing
		J30	Fuel and Oil Hoses
		J312	Automotive Gasolines
		J1681	Gasoline, Alcohol, and Diesel Fuel Surrogates for Material Testing
		J2835	Recommended Practice for Flex Fuel Vehicles

Pipeline and Piping Infrastructure; Transmission and Distribution		
ASME		
	B31G	Manual for Determining Remaining Strength of Corroded Pipelines: Supplement to B31 Code-Pressure Piping
	B31.1	Power Piping
	B31.3	Power Piping
	B31.4	Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
	B31.8	Gas Transmission and Distribution Piping System
	B31.8S	Managing System Integrity of Gas Pipelines
	B31Q	Pipeline Personnel Qualification
	API 579-1/ASME-FFS-1	Fitness For Service
	PCC-1	Guidelines for Pressure Boundary Bolted Flange Joint Assembly
	PCC-2	Repair of Pressure Equipment and Piping Standard
	RTP-1	Reinforced Thermoset Plastic Corrosion Resistant Equipment
	BPVC-IX	BPVC Section IX-Welding and Brazing Qualifications
	BPVC-X	BPVC Section X - Fiber Reinforced Plastic Pressure Vessels (Boiler Pressure Vessel Code)
	BPVC-XII	BPVC Section XII - Rules for Construction and Continued Service of Transport Tanks (Boiler Pressure Vessel Code)
	B16.5	Pipe Flanges and Flanged Fittings: NPS through NPS24
	B16.34	Valves -- Flanged, Threaded, and Welding End
EPA		
	Flex Pipe Survey	Survey of Flexible Piping Systems, March 1997

Storage and Distribution		
API		
	Standard 2610	Design, Construction, Operation, Maintenance, and Inspection of Terminal and Tank Facilities
	Standard 650	Welded Steel Tanks for Oil Storage Publication
	API 579-1/ASME FFS-1	Fitness For Service
	TR 939-D	Stress Corrosion Cracking of Carbon Steel in Fuel-Grade Ethanol: Review, Experience Survey, Field Monitoring, and Laboratory Testing
	RP 1004	Bottom Loading and Vapor Recover for MC-306 and DOT 406 Cargo Tank Motor Vehicles
	RP 1007	Loading and Unloading of MC-306 and DOT 406 Cargo Tank Motor Vehicles
	RP 1626	Storing and Handling Ethanol and Gasoline Ethanol Blends at Distribution Terminals and Service Stations
	RP 1627	Storage and Handling of Gasoline-Methanol/Co-solvent Blends at Distribution Terminals and Service Stations
	RP 1637	Color-Symbol System to Mark Equipment and Vehicles for Product Identification at Gasoline Dispensing

		Facilities and Distribution Terminals
	Publication 1642	Alcohol, Ethers, and Gasoline Alcohol and Gasoline-Ether Blends
	Publication Literature Review	Impact of Gasoline Blended with Ethanol on the Long-Term Structural Integrity of Liquid Petroleum Storage Systems and Components
	Developing Standard MPMS Ch. 11.3	Ethanol and Gasohol Blends with Volume Correction Factors
NFPA		
	NFPA 30	Flammable and Combustible Liquids Codes
	NFPA 30A	Code for Motor Fuel Dispensing Facilities and Repair Garages
UL		
	UL 58	Steel Underground Tanks for Flammable and Combustible Liquids
	ANSI/UL 142	Steel Aboveground Tanks for Flammable and Combustible Liquids
	UL 971	Nonmetallic Underground Piping for Flammable Liquids
	UL 1316	Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products, Alcohols, and Alcohol-Gasoline Mixtures
	UL 2080	Fire Resistant Tanks for Flammable and Combustible Liquids
	UL 2085	Protected Aboveground Tanks for Flammable and Combustible Liquids
	UL 2244	Aboveground Flammable Liquid Tank Systems
	UL 2245	Below Grade Vaults for Flammable Liquid Storage Tanks

Task 1 Survey

The following nine pages contain the survey developed and issued to the RFA (and its technical committees), ethanol producers, and pipeline operators.

Dear Survey Participant:

GTI is pleased to initiate the DOT PHMSA sponsored project, *"Feasibility of Using Plastic Pipe for Ethanol Low Stress Lines"*.

> This research project will address the feasibility of using currently available polymer (thermoplastic or thermoset) pipe for new ethanol gathering systems.

> A comprehensive study will be performed to assess the effects of ethanol blends on potential polymer pipe candidate materials, both polymeric and composites, as low cost, low maintenance alternatives to specially designed and joined metallic pipelines.

As an initial step, we have prepared a survey to ensure we are capturing and addressing the concerns of the ethanol industry. Part of its purpose is to survey ethanol producers and distributors about their experiences with trace constituents in ethanol, and what polymeric materials are in common use for transportation of ethanol. GTI would greatly appreciate your input through this survey.

<u>All comments, information, and data received as a result of this survey will be kept under strict confidentiality</u>. GTI would be pleased to provide a survey summary (with all specific company identifications removed) to any respondent once the results are tallied.

Please send (email is preferred) the completed survey by Fri. March 27, 2009 to:

Ms. Karen Crippen, GTI
Email: karen.crippen@gastechnology.org
Fax: (847) 768-0970.

You may also call Ms. Crippen at: (847) 768-0604.

The *Renewable Fuels Association* (RFA) is on the steering committee for this project. If you have any concerns regarding this project or survey, you may contact:
Ms. Kristy Moore at (202) 289-3835, or by email at kmoore@ethanolrfa.org.

Thank you for your time to fill out this survey.

Andy Hammerschmidt
GTI Team Project Manager
andrew.hammerschmidt@gastechnology.org
847-768-0686

A. Questions Focusing on Additives and Trace Constituents in Ethanol

- *Additives or trace constituents could have a potential deleterious effect on polymeric materials even at low concentration levels.*
- *The effect could be synergistic, depending on the specific chemical interaction.*
- *This part of the survey is designed to determine what constituents may be present, especially those compounds beyond what is typically monitored for.*
- *GTI would also like to analyze a representative selection of produced ethanol.*
- *Any published report of data obtained from this survey and from analysis of submitted ethanol samples will be completely confidential (anonymous). The different data sets would refer only to "Company A", "Company B", etc.*

1. Appendix 1 of this survey contains a table listing the fuel components, additives, and impurities. [This is important information since these constituents may affect the physical/mechanical properties of some polymer pipe materials]. Please enter any available data you would be willing to share in the column labeled "Typical Concentrations".

> Entered data in Appendix 1: ___YES ___NO.

----

2. If there are any *trace constituents* or *by-products* [not included in Appendix 1] that might be introduced by the process of producing ethanol you are using, please list these directly below with any typical concentrations, if known [This is important for the same reasons as #1 above].

>

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3. During processing, do you monitor (test for) for any trace constituents? (e.g., *ASTM D4806 - Standard Specification for Denatured Fuel Ethanol for Blending with Gasolines for Use as Automotive Spark-Ignition Engine Fuel*)?

If yes, please provide a typical chemical analysis data sheet (all responses will be kept confidential). [This is important for the same reasons as #1 above].

> Attached typical chemical analysis data sheet: ___YES ___NO.

----

4. Do you monitor for any constituents beyond what is listed in various specifications?

If yes, please list below with typical concentrations.

>

----

5. What *specific* additives and concentrations of: corrosion inhibitors, denaturing agents, or drag reducing agents do you add to your ethanol product before it ships? [This information is important since these chemical agents may come into contact with the proposed plastic gathering lines if they are added to the ethanol prior to transport out of the facility].
>

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6. At what point in the distribution system are the additives introduced or injected? [We are requesting the information for the same reason as #5 above].
>

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7. Would you be willing to supply GTI with a physical sample (e.g., 500ml) of your ethanol? GTI would supply bottles, shipping containers, shipping instructions, and pay any shipping costs (all results would be kept confidential). [These samples will be analyzed for chemical constituents and the data will be used to validate and fill in the gaps of the data received from the survey and published literature/references].
If yes, please provide contact information below or contact Karen Crippen, GTI at (847) 768-0970.
>

B. Questions Focusing on Transportation of Ethanol

- *Knowledge of typical industry transportation practices is valuable supplementary information.*
- *In addition, any experience with material failures (of polymer or elastomeric components in contact with your ethanol stream) would supply important background data for the project scope.*
- *<u>As mentioned previously, all responses will be kept strictly confidential</u>.*

----
8. How is the ethanol transported (1) *within* the processing plant (and what materials are the transport vehicle/system made from) and (2) *from* the plant after processing (i.e., do you use pipelines, trains, tanker trucks, or barges)? Estimate the number of barrels per day and barrels per year (or gallons per year) that the plant produces. Also estimate the average distance of transport from the plant to the central distribution point, e.g., barge terminal. [This is important information since it will govern the size and flow rate of the required gathering lines].
>

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9. What is the temperature of (1) the current ethanol storage tanks in the process plant; and (2) the ethanol product itself at the time of transport out of the plant? [This is important information since the temperature will affect the material compatibility of the plastic pipe material with ethanol and its additives].

>

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10. What ancillary (secondary) components come into contact with the ethanol? Specific sizes are not necessary, but general information of valves, fittings, diaphragms, o-rings, seals, etc.

---

11. What polymer materials are the components mentioned above made from? [This is important to help to build a list of *materials* already being used in conjunction/contact with ethanol in the plant environment].

>

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12. Do you find that your company must replace any polymeric or elastomeric components often (*prior* to failure)? [This could give an indication of what polymer/plastic/elastomeric materials are more susceptible to ethanol/additive degradation].

>

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13. To what extent do you have issues with polymeric components actually failing in the plant? [This information is important for the same reason that was given in #12 above].

>

---

14. Are you concerned about issues such as contamination during transportation, phase separation, or corrosion? What *contaminants* might be introduced (e.g. additional water)? [As with the additives and trace constituents, it will be important to understand what other contaminants might come into contact with the polymer pipe material used for ethanol gathering lines].

>

Appendix 1 is on the next page.

Appendix 1 - Chemical Composition of Ethanol (Fuel Components, Additives, and Impurities)

Parameter	*Typical Concentration*	*Specification Limit in U.S.*	*Source*	*Concern*
Fuel Components				
Ethanol			Major constituent	
Methanol		0.5% (ASTM)	Fermentation by-product	Combustion
Heavier alcohols, glycerol		2% (ASTM)	Fermentation by-product	Combustion
Additives				
Benzene, Toluene, etc.		0.06% (CARB)	Denaturant	Combustion, environmental
Olefins		0.05% (CARB)	Denaturant	Combustion
Paraffins			Denaturant	Combustion
MTBE, ETBE			Corrosion inhibitor	
Impurities				
Water		1% (ASTM)	Processing by-product	Corrosion
Ammonia			Milling pH control	Precipitation with sulfate
Sulfate		4 mg/kg	Milling pH control, Impurity in feedstock	Precipitation, plugging
Chloride		42 mg/kg	Milling, Impurity in feedstock	Corrosion
Phosphorus, Nitrogen, Sulfur		10 mg/kg (CARB, sulfur only)	Impurity in feedstock, fertilizer, nutrients	Corrosion
Copper		0.07 – 0.1 mg/kg (ASTM)	Distillation processing	Oxidation catalyst
Lead			Distillation processing, Feedstock contamination	Environmental
Sodium, potassium, iron, calcium			Feedstock contamination	Corrosion, precipitation
Acetic, lactic, oxalate or other organic acids		0.005 – 0.007 % (ASTM)	Fermentation by-product	Corrosion
Protein			Fermentation by-product	Corrosion
Lignin			Incomplete hydrolyzation	Combustion
Enzymes			Fermentation additive	Environmental, cost
Glucose or other sugars			Incomplete fermentation	Environmental, cost
Diethyl ether			Production by-product	Environmental, corrosion
Ethylene			Production by-product	Combustion
Phosphate or sulfate ester			Production by-product	Combustion, corrosion

Ethanol Physical Sampling and Packing Protocol (for sample collection and submission)

A simple, but complete, sampling protocol was drafted to assist volunteer companies in properly sampling, packing, recording, and shipping sample shipments.
The protocol is presented directly below and will be provided to all companies that express interest in submitting ethanol samples to supplement the Task 1 research effort and survey results.

1. Sampling and Packaging Protocol

   1.1. Samples of ethanol should be collected in clean borosilicate glass containers with Teflon lined caps. Fill the container completely, leaving little headspace. 500ml would be more than enough.

   1.2. Attached the lid securely and seal around the rim with an elastomeric tape such as electrical tape.

   1.3. Wrap sealed bottle with absorbent material.

   1.4. Place wrapped bottle inside a plastic bag to contain the material should the bottle break.

   1.5. Place inside paint can packaging.

   1.6. Seal paint can by lightly tapping its lid down with a hammer.

   1.7. Apply protective plastic over ring or clips, or seal metal drum. See Figs. 1 & 2.

Fig. 1. 4G box and paint can packaging system with plastic over ring and Styrofoam inserts.

Fig. 2. Paint can with clips.

   1.8. Place can in box using Styrofoam inserts.

   1.9. Fill out chain of custody record (see the full form located at the end of this document) and enclose it in the box or drum.

   1.10. Seal box or drum and prepare shipping paperwork.

2. Filling out the Chain of Custody Record

    2.1. **Company Name and Address of Sampling Site:** This field is used to specify where the samples came from. Fill in the name of your company and the complete address of the site where the samples were taken.
    2.2. **Sampler**: The actual person who performed the sampling.
    2.3. **Signature**: The actual person who performed the sampling.
    2.4. **Sample**: How your company wishes to identify the samples. Can be any information or means of identifying the sample: alphanumeric combinations, etc.
    2.5. **Date**: Date of sample collection.
    2.6. **Time**: Time of sample collection.
    2.7. **Sample Description**: Complete sample description (component type, etc.)
    2.8. **Comments**: In the final column, please list any comments regarding the sampling process or the samples themselves that may be of use to the lab.
    2.9. **Relinquished by**: When you relinquish custody of the sample. The FedEx shipping documentation is proof of when samples are received by FedEx, so the driver does not have to sign the form. It will be signed off as a final receipt when received in the laboratory.

3. Shipping

- The sample must be shipped as a hazardous material. Hazardous materials can be shipped either by ground shipment, or on a plane for overnight delivery. One will need a flammable liquid sticker. The proper UN shipping designation for ethyl alcohol (in the U.S.) is UN1170. One must also be prepared to provide a copy of the Material Safety Data Sheet (MSDS) for your materials if FedEx requests it.
- Hazardous material shippers must be properly qualified through a FedEx sales representative before tendering hazardous material packages, there are no exceptions. There are classes that can be taken, and FedEx also offers an on-line hazardous materials training seminar.

The following material is directly excerpted from FedEx's web site:

[http://www.fedex.com/us/services/options/ground/hazmat/packaging.html?link=4]

- All hazardous materials must be packaged in United Nations Performance Oriented Packaging (UN POP).
- All packaging must meet the requirements set out in 49CFR 173.24 and 173.24a.
- Packaging that is not in new or “like new” condition will not be accepted by FedEx.
- In addition, the following requirements apply:
    - ⇒ All paint containers with friction-fitted lids must have a minimum of four clips, or a retaining ring, around the container lid.
    - ⇒ Hazardous materials cannot be shipped in any FedEx packaging.

⇒ When required, all Class 2 cylinders must be placed inside an overpack (outer package) marked “Inside packages comply with prescribed specifications.”

⇒ Fiberboard packaging must display a Minimum 200 lb. Bursting Test seal or 32 Edge Crush Test (ECT) seal. Gross weight cannot exceed the package specifications listed on the seal or our maximum weight limit of 70 lbs. (32kg) per package.

⇒ For packages weighing up to 20 lbs., use at least 32-edge crush test or 200-lb. bursting test corrugated containers.

⇒ For packages weighing 21–50 lbs., use at least 44-edge crush test or 250-lb. bursting test corrugated containers.

⇒ For packages weighing 51–70 lbs., use at least 55-edge crush test or 275-lb. bursting test corrugated containers.

⇒ FedEx Ground does not accept pails or drums over 8 gallons (32 liters). All pails or drums must be UN POP. FedEx will accept authorized pails or drums as single packaging.

NOTES:

⇒ This information is provided only as a guide. It assumes a representative sample can be obtained. It is the sampler’s responsibility to ensure a representative sample. Any historical information regarding the sample would aid us in better analyzing your sample. This would include previous results of laboratory or field screening analyses.

⇒ It is the sampler’s responsibility to ensure sampling is performed in a safe manner. Neither GTI nor any person acting on behalf of GTI assumes any liability with respect to the use of, or for damages resulting from the use of, any information presented in this procedure.

The chain of custody form is on the next page.

CHAIN OF CUSTODY RECORD

Gas Technology Institute
1700 S. Mt. Prospect Rd.
Des Plaines, IL 60018

Company Name and Address of Sampling Site	Sampler Name
	Signature

Sample	Date	Time	Sample Description	Comments

Relinquished by (signature, date, time)	Received by (signature, date, time)	Relinquished by (signature, date, time)
Received by (signature, date, time)	Relinquished by (signature, date, time)	Received in the lab by (signature, date, time)

Remarks

Thermoplastic Piping - Advantages and Limitations to Consider for Use with Ethanol Gathering Networks

Advantages

- Mature ASTM Standards exist for proper short term and long term testing and use of thermoplastics and thermoplastic piping,
- A very competitive industry which offers excellent value to the end user of these products,
- Decades of successful use in many industries, including oil, gas, chemical, etc.,
- Tremendous corrosion resistance in buried environments,
- Outstanding chemical resistance to many chemicals and solvents,
- Easy to lift, cut, join, and install,
- Produced using less energy than metal,
- Flexible (important for underground applications) and tough,
- Outstanding hydraulic (flow) properties, and
- Clear marking and identification via print lines.

Limitations

- Low strength and low stiffness,
- Lack of technology to easily locate underground (can bury tracer wire with the pipe to overcome this), and
- Sensitivity to high temperatures.

Methods of Joining Thermoplastic Pipe

There are a variety of methods to join thermoplastic pipe. Selection from the possible methods depends on the material of the pipe, the function of the pipe, and the corrodent/material being transported. The joining methods can be divided into two general groups: permanent joint techniques and nonpermanent joint techniques.

Permanent Joint Techniques:

- Solvent cementing
- Butt fusion
- Socket fusion (heat and electro-fusion)

Nonpermanent Joint Techniques:

- Threading
- Flanging

- Bell-ring-gasket joint
- Compression insert joint
- Grooved-end mechanical joint

A brief summary of each method with advantages and disadvantages is provided below and will be useful in later sections of this report.

Solvent Cementing

Used with PVC, CPVC, ABS, and other styrene based materials.

Advantages:

- No special tools,
- Pipe is less expensive,
- Pull-out resistant,
- Many fittings to choose from,
- Pressure resistant up to burst pressure,
- Excellent chemical resistance (i.e., joint is same material),
- No threads to cut, and
- Very easy installation.

Disadvantages:

- Cannot dissemble, and
- Leaky joints hard to repair.

Butt Fusion

This method provides a very strong joint (as strong as or stronger than the pipe). Pipe can be put into service once cooled. Used extensively with PE, PB, PP, and PVDF.

Advantages:

- Pull-out resistant,
- Pressure resistant beyond burst pressure of the pipe, and
- Excellent chemical resistance (i.e., joint is same material).

Disadvantages:

- Cost of fusion equipment,
- Bulkiness of equipment,
- Cannot disassemble the joint, and
- Fusion procedures must be followed carefully.

Socket Fusion

This method is also used for polyolefins such as PE, PB, PP, and PVDF. There are two different methods (a) socket heat joints and (b) electrical-resistance fusion (EF) joints.

EF Socket Fusions

The EF sockets use heat from an electrified copper coil (usually installed/imbedded in the fitting by the manufacturer) to soften the outside surface of the pipe end and the inside surface of the fitting socket. Used commonly with PE in the gas industry and PP in acid waste drainage systems.

<u>Advantages:</u>

- Piping can be "dry fitted" and assembled before permanent joints are made.

<u>Disadvantages:</u>

- Imperfect heat distribution possible which could result in low joint strength and possible corrosion resistance problems,
- Cannot be disassembled,
- Must follow joining instructions carefully, and
- Cumbersome equipment required.

Heat Socket Fusions

These types of fusions are the preferred type of fusions for systems handling corrodents. The method uses an electrically heated tool, which softens the outside surface of the pipe and the inside surface of the fitting. This method is used on all polyolefins.

<u>Advantages:</u>

- Joint as strong as the pipe,
- Small and inexpensive equipment,
- Pull-out resistant, and
- Excellent chemical resistance.

<u>Disadvantages:</u>

- Need high degree of skill and dexterity to form a good joint, and
- Cannot be disassembled.

Threaded Joints

Used on smaller diameters, usually 4 inches or less.

<u>Advantages</u>:

- Easy disassembly for maintenance.

Disadvantages:

- Reduces Maximum Allowable Operating Pressure (MAOP) by up to 50%,
- Threaded joints in polyolefins are leak hazards if pressure exceeds 20 psig (due to low modulus of elasticity), and
- Must use heavier wall pipe (more expensive).
- Leakage at the joints can still be a problem

Flanging

Flanges are available for most thermoplastic pipe. The flange is affixed to the pipe by any of the other methods listed above.

Advantages:

- Can be used to connect to pumps, equipment, or metallic piping (tie-ins),
- Excellent for temporary piping systems,
- For lines that require periodic disassembly,
- Reduction in field labor since joints can be pre-made and bolted together in the field, and
- For remote locations or poor weather (where fusion methods or equipment are difficult to employ).

Disadvantages:

- Must choose proper gasket for corrosion resistance,
- High material and labor costs, and
- Bulky.

Bell-Ring-Gasket Joints

This type of joint is commonly used for underground, pressure-rated PVC piping for water. It can also be used to connect PVC to metal pipe. An elastomeric ring is retained in a groove in the female joint section. The ring becomes compressed as the pipe is inserted into the joint.

Advantages:

- Simple and quick, and
- Reduced labor cost.

Disadvantages:

- Difficult to make leak free, and
- Danger of pull-out (needs anchoring).

Grooved-End Mechanical Joint

The pipe ends are grooved and a metal coupling with an elastomeric seal is fitted over the pipe ends with a bolt and hinge. This joint is used primarily with PVC and CPVC since they are sufficiently rigid to retain the integrity of the grooves.

Advantages:

- Easy field assembly, and
- Can disassemble the joint.

Disadvantage:

- Must find compatible elastomer for corrodent being handled.

Key Thermoplastic Materials/Resins[3]

Thermoplastic pipe is made up of the primary resin (polymer) and various additives. The resin provides the basic/major properties of the component (pipe) made from it. The additives provide special properties desired during fabrication and use.

Commercially Available Thermoplastic Pipe Products (Common Resins)[4]

Thermoplastics have significantly different properties between material classes. To successfully use these materials in the short and long-term, one must understand their physical, mechanical, and chemical properties when exposed to various environments and applications.

The major thermoplastic materials with joining methods and typical applications are listed in Table 7 below.

Table 7. Most Common Thermoplastic Materials (used to make pipe)

Material	Joining Method	Applications
PVC - Polyvinyl Chloride	Solvent cementing, threading, and heat fusion	Drains, vents, waste streams, sewage, casings, and chemical processing
CPVC - Chlorinated Polyvinyl Chloride	Solvent cementing, threading, and heat fusion	High temperature applications
PE - Polyethylene	Heat fusion and mechanical fittings with inserts	Water, corrosive chemicals, natural gas, and electrical conduit
PP - Polypropylene	Heat fusion and threading	Chemical waste, natural gas, and oil field
PA - Polyamide	Heat fusion and mechanical fittings	PA11 and PA12 are used to a limited extent for extruded pipe in the natural gas industry (or research applications).
ECTFE - Ethylene Chlorotrifluoroethylene	Butt fusion only	Cryogenic, radiation areas, high wear applications, liners, high-temperature wire and cable insulation, and chemical waste
PVDF - Polyvinylidene fluoride	Threading, fusion, and flanging	Corrosion resistant valves, pipes, packing material, and process equipment
Saran™ - Polyvinylidene Chloride	Threading only	Food process and meat industries (as liner)

PVC - Polyvinyl Chloride

PVC has been in use for over 30 years in the chemical processing, industrial plating, water supply systems, chemical drainage, and irrigation networks. It makes up the majority of the thermoplastic piping market with PE running second.

PVC is an amorphous (non-crystalline) polymer which contains 56.8% chlorine. PVC is stronger and more rigid than other thermoplastic materials. It has a high tensile strength and modulus of elasticity. PVC has the highest Long-Term Hydrostatic Strength (LTHS) at 73°F of any of the major thermoplastics.

There are two principal Types of PVC - I and II. Type I is un-plasticized or rigid PVC and Type II is modified with rubber and is called high-impact, flexible, or non-rigid PVC. Most PVC pipe is of the high-impact type which has a somewhat compromised chemical resistance as compared to Type I.

PVC piping is available in ¼ inch to 16 inch nominal diameter in Schedule 40 and 80 wall thicknesses. There are six SDR standards for PVC (SDR 13.5 through SDR 32.5) and many additional, larger diameters (e.g., up to 24 inch diameter) available.

ASTM D1784 - *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds* provides a wealth of information related to PVC grades. However, the chemical resistance specifications in this ASTM exposes PVC to Sulfuric Acid (H_2SO_4) and ASTM Oil No. 3 under short term conditions (e.g., up to 30 days of immersion). This type of exposure data is not relevant to long-term ethanol compatibility.

The preferred method of joining PVC pipe is by solvent cementing. For schedule 80, pipe threads can be used. Flanged joints are always an option, as are bell and ring gasket joints (underground water pipe), grooved-end mechanical joints, and simple compression insert joints.

CPVC - Chlorinated Polyvinyl Chloride

CPVC is made by post-chlorination of PVC to increase the chlorine content to approximately 67% and has very similar properties to PVC but withstands higher temperatures (although at a higher cost than PVC). CPVC has been used for 25 years in the chemical process industry and is widely used for "condensate" return lines to move hot water.

As with PVC, the preferred method of joining CPVC pipe is through solvent cementing. Schedule 80 pipe may be threaded if joints will not exceed 150°F. Flanges can be used as necessary.

PE - Polyethylene

Although PE is not as strong and rigid as PVC, it has excellent flexibility, ductility, and toughness which makes it a very good candidate for buried pipelines and conduit. PE is a partially crystalline material. PE has very good chemical resistance and good cold weather properties. It comes in a variety of densities with pressure applications using medium (Type II) and high (Type III) density PE resins. PE pipe is used in natural gas, mining, industrial, and sewer applications.

Typical high density PE pipe is available in ½ inch to 36 inch diameters. It may be used in pressure applications up to 140°F (180°F in non-pressure applications).
PE pipe is primarily joined by thermal fusion techniques.

Cross-linked PE piping material has higher strength, stiffness, and abrasion/chemical resistance compared to regular PE, especially at higher temperatures (e.g., 200°F). Cross linked PE is usually joined with threads. Because of the restriction of being joined by threads, PEX may not be the best selection for the ethanol gathering application.

PP - Polypropylene

PP is a cost effective material that offers excellent physical, chemical, mechanical, and thermal properties. PP has lower impact strength than PE, but higher working temperatures and tensile strengths. Unmodified PP is the lightest weight plastic pipe and generally has some of the best chemical resistance.

Although excellent in chemical resistance to caustics, solvents, acids, and other organic chemicals, it is not recommended for use with oxidizing-type acids, detergents, low-boiling hydrocarbons, alcohols, and some chlorinated organic materials[4].

Polypropylene is produced in schedule 40 and 80. It is available in standard pressure ratings of 45, 90, and 150 psig. The 150 psig rated pipe is available in ½ inch to 20 inch diameters.

PP can be joined by thermal fusion (preferred method), threading (restricted to schedule 80 pipe), and flanging.

PA - Polyamide[5]

All nylons are polyamides, i.e., polymers that contain an amide group as a recurring part of their chain structure. There are many monomers for nylons which can include linear (aliphatic), side groups, and ring-containing members.

For potential ethanol transport there are two types of polyamide that are produced in pipe form:

- Polyamide 11 (PA11) or Poly[imino(1-oxo-1,11-undecanediyl)] with Castor Oil used as the source monomer, and
- Polyamide 12 (PA12) or Poly[imino(1-oxo-1,12-dodecanediyl)] with Butadiene as its source monomer.

Only PA11 and PA12 are distributed on a large scale as plasticized resins for required flexibility.

PA11 has been used for many years in the extrusion of flexible, steel-reinforced pipe for offshore petroleum production to connect wellheads to platforms, for crude pumping, and oil field fluid transfer. Natural gas distribution networks have been made from un-plasticized PA11 for many years. Regions of Australia use PA11 as the exclusive pipe for natural gas in both small and large diameters. Properties valued are low permeability to methane, high strength, resistance to stress crazing, ease of installation, cold impact strength, and chemical resistance. PA11 has been recently approved by the U.S. DOT/PHMSA (effective 01/23/2009) for natural gas use up to 200 psig with a design factor of 0.40 for pipe up to 4 inches in diameter.

PA12 has been used in the automotive industry for tubing for fuel, air, brake, and other lines. PA12 has been formed into gas pipe and an extensive testing program has been recently completed to support its use up to a proposed 250 psig with a design factor of 0.40 through 6 inches in diameter. Two special permits have been granted to allow "on-system" installation to serve customers.

One important property of nylons is their solvent resistance. This is the result of their high crystallinity and strong inter-chain interactions due to hydrogen bonding. Hydrogen bonds are the strongest secondary bond forces (~33kJ/mole). Amorphous regions are more susceptible to attack by solvents than crystalline regions (which have crystal lattice forces to overcome in addition to hydrogen bond forces). Therefore semi-crystalline nylons like PA11 and PA12 have better solvent resistance than amorphous nylons like PA-6I/6T.

Alcohols and solvents have strong hydrogen bonding capability and therefore attack amorphous regions of nylons. In general, absorption of solvents by nylon diminishes as the hydrogen bonding capability of the solvent decreases. This can be analyzed semi-quantitatively through the use of solubility parameters.

ECTFE - Ethylene Chlorotrifluoroethylene

ECTFE is an alternating copolymer of ethylene and chlorotrifluoroethylene. It provides excellent chemical resistance and has a wide temperature band for use. ECTFE is a tough material with superior impact strength.

ECTFE piping is available in sizes of 1 inch through 3 inches in an SDR pressure rated system of 160 psig at 68°F. It is joined only by the butt fusion method.

Trade Names: Halar (Solvay Solexis).

PVDF - Polyvinylidene fluoride

PVDF is a crystalline, high molecular weight polymer of vinylidene fluoride containing 50% fluorine. It is very similar in structure to PTFE, though not fully fluorinated. It has a high tensile strength and is resistant to gas permeation.

PVDF pipe is available in schedule 40 and 80 and two pressure-rated systems (150 and 230 psig). It can be operated continuously at 280°F. Pipe is available in sizes ½ inch through 6 inches in diameter.

PVDF can be joined by threading (schedule 80), fusion welding (preferred), and flanging.

Trade Names: Kynar (Elf Atochem); Solef (Solvay Solexis); Hylar (Solvay Solexis USA); and Super Pro (Asahi/America).

Polyvinylidene Chloride

Polyvinylidene chloride pipe (Saran) has limited applications due to its relatively low operating pressure which decreases rapidly as temperature increases above ambient. It is used more often as a liner for steel pipe. Pipe is available only in schedule 80 with diameters of ½ inch to 6 inches.
Saran pipe is joined only by threading.

Trade Names: Saran (DOW).

Thermoplastics / Fluoroplastics - Not Suitable for Use as Ethanol Gathering Lines

The following polymers are not considered for ethanol gathering line use since they are not commonly made in pipe form (i.e., only liners or very small tubing) and/or are cost prohibitive

- **PTFE** - Polytetrafluoroethylene, also known under trade names (Teflon, Halon, Fluon, Hostflon, Polyfon, etc.) - limited to liner use.
- **FEP** - Fluorinated Ethylene Propylene - limited to liner use.
- **PFA** - Perflouoralkoxy - 2 inch diameter or smaller tubing.
- **ETFE** - Ethylene Tetrafluoroethylene - primarily a lining for steel.
- **CTFE** - Chlorotrifluoroethylene - only available as a liner.

Environmental Effects of Solvents on Thermoplastics - General Discussion [6]

Chemical/environmental resistance of plastics is inherently more complex than that of metals for the following reasons:

1. No two families of plastics are exactly alike and the families vary greatly in the number and type of chemicals to which they are vulnerable;
2. Plastics interact with chemical environments by a number of different mechanisms such as: chemical reaction, solvation, absorption (sorption), plasticization, and stress-cracking (environmental stress cracking);
3. Much of the chemical resistance test development has been directed toward non-pressurized, short-time tests for screening environments, particularly for environmental stress-crack resistance. Such tests are usually not helpful in part design and rarely so in the prediction of service life[7].

Permeability and Swelling

Unlike most metals, plastics are generally permeable to organic chemicals to varying degrees. Because of this, the presence of environmental liquids in a plastic material can have a profound effect on their mechanical properties. The action of sorption may induce plasticization, swelling dissolution, re-crystallization, and leaching of additives in solids, all of which adversely impact mechanical properties.

After a plastic component is exposed to an organic chemical, aggressive molecules may diffuse into the component, leading to plasticization. Swelling of the material results in high stresses, which can cause crazing or cracking.

Qualitatively, it is convenient to use the Flory-Huggins relationship. The basic idea is that likes dissolve likes. Solubility parameters are often used to determine the degree of solubility of a polymer in a solvent, and the interaction between different materials. A solvent with characteristics similar to that of the plastic may dissolve the plastic[8]. Also, when solvents and polymers have similar polarities, the polymer will dissolve in or be swollen by the solvent. Because longer chains are more entangled, higher molecular weight hinders dissolution. Semi-crystalline polymers are much harder to dissolve than similar amorphous materials. The tightly packed crystalline regions are not easily penetrated because the solvent molecules must overcome the intermolecular attractions. The presence of cross-links prevents dissolution and polymers can only swell in this case.

Crazing and Cracking

As the difference between the solubility parameters approaches 0, the solvent will be the most effective for dissolving the plastic. The solvent uptake by the plastic induces swelling and the swollen material is plasticized. Its mechanical properties are then below those of an un-swollen solid and the elongation value at break increases. The critical strain or stress to obtain crazing (or even cracking) of plastics is observed to also be a function of the difference between the solubility parameters of the plastic and the organic agent[9,10]. In a strong swelling agent the glass transition temperature (Tg) of a plastic is greatly reduced and the fibrils in a craze are highly plasticized and cannot withstand external stresses. Cracks can form rapidly, followed by fracture. In a relatively weak swelling agent, plasticization is limited and there is more crazing vs. cracking.

Superimposed Stress for Structural Components and Environmental Stress Cracking

Structural components (e.g., a pressurized pipe) are subjected to loading during their service. The applied stress may affect the sorption kinetics of the solvent and the equilibrium swelling levels, causing both to increase [11,12,13,14]. As the stress increases, the equilibrium solubility increases which decreases the materials resistance to crazing and cracking. If the material has micro-cracks, the local stress around the cracks increase and lead to increased sorption of the solvent and crazing and cracking. If the agent is a weak solvent for the plastic, the addition of stress imparts strain to the material and allows the solvent to penetrate and weaken the polymer. The stress then causes fracture at these weak areas. This is often termed "environmental stress cracking, ESC (or crazing if not as severe)".

Polyethylene (PE). Because PE is semi-crystalline the environmental degradation from solvents is limited to the amorphous regions. The solubility parameter of PE is 35 $(J/cm^3)^{1/2}$ or 8 $(cal/cm^3)^{1/2}$, and the most widely used ESC agent is nonylphenoxpoly(ethyleneoxy)ethanol (trade name Igepal) which is a surfactant and has a solubility parameter of 40.8 $(J/cm^3)^{1/2}$ or 9.75 $(cal/cm^3)^{1/2}$. Igepal does not swell the PE but under stress it "opens up" enough of the amorphous region to lead to stress-induced plasticization. This same process has been reported in various alcohols[15]. It was also noted that the ESC failure in Igepal, which has a surface tension higher than that of any of the alcohols used in the noted research, occurs as rapidly as that in methyl and ethyl alcohol (ethanol).

The Handbook of PE Pipe[16] details how to consider PE pipe for applications with various chemicals. Preliminary measures of the potential effect of a medium on the properties of PE are by the "soak" or "chemical immersion" test without stressing the material. Strips of PE are soaked for a period of time (usually less than a month) at a specified temperature. After the soaking changes in dimensions, weight, and strength (generally tensile strength and elongation at break) are measured. These types of results [this type of data is summarized and presented in the next section of this report, *Ethanol Chemical Resistance Data*] are useful as a guide for non-pressurized applications (e.g., sewer or drainage pipe) where the pipe has minimal stress imposed on it. These types of tests are not applicable to long-term exposure of PE or other thermoplastics to solvents when they are used in pressurized applications. When this is the case, specialized testing is prudent and the use of de-rating factors is common.

PE Material Optimization against ESC [17,18,19,20,21,22]- As noted earlier, PE materials that contain relatively few tie molecules are more susceptible to ESC. Materials with more tie molecules are more resistant to this type of failure. As molecular weight increases, generally the tie molecule concentration increases. Because melt index is inversely proportional to molecular weight, it is desirable to have a material that has a low melt index. Through the optimal use of co-monomers, the resistance of PE to ESC has improved greatly in recent years. An ASTM standard [ASTM F1248: "Standard Test Method for Determination of Environmental Stress Crack Resistance (ESCR) of Polyethylene Pipe")] was withdrawn in 2007 because the committee determined the slow crack resistant PENT test was sufficient. The Handbook of PE Pipe[23] also notes for surface active agents (e.g., detergents), alcohols, and glycols (including anti-freeze solutions) – **If these agents may be present in the fluid a precautionary measure is to specify PE pipe which is made from a material which exhibits very high resistance to slow crack growth (e.g., materials for which the second number in their standard designation code is either 6 or 7, such as PE2708, PE3608, PE3708, PE3710, PE4608, PE4708 and PE4710). For such materials no de-rating is needed."**

Hydrogen Bond Destruction

Some organic acids can disrupt hydrogen bonding between the large macro-molecular chains in bulk polymers. Solvent molecules can form a new hydrogen bond between the solvent and the polymer molecules. This leads to a dissolution process of the material. Polyamides (nylons) can be included in this class of materials since formic acid or phenols can promote stress cracking[10].

Solvent Leaching of Additives

Additives such as plasticizers, fillers, stabilizers, and colorants are introduced into plastics to improve properties. Leaching of these additives may result in deterioration of properties. The chemical resistance of plasticized plastics to organic liquids is usually less than that of un-plasticized plastics.
Key additives used with thermoplastic pipe resins are noted in Table 8 below.

Table 8. Thermoplastic Pipe Additives

Additives	Purpose
Antioxidants	Prevent/retard reactions with oxygen and peroxides
Colorants	Color material
Coupling Agents	Improve bonding characteristics
Fillers and Extenders	Reduce cost of high priced resins; improve physical and electrical properties
Heat Stabilizers	Prevent damage from heat and light
Preservatives	To prevent degradation from microorganisms
UV Stabilizers	Slow degradations from sunlight

Adding a plasticizer enhances polymer chain mobility and therefore also enhances the diffusion coefficient of liquids. Organic additives can be extracted from plastics by solvents and reduce mechanical strength because of the development of a somewhat porous structure in the solid[24].

Ethanol Chemical Resistance Data

The best measure and assurance of chemical resistance comes from the history of many successful applications. Resistance tables are often adequate, although the effects of concentration, temperature, and time and the data on absorption, dimensional change, and change in mechanical properties are limited. If the material is going to be used under pressurized (stressed) conditions, then the data below may not be fully applicable.

From *PPI TR-19/2007* comes a prudent warning of using chemical compatibility tables without restriction:

> *Chemicals that do not normally affect the properties of an unstressed thermoplastic may cause completely different behavior (such as stress cracking) when under thermal or mechanical stress (such as constant internal pressure or frequent thermal or mechanical stress cycles). Unstressed immersion test chemical resistance information is applicable only when the thermoplastic pipe will not be subject to mechanical or thermal stress that is constant or cycles frequently.*
>
> *When the pipe will be subject to a continuous applied mechanical or thermal stress or to combinations of chemicals, testing that duplicates the expected field conditions as closely as possible should be performed on representative samples of the pipe product to properly evaluate plastic pipe for use in this application.*

The following sections are from published compatibility data tables (references are cited). One will note from the data below, several of the published references conflict in their assessment of the compatibility of one or more of the materials with ethanol. In some cases one reference may even classify a material as incompatible with Ethanol while another reference classifies the same material as compatible. The assigned classification for this initial review is based on all the compatibility data collected to date and is taken as a whole.

Note the following color coding (shading) is used in most tables when appropriate:

Green - Positive (desirable) compatibility
Yellow - Moderate or borderline compatibility
Red - Not compatible

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A. Corrosion Resistance Tables [25]

Table 9. In Pure Ethanol

Material	Temperature Range of Use
PA – Polyamide	Data not available
PE – Polyethylene	60-150F
PP – Polypropylene	60-220F
PVC - Polyvinyl Chloride	60-130F (limited/short term use only)
CPVC - Chlorinated Polyvinyl Chloride	60-200F
ABS - Acrylonitrile-butadiene-styrene	60-130F

Table 10. Chemical Resistance of PA12 at 23°C[26]

Chemical (Concentration %)	Rating
Acetic acid (10)	2
Acetaldehyd (40)	1
Acetone (100)	1
Butanol (100)	1
Carbon Tetrachloride (100)	2
Diesel oil (100)	1
Ethanol (96)	1
Formic Acid (10)	3
Gasoline, unleaded (100)	1
Heptane (100)	1
Hydrogen Peroxide (2)	2
Methylene Chloride (100)	3
Perchloroethylene (100)	2
Phenol (75)	3
Potassium Hydroxide (10)	1
Sulfuric Acid (10)	2
Toluene (100)	1

Ratings:

1. Resistant, little or no absorption
2. Limited resistance, absorption causing dimensional changes and slight reduction in properties
3. Considerable absorption and/or attack, limited product life

Note:

The effect of moisture on nylons must always be taken into consideration. This is also true when nylon is exposed to large quantities of organic solvents or substances that may contain relatively small amounts of water.

B. Compatible Polymers[27]

Suitable materials (thermoplastics) for ethanol service: **Polypropylene (PP)**.
Materials (thermoplastics) to **avoid** for ethanol service: **PVC and Polyamides (PA)**.

C. Effects of E20 on Plastic Automotive Fuel System Components[28]

E20 is 20% ethanol and 80% gasoline. The following are considered suitable materials (qualified for ethanol use) based on acceptance in flex fuel vehicles:

- EVOH - Ethylene vinyl alcohol
- **HDPE - High density polyethylene**
- HTN - Zytel
- LDPE - Low density polyethylene
- **PA12 - Polyamide 12**
- PA46 - Polyamide 46
- POM - Polyoxymethyle
- PP - Polypropylene
- PPA - Polyphtalamide
- PPS - Polyphenylene Sulfide
- PTFE - Polyteraflouroethylene.

The following were tested and considered compatible with Fuel C, E10, and/or E20:

- PA6 - Polyamide 6
- PA66 - Polyamide 66
- PEI - Polyetherimide
- PET - Polyethylene terephthalate.

The following were adversely affected by either: Fuel C, E10, and/or E20:

- PBT - Polybutylene terethalate
- PUR - Polyurethane
- PVC - Polyvinyl chloride (flexible type).

D. Corrosion Resistance Tables[29]

Table 11. In Pure Ethanol

Material	Max Temperature (°F) Range of Use with Ethanol	Min./Max. Temperature(°F) Range of Use Ambient and No Corrodent
PA - Polyamide	250	-60/300
PE - Polyethylene	140	-60/180
PP - Polypropylene	180	32/215
ABS - Acrylonitrile-butadiene-styrene	140	-40/140
PVC - Polyvinyl Chloride	140	0/140
CPVC - Chlorinated Polyvinyl Chloride	210	0/180
PUR - Polyurethane	Not Recommended	NA

E. Chemical Resistance of Thermoplastic Piping Materials (TR-19/2007)[30]

Table 12. Chemical Resistance from TR-19/2007

Material	Compatibility
CPVC - Chlorinated Polyvinyl Chloride	C to 140
PP – Polypropylene	140
PVC - Polyvinyl Chloride	140
PE – Polyethylene	140
PVDF - Polyvinylidene fluoride	R to 122
PEX - Cross-linked PE	R to 140
PA11 – Polyamide	C to 104
ABS - Acrylonitrile-butadiene-styrene	No Data

Resistance Codes

The following code is used in the data table:

Code	Meaning	Typical Result
140	Plastic type is generally resistant to temperature (°F) indicated by code.	Swelling < 3% or weight loss < 0.5% and elongation at break not significantly changed.
R to 73	Plastic type is generally resistant to temperature (°F) indicated by code and may have limited resistance at higher temperatures.	Swelling < 3% or weight loss < 0.5% and elongation at break not significantly changed.
C to 73	Plastic type has limited resistance to temperature (°F) indicated by code and may be suitable for some conditions.	Swelling 3-8% or weight loss 0.5-5% and/or elongation at break decreased by < 50%.
N	Plastic type is not resistant.	Swelling > 8% or weight loss > 5% and/or elongation at break decreased by > 50%.
—	Data not available.	

Summary of Initial Ethanol Compatibility Screening* of Thermoplastic Materials that are Currently Available in Pipe Form

*This is a preliminary list, subject to change as more information is collected. As noted in the previous section, the term "compatible" is based on non-pressurized (i.e., unstressed) short-term (≤ 30day exposure) tests of the resin materials. **Final compatibility selections/predictions must include sufficient long-term, pressurized testing applicable to the desired field application.**

Only resins that are currently listed in the Plastic Pipe Institute (PPI) Technical Report TR-4[31] are presented below. PPI TR-4 provides a listing of Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB) and Minimum Required Strength (MRS) ratings for thermoplastic piping materials or pipe.

The listings in PPI TR-4 have been established in accordance with PPI TR-3[32], "Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB) or Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe".

There may have been additional candidate materials not listed below that are not tabulated in the latest revision of PPI TR-4. Although PEX is listed in the table below as a candidate, the constraint of threaded connections will limit its applicability to many gathering applications.

Table 13. Compatible Thermoplastic Materials Currently Available in Pipe Form

Pipe Material Designation Code	Companies That Produce The Listed Material (Independent Listings Only)	Material Designation
Polyethylene (PE)		
PE 2708	Borealis AB	BorSafe ME3440
PE 2708	Borealis AB	BorSafe ME3441
PE 2708	Borealis AB	BorSafe ME3444
PE 2708	Chevron Phillips Chemical	MARLEX TR-418P8
PE 2708	Chevron Phillips Chemical	MARLEX TR-418P8D
PE 2708	Dow Chemical Company	CONTINUUM DGDA 2420 YL
PE 2708	Dow Chemical Company	DOWLEX 2344
PE 2708	Formosa Plastics Corporation	HP3902/MDYC-303
PE 2708	Formosa Plastics Corporation	HP3902/PO2107
PE 2708	Formosa Plastics Corporation	HP3902/PO2240
PE 2708	INEOS Olefins & Polymers	K38-20-160
PE 2708	INEOS Olefins & Polymers	TUB 172
PE 2708	NOVA Chemicals Ltd	NOVAPOL HD-2100-U YELLOW
PE 2708	Total Petrochemicals USA	HDPE 3802 B
PE 2708	Total Petrochemicals USA	HDPE 3802 BLUE
PE 2708	Total Petrochemicals USA	HDPE 3802 Y-CF

Pipe Material Designation Code	Companies That Produce The Listed Material (Independent Listings Only)	Material Designation
PE 3708	Borealis AB	BorSafe HE3470-LS
PE 3708	Total Petrochemicals USA	HDPE 3344N
PE 3710	Total Petrochemicals USA	HDPE 3344N/SW2139
PE 4708	Chevron Phillips Chemical	MARLEX H525P8L
PE 4710	Borealis AB	BorSafe HE3490-LS
PE 4710	Borealis AB	BorSafe HE3494-LS
PE 4710	Chevron Phillips Chemical	MARLEX H516
PE 4710	Chevron Phillips Chemical	MARLEX H516C
PE 4710	Chevron Phillips Chemical	MARLEX H525P8F
PE 4710	Chevron Phillips Chemical	MARLEX H525P8H
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8I
PE 4710	Chevron Phillips Chemical	MARLEX 934698H
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8F
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8E
PE 4710	Chevron Phillips Chemical	MARLEX 9346P8
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2481 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2490 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2490 NT
PE 4710	Dow Chemical Company	CONTINUUM DGDA 2492 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDB 2490 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDC 2480 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDC 2480 NT
PE 4710	Dow Chemical Company	CONTINUUM DGDC 2482 BK
PE 4710	Dow Chemical Company	CONTINUUM DGDD 2480 BK
PE 4710	Equistar Chemicals, LP	ALATHON L4904 Black
PE 4710	Equistar Chemicals, LP	ALATHON L5008HP Black
PE 4710	INEOS Olefins & Polymers USA	TUB 121
PE 4710	Total Petrochemicals USA	HDPE XS10 B
PE 4710	Total Petrochemicals USA	HDPE XT10 N/BLK
PE 4710	Total Petrochemicals USA	HDPE XT10N (natural)
Crosslinked Polyethylene (PEX)		
PEX 0008	INEOS Olefins & Polymers USA	XF1513
PEX 1008	None Listed	None Listed
Polyvinylidene Fluoride (PVDF)		
PVDF 2020	Arkema	KYNAR 1000
PVDF 2020	Arkema	KYNAR 740
PVDF 2025	Solvay Solexis	SOLEF 1010
Polyamide (PA)		
PA 32312 (PA11)	Arkema	Rilsan 11
PA 42316 (PA12)	Evonik Degussa	VESTAMID PA12
PA 42316 (PA12)	UBE America	UBESTA 3035

Summary of Resin Manufacturer Feedback Related to Thermoplastic Materials for Potential Ethanol Use that are Currently Available in Pipe Form

GTI contacted the following resin manufacturers regarding their thermoplastic material compatibility with ethanol:

- Borealis
- Solvay Solexis
- Arkema
- DOW
- Equistar
- Evonik
- Formosa
- INEOS
- NOVA
- CP Chem
- Total
- UBE

GTI requested any ethanol compatibility information with each manufacturer's specific resin line as noted in Table 13 above.

This data could be shrink-swell compatibility data, long-term hydrostatic test data, or any other type of qualitative or quantitative test data related to ethanol compatibility with the subject resins. Pressurized (in ethanol), long-term pipe testing data was specifically called out in the request since this type of data would be most applicable to the end use of the pipe product. If the manufacturer had no ethanol specific data, then a request for other alcohol compatibility data with the subject resin was made.

A request was made that if the manufacturer was producing any other resins that might be compatible with ethanol, but were not listed in the draft public project reports to date that were provided, to identify these and provide any helpful data/information to GTI.

Finally, it was requested that if the manufacturer did not have any data/information (or could not share it) then a communication to this effect would be appreciated.

A summary of the information shared by the manufacturers is shown in Table 14 below.

Table 14. Summary of Ethanol/Polymer Compatibility Information Available from Manufacturers Upon Request

Resin Manufacturer	Long-term hydrostatic test data	Other alcohol (i.e., not ethanol) compatibility data	Other resins with ethanol compatibility not listed in the draft report	No additional data available
CP Chem	No	No	No	Shared some compatibility data (non-pressurized) that reinforced literature search to date
Solvay Solexis	Yes (burst testing on PVDF)	Yes (Permeation data with methanol)	No	Immersion testing on PVDF, Permeability of PVDF, and Immersion testing of ECTFE.
Equistar	No	No	No	Anecdotal information that HDPE drums have been used for high purity ethanol successfully
DOW	No	No	No	No
Formosa	No	No	No	Expect HP3902 resins to perform similarly to other PE2708 resins
Evonik	No	Yes	No	
Arkema	No	Yes (E85)	No	
UBE	No	No	No	Shared data that reinforced literature search to date

Summary of Submitted Test Data from Thermoplastic Resin Manufactures

Evonik Test Data – PA12

The following summarizes test data for Vestamid L 2124 (PA12) 8x1 mm tubing exposed to ASTM Fuel C and methanol at different ratios (methanol percent tested at 0%, 10%, 15%, 30%, 50%, 85%, and 100%) for 25 days. After exposure standard mechanical and chemical analysis were performed. The tests were performed at shorter intervals to evaluate against time. ASTM fuel C simulates gasoline with 50/50 toluene, isooctane mixture (500ml toluene, 500ml isooctane), these tests were focused on evaluating the plastic's ability to withstand gasoline and ethanol mixtures for vehicle use. The data is located in Appendix A on page 96 and is summarized below.

- Plasticizer Content – All exposures resulted in loss of the plasticizer with some methanol concentrations (15%-85%) resulting in complete loss of plasticizer.
- Fuel Permeability – Fuel permeation occurred at a constant rate over the time scale of the test and peaked at 50% methanol content.
- Axial Change in length – All concentrations initially caused expansion until settling at a steady length change at approximately 4 days. At 100% methanol, the tubing shrunk o.5% axially.
- Diameter Change – The mixtures of the Fuel C and methanol resulted in a varying diameter with exposure time. The diameter changes were limited to within 1.25% of the original diameter.
- Hoop Stress – The hoop stress strength of the material increased over the test period of 25 days with methanol present. The change was not consistent and variety during the test time. There was no significant loss of strength from the initial 23 MPa (3,300 psig).
- The summary table in Appendix A summarizes the changes over the 25 day test period.
  - Permeation rate – the g/m^2*day rate is converted to g/day of a mile long 2" IPS pipe by multiplying by 289. 100% methanol results in 13 kg of loss per mile of 2" pipe. Mixtures near 50% result in greater permeation.

The following summarizes the test data for Vestamid L2121 (PA12) 8x1 mm tubing exposed to ASTM Fuel C and methanol at different ratios the same as in the above tests the only difference is that exposure tests were for an additional 5 days to bring the total time of the test to 30 days. Note this is a different resin material but is still polyamide 12. The data is located in Appendix A on page 100 and is summarized below.

- Plasticizer Content – All exposures resulted in loss of the plasticizer with some methanol concentrations (15%-85%) resulting in complete loss of plasticizer.
- Fuel Permeability – Fuel permeation started at 3 days and was constant over the time scale of the test and peaked at 50% methanol content.
- Axial Change in Length – This data shows all concentrations resulted in an increase of length of the tubing. This data demonstrates a resin difference with the earlier resin that showed a contraction at 100% methanol.

- Diameter Change – All mixtures of the Fuel C and methanol resulted in an increase in diameter. The pure concentrations resulted in little to no change in diameter after 30 days of exposure. This shows a difference from the previously tested resin.
- Hoop Stress – The hoop stress strength of the material decreased over the test period of 30 days with methanol present. The change occurred within 3 days and resulted in a 43% loss of hoop stress strength to approximately 22 MPa (3,190 psig). This places this resin's strength similar to the previously tested resin after methanol exposure.
- The summary table in Appendix A summarizes the changes over the 30 day test period.
    - Permeation rate – the g/m^2*day rate is converted to g/day of a mile long 2" IPS pipe by multiplying by 289. 100% methanol results in 9.2 kg of loss per mile of 2" pipe. Mixtures near 50% result in greater permeation.

This test data demonstrates that on a similar alcohol (methanol) there are minimal physical changes (dimensions and strength) with 100% methanol exposure over 25 and 30 days for both PA12 resins. However, this data does show that different resins of the same material can behave very differently when exposed to the same conditions. This demonstrates the importance of testing a given pipe material against its expected service conditions. Both resins showed there was complete loss of the plasticizers from the polyamide 12 tubing. The acceptable environmental impact from loss of an alcohol through the pipe material needs to be considered. It is important to note that the permeation rate will be affected by the temperature of exposure.

Evonik additionally provided data for multilayered pipe material exposed to E85A for 5,000 hours (208 days). The base tube material is Vestamid (PA12) with different barrier layers and as a monotube. The exposure time was up to 5,000 hours on a 8 x 1 mm tube, with weekly fuel changes, 80°C fuel temperature, 2 bar fuel pressure (29 psig), and 80 L/hr. (21.1 gallons/hour) flow rate. These test conditions represent a worst case scenario for automotive fuel use in vehicles. The following bullet points describe the provided information.

- Description of the different tube configurations with barrier layers. To join some of the barrier layers with PA12, an adhesive/binder layer is necessary.
- Elongation at break – These results showed some or no loss of elongation at break for all the different tubes after 5,000 hours. The PA12 tube performed similarly to the tube with barrier layers.
- Stress at break – All of the pipe materials lost strength with E85 exposure, with the mono tube losing the most at 33%.
- Permeation – The permeability of PA12 with Ethylene Vinyl Alcohol (EVOH) increased with increasing ethanol content and temperature.
- Permeation – The PA12 mono tube had the greatest permeation rate of 200 g/m^2*day at 100% ethanol and 60°C. The barrier layers reduced this permeation rate to sub 10 g/m^2*day.

Arkema Data submitted - PVDF

PVDF and poly(vinylidene fluoride-co-hexafluoropropene) (PVDF-HFP) copolymer resins are used all along the petroleum supply chain from oil & gas exploration, production, refineries, and distribution to automobiles. Some examples of applications are in flexible pipes and umbilicals for offshore exploration, pipe for natural gas distribution, underground pipes for gas stations, and fuel lines in trucks and automobiles.

In addition to improved corrosion resistance over metals in fuel service, PVDF and PVDF/HFP resins have the broadest range of fuel service among commonly used plastics. Many of the new modified fuels cannot be handled using traditional materials. PVDF and PVDF/HFP resins can be used to handle more aggressive blends like gasoline/MTBE blends, gasoline/ethanol blends, and diesel/biodiesel blends. PVDF and PVDF/HFP resins are also good with pure ethanol and the manufacturer rates the homopolymer up to 140 °C. Property changes after six months of exposure in cellulosic ethanol (CE) CE85 and CE50 Ethanol Blends are shown for these resins in Table 15 and Table 16.

Table 15. Exposure Test Results in CE85

6 Month Exposure In CE85 @ 40^0 C				
Material	Tensile Strength % Change	Weight % Change	Length % Change	Permeation ($g/m^2/day$)
Kynar 740	99.39	100.63	101.15	0.94
Kynar 2850	98.58	101.41	101.60	1.30
Kynar 2800	99.21	101.61	102.34	2.25

Table 16. Exposure Test Results in CE50

6 Month Exposure In CE50 @ 40^0 C				
Material	Tensile Strength % Change	Weight % Change	Length % Change	Permeation ($g/m^2/day$)
Kynar 740	96.88	101.25	101.36	1.59
Kynar 2850	94.13	101.67	101.83	2.09
Kynar 2800	98.30	102.53	102.80	3.81

This data shows that PVDF is effective at withstanding a fuel and ethanol mixture. However, as an entire pipeline material PVDF would most likely be too expensive and is more appropriate as a barrier layer if necessary.

Solvay Solexis Data submitted - PVDF and Halar ECTFE

In general, Solef PVDF has good chemical resistance in ethanol as immersion testing shows limited weight gain (< 2 %), even at the boiling point (weight increases are considered negligible below 2%, significant but acceptable for mild applications from 2 to 5%, and unsatisfactory above 5%). Good chemical resistance is confirmed by handbooks, where PVDF is recommended for use in contact with ethanol up to above 100°C.

However, in the presence of mechanical stresses, there is some effect. Bursting tests show that Solef PVDF pipes break at stress values lower than in water. However, the stress at break is still much higher than the 2.2 MPa at 10-25°C and 5 MPa at 38°C for comparison.

Permeability of ethanol in Solef at 10-25°C is very low: at 25°C it is about 0.03 $g \cdot mm/m^2 \cdot day$. Although data was not available at 10°C it has been extrapolated to a value of 0.004 $g \cdot mm/m^2 \cdot day$.

Due to the lack of hydrogen bonds with alcohols, Halar ECTFE is even more resistant than Solef to ethanol and shows very low weight change in immersion testing. At low temperatures, weight increase is close to zero (+0.3% at 50°C) and it is still below 2% at 140°C, the highest tested temperature.

Unfortunately no permeation data is available for Halar in ethanol. However, in methanol at 50°C the permeability coefficient is 6 $g \cdot mm/m^2 \cdot d$, slightly lower than that of Solef (about 7 $g \cdot mm/m^2 \cdot day$). Permeability of ethanol is expected to be lower as the molecule is bigger and less polar than methanol.

The data for PVDF and ECTFE is located in Appendix B on page 108.

Task 2 & 3 Composite Piping - Identify Composite Pipeline Materials and Perform a Materials Compatibility Analysis

In general, the composite piping reviewed included systems comprised of a thermoplastic pipe wrapped with a high strength material. This high strength material, usually fibers, is then shielded by an outside layer of thermoplastic. Composite piping has and continues to be used for flow lines, oil and gas production, water disposal and injection, and subsea applications. Some benefits of composites over steel piping include:

- Chemical and corrosion resistance,
- Can be manufactured and ported in long lengths (requiring fewer connections),
- Lightweight, and
- Does not require cathodic protection.

Product literature on eleven (11) thermoplastic piping products used for rehabilitation or replacement of steel pipelines was reviewed. Each was evaluated for their potential use in ethanol transportation based on application, availability, material, size, and pressure. The intended use for three (3) products was for rehabilitation of steel only and so they were removed from consideration. The eight (8) remaining products have been split into two categories based on likeliness to be compatible with ethanol.

In ranking, preference was given to stainless steel and plastic connectors and PE, PEX, PVDF, and PP liners. Only the materials in direct contact were considered though permeation has the potential to affect the reinforcement layer. All the composite pipes evaluated can be produced and are available for use in the U.S. though no consideration was given for regulatory concerns associated with using these products. The pressure ratings given for the products were not based on ethanol. Therefore, manufacturers should be consulted before using these products beyond their intended use.

Removed from Consideration

The pipe products removed from consideration were IT3 Multiwall, Primus Line, and Tite Liner. IT3 Multiwall rehabilitates steel pipe by inserting a plastic pipe and cementing the annular space. Primus Line is a multilayer liner that requires installation in an existing pipeline. The Tite Liner product reduces the diameter of PE pipe to pull into an existing line. Although the PE can be a standalone pipe, the Tite Liner product is for rehabilitation.

Table 17. Removed from List

Name	Contact Material	Joining	Size	Pressure
IT3 Multiwall	PE, PVC, PB, FRP	Multiple kinds	2"+	4,000 psig
Primus Line	Thermoplastic TPU elastomers	Resin	5.9-19.6"	350 psig
Tite Liner	HDPE, PE100	Lined Fittings	2-12"	5,000 psig

Potentially Compatible Composites

Airborne -Thermoplastic Composite Flowline (TCF)

Airborne's TCF product consists of fiber reinforced thermoplastic tapes melt-fused onto a thermoplastic liner and protected by a thermoplastic compound. The product features an Integrated Permeation Barrier and is currently in use as an alternative to steel flow lines.

According to the company's website, the ID material could be PE, PP, PA, or PVDF. Joining can be accomplished with stainless steel or welded plastic connectors. TCF is available in the U.S. in 3, 4, or 5" ID at 1500 psig or 2, 3, 4, or 5" ID at 2500 psig.

From correspondence with Airborne, the product has not been used with ethanol but PP would be the recommend inner most material.

Flexpipe Systems - Flexpipe

Flexpipe is currently in use in oil and gas gathering, water disposal and injection, and gas transmission lines. The pipe is spoolable to 6,890 ft and is joined with metallic fittings which can be nickel plated or thermoplastically coated. According to the manufacturer, the inner material layer is HDPE but could be substituted upon requalification testing. The manufacturer reports the product is commonly exposed to methanol without issue. The pipe is available in nominal diameters of 2, 3, and 4" at 300, 750, or 1,440 psig.

Wellstream - FlexSteel™

Wellstream's FlexSteel consists of a flexible steel core with an HDPE liner and exterior cover. It is suited to oil and gas gathering, water or fuel transfer lines, and injection lines. The connectors are made from stainless steel and may only have to be installed every 8,858 ft. The FlexSteel product line includes four different pressure limits, 750, 1,000, 1,500, and 2,250 psig. The nominal diameters range from 2-6".

Through correspondence, Wellstream informed GTI that FlexSteel has been investigated for use with ethanol and believe it to be capable though they have not sold it for that purpose. The primary material in contact with the fuel stream would be PE4710/PE100 but Wellstream has experience using PAs, fluoropolymers, PPSs, and TPEs.

Future Pipe Industries – Spoolable Reinforced Composite (SRC)

SRC is manufactured by wrapping either a composite laminate of glass fibers and/or carbon fibers in a cured epoxy over a plastic liner. The pipe is applicable for oil and gas gathering, injection lines, disposal and transmission lines, and saltwater applications. The plastic liner material determines the suitability to a given application. The product names are Cobra (HDPE), Python (PEX), and Boa (PA11). SRC is available in sizes 1-4" and pressures up to 2,250 psig. Joining is accomplished via ANSI B16.5 Lap Joint Flange.

Smart Pipe Company, Inc - Smart Pipe®

Smart Pipe consists of high strength fibers wrapped onto a thermoplastic pipe and protected by a PE sheath. The pipe features a monitoring system and comes in multiple configurations. According to email correspondence, the inner pipe could be constructed from PE100, HDPE, PA11, PA12, Nylon 11, Nylon 12, or DuPont Pipelon 401. The fiber wrap has been constructed with Spectra®, Kevlar®, and E-Glass. Connections can be made with steel or stainless steel connectors though the pipe can be manufactured onsite in lengths up to 50,000 ft. The Smart Pipe product is available in diameters 6-16" at pressures between 125-1,440 psig.

Pipelife - Soluforce®

Soluforce reinforced thermoplastic pipe (RTP) consists of a PE100 inner core reinforced by a fiber or steel tape and coated with PE100. The pipes are delivered on disposable reels in 400m (1,300ft.) lengths. Connections are made by butt fusing the inner layer then electrofusing an inline coupling over the joint. End flanges are made of stainless steel. Soluforce is offered in 4 or 5" ID in three configurations, Light, Classic, and Heavy. The pressure ratings for water in these products range from 522-2200 psi. For hydrocarbons, pressure ratings range from 377-943 psi. In gas applications, the pressure ratings range from 377-2,200 psi.

Table 18. Summary of Best Candidates for Ethanol Transport

Name	Contact Material	Joining	Size	Pressure
Airborne	PE, PP, PA, PVDF	Welded Plastic or stainless steel connectors	2, 3, 4, 5"	1,500-2,500 psig
Flexpipe	HDPE	Fittings can be nickel plated or thermoplastically coated	2, 3, 4"	300, 750, 1,440 psig
FlexSteel™	HDPE, PE100	SS	2-6"	750-2,250 psig
Future Pipe SRC	HDPE, PEX, PA11	ANSI B16.5 Lap Joint Flange	1-4"	2,250 psig
Smart Pipe	HDPE	Steel but segments are continuous to ~9.5mi	6-16"	125-1,440 psig
Soluforce	PE100	Fusion and Coupling / SS end flange	4, 5"	522-2,200 psig*

*Pressure rating is for water applications.

Less Compatible Composites

DeepFlex Inc. - DeepFlex

DeepFlex composites are used for risers and flowlines as well as jumpers and well services. The pipe is constructed from flexible steel and an extruded polymer. Because no information was available to determine the polymer, the DeepFlex product was not included in the above set of candidates. Connections can be made to transition from DeepFlex to ANSI or API. The pipe is available in 2-8" diameters and can sustain pressures up to 10,000 psig.

Fiberspar – Line Pipe

Fiberspar's LinePipe is used in oil and gas production and pumping corrosive fluids. The inside of the pipe is constructed from HDPE or PEX. The pipe is available in nominal diameters between 2 and 6” and pressures of 750, 1,500, and 2,500 psig. The pipe can be installed in continuous lengths of up to 10,000 ft. Joining is achieved by mechanical compression and elastomeric seals. Because the elastomeric material could be one susceptible to degradation from ethanol, LinePipe was not included in the above section.

Table 19. Less Compatible Potential Solutions

Name	Contact Material	Joining	Size	Pressure
DeepFlex	Extruded Polymer	Transition to ANSI or API	2-8"	10,000 psig
LinePipe	HDPE, PEX	Mechanical compression and elastomeric seals	2-6"	750-2500 psig

Table 20. Composite Company Websites

Name	Website
Airborne	http://www.airbornetubulars.com
DeepFlex	http://www.deepflex.com/
Fiberspar LinePipe	http://www.fiberspar.com/
Flexpipe	http://www.flexpipesystems.com/main/home.html
FlexSteel	http://www.wellstream.com/products/onshore/flowlines.php
Future Pipe SRC	http://www.futurepipe.com
IT3 Multiwall	http://www.unisert.com/about.html
Primus Line	http://www.raedlinger.com/Primusline/englisch/index.htm
SET	http://www.enventuregt.com/
Smart Pipe	http://www.smart-pipe.com/
Soluforce	http://www.soluforce.net/
Tite Liner	http://www.unitedpipeline.com/

Fiberglass Piping

Though the list should not be considered all-inclusive, fifteen (15) fiberglass piping products were investigated for use with ethanol. They were rated by likeliness to be compatible with fuel ethanol. The rating system is from 1 - Cannot be used to 4 - Can be used, where a 3 rating is more likely to be compatible with ethanol than a product rated 2.

Three products received ratings of 4 as they are currently used for piping ethanol and are listed by UL 971 "Nonmetallic Underground Piping for Flammable Liquids." UL 971 demands compatibility tests with methanol and ethanol at 100% for a minimum of 270 days with a 50% maximum loss in strength. Additionally, there is a maximum permeation level of 2 g/m^2/day allowed in a 180 day test. Eleven were assigned a rating of 3 because chemical compatibility data for those products specified compatibility with "Ethyl Alcohol" or "E95-100". The remaining product was rated 2 because there was no evidence to support or disprove compatibility with ethanol.

Fiberglass Piping That Can be Used with Ethanol (Rating = 4)

Dualoy 3000/LCX

This product from Ameron is described as a filament-wound fiberglass reinforced epoxy pipe with integral epoxy liner and exterior coating. The pipe is joined by a bell and spigot taper/taper adhesive-bonded joint. It is a double walled pipe currently in use for underground fuel lines, including ethanol. The pressure ratings appear to be limited by fittings but are 250, 150, and 125 psig for 2, 3, and 4" pipes respectively.

Dualoy 3000/MCX

The Dualoy 3000/MCX differs from the LCX because it lacks the exterior coating. All other listed specifications are the same.

Red Thread IIA

Red Thread IIA is filament wound with amine cured epoxy resins and continuous glass filaments with a resin-rich interior surface. It is listed under UL 971 for use with alcohol-gasoline mixtures of either ethanol or methanol up to and including 100%. Joints are T.A.B.™ (Threaded and Bonded) or Bell and Spigot. The primary pipe is rated to 250 psig and comes in 2-4" diameters. Chemical compatibility charts showed a maximum recommended service temperature of 120°F with ethanol at 95-100%.

Fiberglass Piping that is Potentially Compatible with Ethanol (Rating = 3)

Ameron Bondstrand 2000, 4000, and 7000

Bondstrand systems are filament-wound Glassfiber Reinforced Epoxy (GRE) pipes used for general industrial service, including chemical, water, heating, ventilation, and jet fuel. Joining is accomplished via a quick-lock straight taper adhesive joint with integral pipe stop in bell end. All are available in sizes 1-16" and up to 232 psig. The 4000 series has optional internal liners. The

7000 series is configured to have anti-static properties. The reported chemical compatibility of these pipes to ethyl alcohol gives the maximum service temperature of 180°F for the 2000 and 4000 series and 150°F for the 7000 series.

F-Chem (9)(20)

F-Chem is filament wound with epoxy, vinyl ester or polyester resins and fiberglass roving. It is commonly used for water, brine, caustics, petroleum products, acids and other chemical waste streams. Connection types include: bell and spigot, o-ring, flanged, or butt and wrap. It is available in sizes 1-72" and up to 150 psig. Chemical compatibility charts showed a maximum recommended service temperature of 80°F with E95-100.

Fiberstrong RV

Fiberstrong RV consists of a thermosetting vinyl ester resin, continuous and chopped fiberglass reinforcement with a resin-rich reinforced liner. Connections are made via butt-wrap or a double bell coupling with two Reka' saw-toothed gaskets. It can handle pressures up to 250 psig and is available in 16-158" diameters. Chemical compatibility for Fiberstrong is limited to a maximum service temperature of 100.4°F for ethyl alcohol between 95-100% concentrations.

Green Thread

Green Thread is filament wound with amine cured epoxy resins and fiberglass roving. It is commonly used with dilute acids, caustics and hot brine. Bell and spigot style joints are used. It is available in sizes 1-24" and is rated for 225-450 psig. The maximum recommended service temperature is 120°F for 95-100% ethanol.

RB-2530 RB-1520

Centricast RB 2530 and RB 1520 pipe is centrifugally cast with aromatic amine cured epoxy resins and high strength glass fabric. They are employed in chemical process solutions, hot caustics, solvents, acids, salts and corrosive combinations. Connections are made with straight socket or flanged joints. The pipes are available in sizes ½ - 14" and up to 150 psig. The maximum recommended service temperature is 125°F for 95-100% ethanol.

Red Thread II

Red Thread II is a filament wound with amine cured epoxy resins and fiberglass roving used for piping saltwater, CO_2, crude oil, natural gas, light chemical: salts, solvents and pH 2-13 solutions. It can handle pressures up to 450 psig. The pipe is available in 2-24" diameters. The maximum recommended service temperature is 120°F for 95-100% ethanol.

Wavistrong

Wavistrong is produced from glass fibers, impregnated with an aromatic or cyclo-aliphatic amine-cured epoxy resin. It is utilized in refineries, LNG plants, Petrochemical, power plants, oil fields, and offshore platforms. Joining is described as adhesive, rubber seal, flanged, and laminated. Wavistrong is manufactured in 1-48" diameters and is rated to 450 psig. Chemical compatibility charts recommend ethyl alcohol applications to not exceed 140°F.

Z-Core

Z-Core is centrifugally cast from a premium epoxy resin with proprietary curing agents. Joints can be straight socket or flanged. It is commonly employed for applications involving aggressive solvents such as methylene chloride and acetone or corrosives such as 98% sulfuric acid. It is available in 1-8" sizes and up to 150 psig. E95-100 applications should not exceed 175°F.

Conley

Conley produces fiberglass reinforced plastic and glass fiber reinforced plastic pipes for waste water treatment, solvents, petrochemical, chemical processing, fuels and industrial waste. Pipes are available in sizes 1-30" and up to 250 psig. The maximum recommended service temperature is 180°F for 100% ethanol for Conley's epoxy pipe. Conley's vinyl ester and novolac vinyl pipes have a maximum service temperature 80°F for 100% ethanol.

Fiberglass Piping with Unknown Compatibility with Ethanol (Rating = 2)

Star® Line Pipe

Star® Line is an aliphatic amine cured epoxy fiberglass pipe. Its primary use is with highly corrosive fluids in oil recovery activities. Joining relies on a Mechanical O-ring (70 durometer nitrile). It can handle pressures up to 450 psig and is manufactured in sizes 2-24".

Table 21. Summary of Fiberglass Pipes

Name	Rating	Chem. Compat.	Material	Size	Pressure	Joining
Dualoy 3000/LCX	4	Listed UL 971	Filament-wound fiberglass reinforced epoxy pipe with integral epoxy liner and exterior coating	2, 3, 4"	250, 150, 125 (fitting)	Bell and spigot taper/taper adhesive-bonded joint
Dualoy 3000/MCX	4	Listed UL 971	Filament-wound fiberglass reinforced epoxy pipe with integral epoxy liner	2, 3, 4"	250, 150, 125 (fitting)	Bell and spigot taper/taper adhesive-bonded joint
Red Thread IIA	4	Listed UL 971	Filament wound with amine cured epoxy resins and continuous glass filaments with a resin rich interior surface	2 - 4"	250	T.A.B.™ (Threaded and Bonded) or Bell and Spigot
Ameron Bondstrand 2000	3	EA 180°F	Filament-wound Glassfiber Reinforced Epoxy (GRE) pipe	1-16"	232	Quick-Lock straight taper adhesive joint with integral pipe stop in bell end.
Ameron Bondstrand 4000	3	EA 180°F	Filament-wound Glassfiber Reinforced Epoxy (GRE) pipe	1-16"	232	Quick-Lock straight taper adhesive joint with integral pipe stop in bell end.
Ameron Bondstrand 7000	3	EA 150°F	Filament-wound Glassfiber Reinforced Epoxy (GRE) pipe	1-16"	232	Quick-Lock straight taper adhesive joint with integral pipe stop in bell end.
F-Chem (9)(20)	3	E95-100 80(3)°F	Filament wound with epoxy, vinyl ester or polyester resins and fiberglass roving	1-72"	150	Bell and Spigot, O-ring, Flanged or Butt & Wrap
Fiberstrong	3	EA 95-100 100.4°F	thermosetting vinyl ester (Novolac Epoxy resin base) resin	16-158"	250	Butt wrap (lamination) or double bell coupling with two

Name	Rating	Chem. Compat.	Material	Size	Pressure	Joining
			fiberglass reinforcement			Reka' saw-toothed gaskets
Green Thread	3	E95-100 120°F	Filament wound with amine cured epoxy resins and fiberglass roving	1-24"	225-450	Bell and Spigot
RB-2530 RB-1520	3	E95-100 125°F	Centrifugally cast with aromatic amine cured epoxy resins and high strength glass fabric	1/2-14"	150	Straight Socket or Flanged
Red Thread II	3	E95-100 120°F	Filament wound with amine cured epoxy resins and fiberglass roving	2 - 24"	450	
Wavistrong	3	EA 140°F	glass fibers, impregnated with an aromatic or cyclo-aliphatic amine-cured epoxy resin	1-48"	450	Adhesive, rubber seal, flanged, laminated
Z-Core	3	E95-100 175°F	Centrifugally cast from a premium epoxy resin with proprietary curing agents	1-8"	150	Straight Socket or Flanged
Conley	3	EA 180°F	FRP	1-30"	250	
Star®Line Pipe	2		Aliphatic Amine Cured Epoxy	2-24"	450	Mechanical O-ring (70 durometer nitrile)

Table 22. Fiberglass Company Websites

Name	Website
Ameron Bondstrand 2000	http://www.ameronfpd.com/product.html http://www.ameron-fpg.com/?t=industry&i=140
Ameron Bondstrand 4000	
Ameron Bondstrand 7000	
Conley	http://www.conleyfrp.com/
Dualoy 3000/LCX	http://www.ameron-fpg.com/files/pdf/FP737F.pdf
Dualoy 3000/MCX	http://www.ameron-fpg.com/files/pdf/FP915B.pdf
F-Chem (9)(20)	http://www.smithfiberglass.com/F-chem.htm
Fiberstrong	http://www.futurepipe.com/usa/inner.asp?P_SectionID=28&P_CategoryID=100
Green Thread	http://www.smithfiberglass.com/greenthread.htm
RB-2530 RB-1520	http://www.smithfiberglass.com/centricastrb.htm
Red Thread II	http://www.smithfiberglass.com/Predthread.htm
Red Thread IIA	http://www.smithfiberglass.com/pdf/B2101.pdf http://www.smithfibercast.com/Predthreadf.htm
Star ® Line Pipe	http://www.fiberglasssystems.com/linepipe.html
Wavistrong	http://www.futurepipe.com/usa/inner.asp?txt=small&P_SectionID=28&P_CategoryID=104
Z-Core	http://www.smithfiberglass.com/Z-core.htm

Summary of Submitted Test Data from Fiberglass Pipe Manufactures

NOV Fiber Glass Systems – Red Thread II/IIA

Abundant pipe system design, engineering data, and case histories were submitted to GTI. Extensive information on the general mechanical properties and system design were provided. NOV fiber Glass Systems shared test data utilized to determine the HDB of the pipe materials is located in Appendix C.

This data could serve as a baseline for any future ethanol testing. No data directly investigating ethanol exposure was available. The epoxy resin utilized in this Red Thread is chemical resistant and has been used extensively in various chemical industries. This has exposed the pipe material to various harsh operating conditions successfully.

The closest ethanol related service life case history is its extensive use in the transportation of gasoline and gasoline test fuels blends at service stations for over 30 years, a specific test case is described in Appendix C.

Ethanol Compatibility Data Gaps

As discussed in the general section on ethanol compatibility with different pipe materials there is often no direct testing evidence that mimics the service life of an ethanol pipeline. The following three areas are where very limited to no direct data could be found.

Long Term Strength Testing With Ethanol

The long term strength of a pipe material is usually calculated by performing sustained pressure tests with air or water at an elevated temperature, such as with ASTM D 2837. However, the introduction of a chemical other than air or water can alter the anticipated long term strength of the pipe. Sound engineering judgment is necessary to determine whether it is appropriate to use the long term strength data from these tests with different chemicals. This determination can be initially based on the chemical compatibility tests discussed in this report. However, these tests are often performed on unstressed resin materials and for a "short" time frame. A negative result in compatibility testing gives a strong indication that a certain constituent will adversely affect a resin. However, absence of negative effects does not indicate with certainty that no strength degradation will occur with long term stressed exposure to a particular chemical.

To better anticipate any strength loss with ethanol exposure, tests that expose a pipe to pressurized ethanol would be appropriate. Tests that determine an "ethanol long term strength" by utilizing ethanol as the test medium in determining the long term strength would be the most appropriate but may not be practical. Physical testing (after ethanol exposure while under stress) would provide superior information for engineering decision making.

Permeability Testing at Operating Pressures

Polymer materials in direct contact with ethanol can be susceptible to permeation. The exact rate of ethanol permeation, if any, is important to determine the environmental and cost acceptability of ethanol losses. Tests should be performed on all the pipeline components (fittings, joint, transitions, and the pipe itself) at the anticipated service temperature and pressure.

Erosion Resistance with Ethanol Flow

An ethanol pipeline will operate for an extended period of time with constant flow. This has the potential to slowly erode the inner surface of pipes and fittings. Depending on the rate of erosion, this could lead to increased permeation or premature mechanical failure. The erosion risk is greatest at sharp turns of the pipe line, such as a 90 degree bend. The resistance of a material to this erosion will depend both on its hardness and chemical compatibility with ethanol. To determine any possible effects, a test loop could be created and monitored to evaluate if any erosion occurs and at what rate.

Task 4 –Evaluate Pipe System Materials/Products for Gathering Applications

System Criteria

To better determine the necessary pipe requirements (sizing, hoop stress, joining, fittings, etc.), a base line system was established. This system will meet requirements as discussed with Mr. Chuck Corr from ADM (project steering committee member). In this discussion the following criteria were determined:

- **Plant Locations**
  - Great plains states – the Corn Belt
  - Little elevation change expected (for corn based ethanol)
- **Capacity:**
  - Average – 50 million gallons per year
  - Current max per plant: 110 million gallons per year
- **Pipeline Configuration:**
  - Tie 4-5 plants to a final plant/distribution point at a Class 1 railroad
  - Direct feed (1-2) plants 40-50 miles away
  - Indirect feed (2-3) plants to a main pipeline that will then carry the ethanol 70 miles
    - The feeder plants could be up to 10 miles away from a main line
  - A pipeline of this length will need to cross railroads and roads – these crossings will need to be addressed
  - Possibility of adding plants to the feeder line at a future date – consider a design to allow for increased capacity at a future date (i.e., do not maximize the system for current requirements)
- **Stable flow from plant with minor fluctuations – pipeline will operate 24 hours 7 days a week**
- **Ethanol make up**
  - Currently transported ethanol contains 2-5% denaturant (gasoline like hydrocarbons)
  - Could (if system is closed) pump "pure crude ethanol" – no denaturant added
  - Make note if this is of considerable importance
- **Final Pressure**
  - 0 psig to fill tank and boost on the spot is acceptable
  - 10-15 psig would allow for filling of tanks without boosting

These requirements will influence a final selection of materials to allow for both the desired capacity and length. These realistic conditions will determine what pressure any pipeline will need to be operated at to allow for the transportation of the desired amount of ethanol.

System Design for Pipeline Comparison

An ethanol pipeline system was designed around a flat theoretical corn producing region. This pipeline was designed to transport ethanol from several production plants to a class 1 railroad. Taking this into consideration, along with comments from the steering committee, the rough theoretical system was designed as shown in Figure 1.

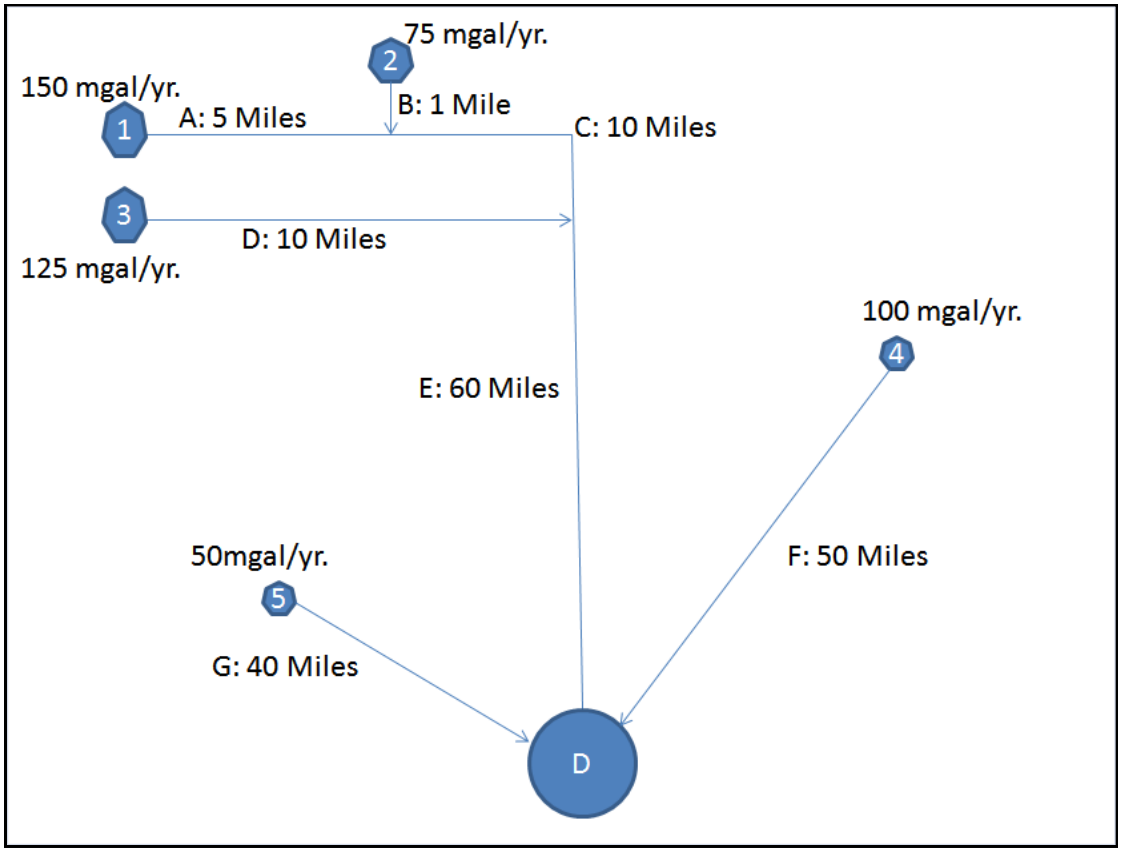


Figure 1: Theoretical piping system used for cost comparisons.

The theoretical ethanol piping system has five (5) ethanol producing plants of various capacities. Two of the plants, numbers 4 and 5, deliver directly to the final destination D. Three other plants feed to a central line which then feeds to the distribution point D. The capacity of each segment of pipe (labeled A through G) is controlled by the facilities that are feeding the line and their production capacity. The different pipe products were considered for the piping system by using the pipes' specification to determine size, flow rates, and other factors. The requirements for each pipeline section are contained in Table 23. The different capacities and lengths of the sections will allow for comparison of the different needs of an ethanol piping system.

Table 23. Section Lengths and Required Capacity

Section	Pipe Length (miles)	Capacity (million gallon/year)
A	5	150
B	1	75
C	13	225
D	10	125
E	60	350
F	50	100
G	40	50

Flow and Pressure Calculations

The calculations to design the pipeline system were based on the *U.S. Army Corps of Engineers – Liquid Process Piping, Engineer Manual* and data supplied by the pipe manufactures. To perform the calculations to determine the pressure drop across the pipe system and the flow capacity of the pipe these assumptions were made:

- No elevation changes: The calculations do not consider any increase in pressure required to flow a liquid up in elevation, nor does it consider the reduced pumping needs if flowing down in elevation. This is a reasonable assumption for the area of the United States that would be utilized for ethanol production.
- Turbulent flow: Initial calculations show that expected flow is turbulent and is not near the transition region to laminar flow.
- Pipe joints do not cause a pressure drop: Pipe joints are necessary to create a pipeline of sufficient length. These joints will vary depending on pipe material. It is assumed that these joints do not contribute any additional resistance to the ethanol flow. This is often assumed to be the case in butt fusions joints for thermoplastic water systems.
- A minimum pressure of 20 psig was maintained on the system: To account for minor fluctuations and possible needs at a final destination or pumping stations the minimum pressure the system was designed at 20 psig. This number could be adjusted as needed.
- No water hammer affects were considered: The sudden change in pressure in a liquid system, such as a complete shut off or pressure variance from pumping stations, will cause a pressure wave to propagate through the liquid. The pressure wave temporarily increases the local pressure and depending on the frequency of events, will cause cyclic loading. These issues are minimal for thermoplastic systems as they tolerate the effect well but could affect the composite pipes. Additionally, a piping system can be designed to minimize the causes of the water hammer effect.
- Crossings have negligible effect: The calculations do account for the same number of crossings for each system by adding a length of pipe equivalent to the expected pressure drop at the crossing to the overall system. However, at a lower number of crossings, these accounts for less than 1% of the total system length. Thus for this comparison, crossings were neglected, and further investigations into pressure losses due to crossings were not warranted.

- Valves were not considered: In any pipeline of this size there would be valves and flow control systems necessary to maintain proper flow and allow for maintenance. These were not considered during this evaluation as they would have had a limited effect on the system and would not affect the choice of which pipe material to use.
- Pumping stations: Pumping stations required to maintain adequate pressure were considered based on the pressure drop calculated from piping losses, and the lower required pressure. The variation of pumping stations accounted for in this study was determined by analyzing the added pressure drop per foot of piping related to each material.

The calculations took into account the properties of ethanol, shown in Table 24. These properties combined with the properties of the pipe material were utilized in determining the flow rates and pressure drops for a given section of pipe in the above benchmark system.

Table 24. Ethanol Properties Used in Calculations

Property	Value	Units
Density	49.3	Pound mass per cubic feet
Viscosity	0.0000736	Pound mass per foot*second
Kinematic Viscosity	0.00001636	Feet squared per second
Specific Gravity	0.789	NA
Bulk Modulus	130824	psi

The flow calculation uses the volume flow through the section along with the pipe diameter to determine the fluid flow rate. As a rule of thumb, this flow rate is recommended to not exceed 13 feet per second. The flow rate, pipe size, and ethanol properties were then used to calculate the Reynolds, Re, number. The friction factor for the pipe is then calculated using these values and the assumed pipe constants in an iterative fashion after using an initial estimate. The friction factor in conjunction with the flow rate, pipe size, and Re number can be used then to calculate the pressure loss for a given length of pipe. This value is then used to determine the total pressure loss over an entire pipe section. Full details of the methodology of these calculations are contained in the *U.S. Army Corps of Engineers – Liquid Process Piping, Engineer Manual.*

The total pressure loss over a pipe section is the minimum pressure required to pump the specified amount of ethanol over the distance of the section, with the specified end pressure. In some cases this pressure can be immense and unrealistic for non-metallic pipes to maintain integrity at those pressures. This can be designed around by introducing larger pipe diameters, which would increase the fluid flow area, and thus reduce the pressure loss over a section of pipe. If the pipe section cannot withstand the pressure required to transport the ethanol, pumping stations are necessary to boost pressures back to design pressure. Essentially this allows the pipeline to be operated at lower pressures by boosting the pressure often before it falls below design pressure.

Materials Chosen to Evaluate

This base system was then designed for use with the previously identified non-metallic piping systems. This allowed for the evaluation of the feasibility of utilizing the pipe materials for ethanol transport. The design of this example piping system assumes the pipe will maintain its current pressure rating (HDB) and not fail prematurely due to the presence of ethanol. This assumption was made for this analysis and would need further testing to verify.

The materials chosen for this evaluation were:

1. High density polyethylene: HDPE 100 materials were considered for this effort. This is a common piping material and has wide acceptance in the natural gas industry. HDPE will act as a baseline for considering a non-metallic piping system.
2. Polyamide: PA materials are coming into wider use in the delivery of natural gas and have higher pressure carrying capacity than PE materials of the same SDR.
3. Epoxy Resin pipe (Red Thread II): These materials have been used extensively in gasoline stations, gathering systems, and other chemical environments. The epoxy pipe has a higher pressure rating than that of thermoplastics.
4. Composite pipe: Composite pipe is becoming more utilized and considered for different applications as it can maintain high strength along with the chemical resistance of lower strength polymers. The composite pipes have the highest pressure rating of the pipe materials considered.

These materials have been used in construction of pipelines and the tools and experience exist to install these materials. There also exists a full complement of fittings and transitions for these pipeline products. This would allow for junctions with other pipeline assets and also for connections to flow control equipment.

Pipeline Feasibility

General trends

The high flow requirements for section E of the pipeline led to the use of larger diameter pipes. Larger pipe diameters have larger cross sectional areas for fluid flow and therefore can maintain high flow volumes without increasing the pressure requirements over desired values. Additionally, in the pipe feasibility investigation focus was given to minimizing the required number of pumping stations, due to the expected cost of these stations. The goal was to have little to no pumping stations for the majority of the length of the pipeline. The roughness factor of the pipe material used was supplied by the manufacturers, but an actual experiment would be the most reliable method for determining the pressure loss over a given section of pipe. However, this may not prove that critical as the overall pressure loss of the pipeline was not significantly affected by changes in the roughness factor of the pipe. An increase by two orders of magnitude of the roughness factor lead to an increase of only 5 psig. This can be accounted for by the turbulent flow of the ethanol within the larger pipe diameters resulting in less contact between the ethanol and pipe wall than in smaller diameter pipes. This noted, the manufacture supplied roughness was found to be sufficient for this feasibility study.

High Density Polyethylene

HDPE has the lowest pressure capacity of all the pipe materials considered but has been used extensively in both natural gas and water applications. Due to the extensive use of this material, there are many fittings available for joining. PE pipe is available in a variety of OD sizes from ½ inch to greater than 12 inches. The pipe sizes and additional information of the HDPE pipes considered is located in Table 25. For diameters 6 inches and below, PE is available in coil form. Using pipe in coil for could prove helpful, as it would drastically reduce the number of joining procedures necessary. The HDPE pipe material was considered to have a maximum pressure capacity of 125 psig for all pipe sizes since each pipe size has the same dimensional ratio of diameter to wall thickness. Table 26 contains the results from the pipeline analysis when using HDPE as the pipe material.

Table 25. HDPE Pipe Sizes, Length, and Pressure

Nominal Pipe size (in.)	Inner Diameter (in.)	Segment length (ft)	Pressure Capacity (psig)
2	1.917	1500	125
4	4.091	1500	125
6	6.023	500	125
8	7.841	50	125
12	11.591	50	125

Table 26. HDPE Example Pipeline Results

Section	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psig)	Number of Compressors
A	6	3.21	500	53	67	0
B	4	3.48	1500	4	25	0
C	8	2.84	50	1373	102	0
D	6	2.68	500	106	96	0
E	12	2.02	50	6336	159	1
F	8	1.26	50	5280	91	0
G	6	1.07	500	423	75	0
TOTAL				**13575**		**1**

Polyamide

Polyamide (PA) pipe materials are becoming more common in the natural gas industry and have been used extensively in gasoline pumping stations. Due to the extensive use of these materials, fittings and transitions are available in a wide variety of sizes. PA pipe is available in the same sizes and configuration as PE as shown in Table 27. The PA pipe material is considered to have a maximum pressure capacity of 250 psig. Table 28 contains the results from the pipeline analysis when using PA as the pipe material.

Table 27. PA Pipe Sizes, Length, and Pressure

Nominal Pipe size (in.)	Inner Diameter (in.)	Segment length (ft)	Pressure Capacity (psig)
2	1.917	1500	250
4	4.091	1500	250
6	6.023	500	250
8	7.841	50	250
12	11.591	50	250

Table 28. PA Example Pipeline Results

Section	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psig)	Number of Compressors
A	6	3.21	500	53	67	0
B	4	3.48	1500	4	25	0
C	8	2.84	50	1373	102	0
D	6	2.68	500	106	97	0
E	12	2.02	50	6336	161	0
F	8	1.26	50	5280	92	0
G	6	1.07	500	423	76	0
TOTAL				**13575**		**0**

Epoxy Resin

The epoxy resin pipe considered in this study is Red Thread II. It has been utilized in gasoline pumping stations and in various harsh chemical gathering installations. The system relies on different joining techniques than that of the thermoplastic pipe materials but has a robust compliment of fittings and joints. The pipe is available in a wide variety of sizes but the OD's considered here range from 2 inches to 12 inches. This pipe is available in stick form only and the pressure carrying capacity changes depending on the sizing of the pipe as shown in Table 29. Table 30 contains the results from the pipeline analysis when using Red Thread II as the pipe material.

Table 29. Red Thread II Pipe Sizes, Length, and Pressure

Red Thread Pipe Sizes (in.)	Inner Diameter (in.)	Segment Length (ft.)	Pressure Capacity (psig)
2	2.238	30	450
3	3.363	30	450
4	4.364	30	450
6	6.408	30	450
8	8.356	40	225
10	10.357	40	225
12	12.278	40	225

Table 30. Red Thread II Example Pipeline Results

Section	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psig)	Number of Compressors
A	4	6.12	30	880	318	0
B	3	5.15	30	176	64	0
C	6	4.26	30	2288	271	0
D	6	2.37	30	1760	72	0
E	12	1.80	40	7920	123	0
F	6	1.89	30	8800	243	0
G	4	2.04	30	7040	354	0
TOTAL				**28864**		**0**

Composite Pipe

The composite pipe considered here is Flexpipe in two different pressure carrying capacities. This material was chosen for its proven use in oil gathering systems, and has been used with ethanol on a small scale in the past. The composite pipe has a high pressure carrying capacity up to 1,500 psig. The currently available sizes are 2, 3, and 4 inches OD pipes. They are all able to be spooled up to a maximum length, as shown in Table 31. Table 32 contains the results from the pipeline analysis when using Flexpipe as the pipe material. Section E with its high required volumetric flow rate, led to a system pressure that is too high for the small diameter Flexpipe to accommodate. To reduce this pressure multiple pumping stations would be necessary to allow for a lower operating pressure. However, depending on the economical analysis, it could be more prudent to add a second pipe for that section. If this was done, the fluid flow per pipe would be halved and the number of necessary compressor stations would be reduced to 5 for each pipe.

Table 31. Flexpipe Sizes, Length, and Pressure Table

Product	Nominal Pipe Size (in.)	Inner Diameter (in.)	Segment Length (ft.)	Pressure Capacity (psig)
FP601	2	2.12	3281	1500
FP601	3	3.02	2297	1500
FP601	4	3.90	1968	1500
FP301	2	2.12	6562	750
FP301	3	3.02	4921	750
FP301	4	3.90	2491	750

Table 32. Flexpipe Example Pipeline Results

Section	Pipe Product	Pipe Size (Inch)	Flow Rate (ft/sec)	Pipe Section length (ft)	Number of Joints	Pressure Drop (psig)	Number of Compressors
A	FP301	4	7.67	2491	11	538	0
B	FP301	3	6.39	4921	2	106	0
C	FP601	4	11.50	1968	35	2915	1
D	FP601	4	6.39	1968	27	776	0
E	FP601	4	17.89	1968	161	30038	20
F	FP601	4	5.11	1968	135	2595	1
G	FP301	4	2.56	2491	85	601	0
TOTAL					**456**		**22**

Long Term Performance Considerations

Thermoplastic Pipe (HDPE and PA)

The thermoplastic piping systems descried here have been used in piping systems for extended periods of time. At the operating temperature and pressures expected for this type of pipeline there is not a concern for premature failure. Thermoplastic pipes have a shorter life expectancy when exposed to higher field temperatures and pressures. However, this is taken into consideration with the design factor and HDB calculations that assume an operating temperature of 73 °F. Other factors, such as installation procedures, can reduce the life expectancy of a pipeline. There are standards and accepted procedures that, if followed, significantly reduce the risks from other mitigating factors such as a poorly installed joint or rocky back fill.

The expectant long term strength and lifetime of the thermoplastic pipe could be affected by the presence of ethanol and its constituents. There was little to no data demonstrating the effects that ethanol had on these materials in a stressed and flowing state. Further studies would be necessary to verify the long term performance of these materials when transporting ethanol.

Epoxy Resin Pipe

The Red Thread II pipe considered here has an extensive case history of use in different gathering environments. Proper installation and joining procedures is important to maintaining the life expectancy of a piping system. The expectant long term strength and lifetime of the epoxy resin pipe could be affected by the presence of ethanol and its constituents, though looking at the case history of the product and similar products ethanol does not appear to have an adverse effect on the pipe material. This cannot be confirmed, as there was no direct testing performed with ethanol as the test fluid to determine any negative effects. Further study and standardized ethanol testing would be advisable to verify the long term performance of these materials.

Composite Pipe

Flexpipe, the composite pipe considered in this case study can have different thermoplastic materials as the inner layer of the pipe as the barrier layer. The remaining composite layers provide the pressure carrying capacity. These systems have been used in gathering systems and within a plant to transport methanol and ethanol. Proper installation and joining procedures are important to maintaining the life expectancy of a piping system. In the case of composite pipe, extra care to prevent cyclic loading from pumping stations is necessary. This can be achieved by utilizing centrifugal pumping stations and/or reducing the pressure rating of the pipe if a consistent pressure cannot be maintained. However, there was no direct testing performed with ethanol as the test fluid to determine negative effects. Further study and standardized ethanol testing would be necessary to verify the long term performance of these pipe materials.

Test Case Summary

Additional material testing is recommended to demonstrate little to no negative effects from ethanol on these pipe materials. If these materials do not have degradation from the pressurized ethanol, then each of these pipe materials could transport ethanol effectively. All of the pipe systems discussed here have a variety of fittings and transitions to make connections as necessary. Each system would need further engineering considerations for crossings, pumping stations, and the most appropriate installation method.

Task 5 - Economic Analysis

Introduction

The pipe system economic evaluation is based on a value engineering methodology, or maximum performance level at minimum cost, which incorporates and considers several components. These include:

- Material compatibility and performance,
- Pipe (resin and extruding costs if appropriate),fitting, and other appropriate material costs,
- Installed costs under a specific set of parameters, and
- Maintenance costs over the life of the installations when available.

The previously completed task work of this project focused on the material compatibility and performance in gathering and transporting ethanol and ethanol blends (Task 3). Several materials were identified as potential candidates and those were further evaluated for operational effectiveness in Task 4. A theoretical ethanol gathering pipeline scenario (Figure 1) was developed to facilitate the benchmarking of pipe system operational performance and included parameters such as flow rate, pipe size, pipe performance characteristics, and ethanol properties to calculate flow regimes for each potential pipeline material candidate.

Pipeline material candidates selected for operational evaluation were:

- High Density Polyethylene (HDPE)
- Polyamides (PA12)
- Epoxy Resin Pipe (Red Thread II)
- Composite Pipe (Flexpipe)

These systems are further explored for economic viability within this section. This presents a difficult task, as raw material costs, such as resins and steel, are constantly changing over time and can have significant variability. This variability makes it impractical to perform a long term evaluation of pipeline system costs and subsequently, any monetary calculations within this analysis should be considered a "snap-shot in time" and periodically updated. To account for this variability in material pricing, a dynamic economical model was developed to provide the base requirements with price as the only variable input. The economic model is based on the theoretical ethanol gathering pipeline system referenced earlier in this report, with Carbon Steel providing the benchmark for comparative analysis. This is described in more detail below.

While the installed cost of the pipe systems is critical to the decision of which material to use, it also depends on many factors. These include:

- Geographic location of the installation (soil type/conditions),
- Paved or non-paved locations,
- Length of the pipeline,
- Diameter of the pipe,
- Form of installation (coiled PE or sticks)
- Number of valves and fittings to be installed,
- Joining methods, and

- Special requirements such as: pipe supports, coatings, or insulation requirements.

Particularly on newer material (Flexpipe) and specifically larger diameter systems, this information can be difficult to attain given that current applications are generally outside ethanol pipeline transportation and have had limited or no installations on this scale.

Maintenance costs must also be considered. Carbon steel pipe will be used as a comparative baseline for the analysis, and may vary significantly from thermoplastic materials with the requirement of long term cathodic protection (buried pipe).

Economic Analysis

As referenced in the introduction, a theoretical ethanol gathering system was developed to both identify operating parameters and performance as well as provide a foundation for economic analysis of the selected piping systems. The structure of the model is designed to allow the user to create multiple operating scenarios for each piping system with the goal of developing the most economical solution, minimizing cost through effective selection of pipe diameter (material cost) and required pipeline pumping stations. Operational parameters of the theoretical system are described in the detail for calculation of pressure differentials for the selected material across the system. General variables in the pricing component of the system include:

- Pipe material
- Pipe diameter
- Pipe length
- Cost per Foot
- Install cost per foot
- Cost per joint fitting
- Cost of pumping

Though a simple model, it provides a basis for system economic comparisons relative to each other as well as general pricing for individual systems. The model does not take into consideration installation situations created by geographical or environmental challenges such as railroad and river crossings, permitting expenses, etc. It is assumed these expenses will be similar regardless of pipe material.

Material and installation costs were challenging to acquire as all non-metallic materials with the exception of HDPE have relatively minimal field installations as a foundation for establishing price. Please note that information on these selected materials are still being acquired, and several materials and pipe sizes have no relevant or confirmed data available to GTI for reporting at this time. This is the case for Flexpipe. Specific pricing for all relevant diameters of HDPE, PA12, RED THREAD II, and Carbon Steel have been acquired and are utilized in the full test case economic scenario detailed in the next section.

Test Case Economic Scenarios

Segment B Scenario

To ensure a relative economic comparison and minimize operational related cost variability, a basic set of parameters was used to perform a simple test case cost scenario. To this purpose, a single gathering line (Terminal 2, Segment B from Figure 1) was selected. Given the amount of cost information available for selected materials, the test case scenario will include Carbon Steel, HDPE, and PA12 in 4"diameter pipe. The segment and operating parameters are defined in Table 33. In a field installed scenario, 4" pipe diameter may not necessarily be the optimal selection given the operational parameters, however it does simplify the test case scenario by eliminating the need for pumping as well as being able to utilize the cost information available for inclusion of PA12. A full economic comparative evaluation of HDPE, PA12, RED THREAD II, and Carbon Steel based on the theoretical model is included in the second test case scenario.

Table 33. Baseline Operating Parameters – Segment B

Pipe Diameter	Flow Requirement	Operating Pressure	Pipeline Length
4"	75 mGal/yr	Minimum 20 psig	~ 1 mile (~5,300 linear ft)

Pipe designation, specifications, material costs, installed costs, and potential maintenance costs are summarized in Table 34 for those materials with verified relevant information available to GTI. Systems included for theoretical gathering system modeling are listed first, with subsequent materials identified as compatible with ethanol and with cost information available also included.

Table 34. Material Cost Summary

Material	Material	Material Cost ($/ft)	Installed Cost/ft	Maintenance Cost
Carbon Steel	API5L-X42 STD Wall, DRL, ERW, FBE Coated, Domestic	Direct Quote (9/2009) - $6.95 Direct Quote (4/27/2010) - $10.80 6 month Range: $6.95 - $10.86(1)(5)	$16 - $32(1) $18 - $59(2)	$3,500 - $4000/mile install costs (3) $300 - $455/mile/year maintenance costs (average)(2)
HDPE	4710 and 3708	Direct Quote (9/2009) - $1.85 Direct Quote (4/29/2010) - $2.05 6 month Range: $1.85 - $3.70(4)	$8 - $16(1)	N/A
Polyamide	Nylon, PA11	Estimated Range at $12 - $15(4)	$8 - $16(1)(5)	N/A
Polyamide	Nylon, PA12	Direct Estimate (4/2010) $23(4)	$8 - $16(1)(5)	N/A
Epoxy Resin	Red Thread II	Direct Quote (4/2010) - $5.39	$20 - $22	N/A
Composite	Flexpipe FP301	Not Available	Not Available	N/A
PVDF	2020, 2025	Estimated Range $18 - $24(4)	Not Available	N/A
PA12 w/PVDF Layer	Nylon, PA12 2020, 2025 PVDF	Estimated Range at $11 - $14(4)	Not Available	N/A
PEX	Cross-linked PE 008, 1008	Estimated Range at $4 - $6(4) Price Quote of 1" PEX - $2.35	Not Available	N/A

(1) Tubbs, 43rd Annual Pipe Report – "Gas Demand, Maintenance Projected to Drive Distribution Spending", Pipeline Gas Journal, December 2008.

(2) Atofina Chemicals, Inc, “Evaluation of Market Potential for PA11, An Executive Summary”, May 2002.
(3) Cynergy Corp, Gas Engineering Department, “Evaluation of 12” Polyethylene Pipe for Cynergy Gas Distribution”. March 2004.
(4) Based on information and discussions with multiple sources including Arkema, Evonik Degussa, Performance Pipe Institute, UBE America, Energy West Inc., Nicor Gas Inc., Groebner & Associates and Resource Center for Energy Economics and Regulation.
(5) For the purpose of this example scenario, it is assumed installation costs for PA11 and PA12 will be similar to that of HDPE for 4” pipe. This is based on each material being available in coils and butt fusion utilized for joining segments of pipe.

Given the operating parameters outlined for the test case scenario, flow calculations were applied and the economic results were calculated for the three materials identified that also had installation costs available. These results are summarized Table 35 and Table 36.

Table 35. Test Case Scenario (Segment B) Operating Parameters

Pipe Product	Segment	Flow (gal/min)	Min. Recommended Pipe Size	Pipe Size (Inch)	Flow Rate (ft/sec)	Total Length(miles)	PipeSection length (ft)	Number of Joints	Equivalent Length (feet)	Pressure Drop (psi)	Min Pressure (psi)	Max Pipe Pressure	Number of Pumping Stations
PA12	B	143	2.71	4	3.48	1	1500	4	5336	25	20	250	0
HDPE	B	143	2.71	4	3.48	1	1500	4	5323	25	20	125	0
X42 Steel	B	143	2.71	4	3.48	1	40	132	5280	25	20	300+	0

Table 36. Test Case Scenario (Segment B) Cost Results

Pipe Product	Segment	Cost Of Material	Cost of Install	Total Cost
PA12	B	$55,440(1)	$47,520 (2)	$102,960
HDPE	B	$10,824(3)	$47,520 (2)	$58,344
X42 Steel	B	$57,024(4)	$105,600(5)	$162,624

(1) Average price of $10.50/ft used in calculation
(2) Average price of $9/ft used in calculation
(3) Direct quote price of $2.05/ft used in calculation
(4) Direct quote price of $10.80/ft used in calculation
(5) Average price of $20/ft used in calculation

Theoretical Ethanol Gathering System Scenario

Additional pricing information was acquired for HDPE, Carbon Steel, RED THREAD II, and PA12. An economic model was performed fully encompassing the theoretical gathering system model. Focus was centered on pipe material, field installation, maintenance, and compression costs for the evaluation. HDPE, RED THREAD II, and Carbon Steel pipe material costs were acquired as direct quotes from pipe distributors/manufacturers within 2 weeks of submitting this draft final report for relevancy. PA12 material costs were provided by a resin manufacturer of PA12. The introduction of additional material pricing such as fittings and joining are generally captured in the field installation costs for each pipe material, which are referenced in Table 34 for HDPE, PA12, RED THREAD II, and Carbon Steel pipe. Maintenance costs for Carbon Steel (cathodic protection) are also referenced in Table 34, and for the purposes of this test case 20 years of maintenance service is included in the calculation.

Economic evaluation of the composite pipeline material Flexpipe for the ethanol gathering system was not pursued due to the limitation in available pipe diameter size. Flow capacity calculations indicated a requirement of 22 pumping stations to meet the required volumes and operating pressures, therefore rendering the pipe material economically prohibitive.

The operational model for each material was executed, and pipe diameter sizes for each particular segment of the ethanol gathering system were calculated and selected for minimum economical impact. Analysis of each pipe material resulted in nearly identical pipe diameters selected with the requirement of one (1) compressor station installation on segment E, with the exception of PA12 and RED THREAD II. Favorable pipe flow characteristics of those materials resulted in sufficient pressure differential to preclude need of a pipeline pumping station. It should be noted that 12" diameter HDPE or smaller was used in the scenario due to a lack of accurate pricing information and resulted in the need of a pipeline pumping station. It is expected that utilization of 16" HDPE would be marginally more economically attractive than the installation of a pumping station.

A summary of economic results is displayed in Table 37, Table 38, Table 39, Table 40.

Table 37. HDPE Results for theoretical ethanol gathering system test case scenario

Pipe Product	Segment	Pipe Diameter	Cost Of Material	Cost of Install (1)	Cost of Pumping	Total Cost
HDPE	A	6	$116,952(2)	$369,600	$0	$486,552
HDPE	B	4	$10,824(3)	$47,520	$0	$58,344
HDPE	C	8	$515,486(4)	$1,029,600	$0	$1,545,086
HDPE	D	6	$233,904(2)	$739,200	$0	$973,104
HDPE	E	12	$5,198,688(5)	$5,068,800	$300,000(6)	$10,567,488
HDPE	F	8	$1,982,640(4)	$3,960,000	$0	$5,942,640
HDPE	G	6	$935,616(2)	$2,956,800	$0	$3,892,416
Total Costs			$8,994,110	$14,171,520	$300,000	$23,465,630

(1) Graduated cost of install per foot per pipe diameter starting at 2" - $8, $9, $14, $15, $16
(2) Direct Quote price of $4.43/ft used in calculation
(3) Direct quote price of $2.05/ft used in calculation
(4) Direct quote price of $7.51/ft used in calculation
(5) Direct quote price of $16.41/ft used in calculation
(6) Estimated cost based on discussions with Archer Daniels Midland

Table 38. Carbon Steel results for theoretical ethanol gathering system test case scenario

Pipe Product	Segment	Pipe Diameter	Cost Of Material	Cost of Install(6)	Cost of Pumping	Cost of Maintenance (2)	Total Cost
CS	A	6	$501,336(1)	$633,600	$0	$56,250	$1,191,186
CS	B	4	$57,024(3)	$105,600	$0	$11,250	$173,874
CS	C	8	$1,961,731(4)	$1,921,920	$0	$112,500	$3,996,151
CS	D	6	$1,002,672(1)	$1,267,200	$0	$112,500	$2,382,372
CS	E	12	$15,716,448(5)	$10,137,600	$300,000(7)	$675,000	$26,829,048
CS	F	8	$7,545,120(4)	$7,392,000	$0	$562,500	$15,499,620
CS	G	6	$4,010,688(1)	$5,068,800	$0	$450,000	$9,529,488
Total Costs			$30,795,019	$26,526,720	$300,000	$1,980,000	$59,601,739

(1) Direct quote price of $18.99/ft used in calculation
(2) Average CP install price of $3,750/mile and $375/mile/yr maintenance (20 years included) used in calculation
(3) Direct quote price of $10.80/ft used in calculation
(4) Direct quote price of $28.58/ft used in calculation
(5) Direct quote price of $49.61/ft used in calculation
(6) Graduated cost of install per foot per pipe diameter starting at 2" - $16, $20, $24, $28, $33
(7) Estimated cost based on discussions with Archer Daniels Midland

Table 39. PA12 results for theoretical ethanol gathering system test case scenario

Pipe Product	Segment	Pipe Diameter	Cost Of Material(1)	Cost of Install (2)	Cost of Pumping	Total Cost
PA12	A	6	$1,188,000	$369,600	$0	$1,557,600
PA12	B	4	$121,440	$47,520	$0	$168,960
PA12	C	8	$5,148,000	$1,029,600	$0	$6,177,600
PA12	D	6	$2,376,000	$739,200	$0	$3,115,200
PA12	E	12	$31,680,000	$5,068,800	$0	$36,748,800
PA12	F	8	$19,800,000	$3,960,000	$0	$23,760,000
PA12	G	6	$9,504,000	$2,956,800	$0	$12,460,800
Total Costs			$69,817,440	$14,171,520	$0	$83,988,960

(1) Price based on pipe resin manufacturer estimate 2" - $7, 4" - $23, 6" -$45, 8" - $75, 12" - $100 (projected)
(2) Graduated cost of install per foot per pipe diameter starting at 2" - $8, $9, $14, $15, $16

Table 40. RED THREAD II results for theoretical ethanol gathering system test case scenario

Pipe Product	Segment	Pipe Diameter	Cost Of Material	Cost of Install [1]	Cost of Pumping	Total Cost
RED THREAD	A	4	$142,296[2]	$528,000	$0	$486,552
RED THREAD	B	3	$21,120[3]	$105,600	$0	$58,344
RED THREAD	C	6	$634,234[4]	$1,372,800	$0	$1,545,086
RED THREAD	D	6	$487,872[4]	$1,056,000	$0	$973,104
RED THREAD	E	12	$9,668,736[5]	$6,969,600	$0	$15,267,488
RED THREAD	F	6	$2,439,360[4]	$5,280,000	$0	$5,942,640
RED THREAD	G	4	$1,138,368[2]	$4,224,000	$0	$3,892,416
Total Costs			$14,531,986	$19,536,000	$0	$34,067,986

(1) Graduated cost of install per foot per pipe diameter: 3" - 6" = $20, > 6" = $22
(2) Direct Quote price of $5.39/ft used in calculation
(3) Direct quote price of $4.00/ft used in calculation
(4) Direct quote price of $9.24/ft used in calculation
(5) Direct quote price of $30.52/ft used in calculation

Summary and Conclusions

This project researched and determined the feasibility of using new materials, both polymeric and composites, as low-cost alternatives to specially designed metallic gathering pipelines. The project focused on the potential integrity effects of using such polymer based pipes when used with typical feed stocks (for ethanol production) at common temperatures and pressures. The work also included designing an ethanol pipe system for gathering to determine both engineering and economic feasibility of polymer pipe system use. Finally, the research effort provided the direction for subsequent relevant research in this area as well as a foundation for developing a program to evaluate future biofuels.

Ethanol production world-wide was studied, including first generation and second generation ethanol production. First generation corn ethanol production provided a typical configuration for ethanol plant spacing and distance from a clean-up or transportation hub, as well as typical requirements for gathering pipeline systems. A summary list of all known feedstocks was compiled for both domestic and non-U.S. ethanol.

Current ethanol transportation methods were studied and supplemented with information from the project steering committee. Most large corn farms are between 10 to 15 miles from an ethanol plant. From the production centers, about 60 percent of ethanol is shipped by rail, 30% by truck and 10% by barges. There is only one recently commissioned U.S. steel pipeline that is transporting fuel grade ethanol blended with gasoline.

In order to perform a materials compatibility analysis the chemistry breakdown of ethanol was needed. In addition to ethanol, there are additives and impurities in ethanol. The largest constituent is the denaturing agent, usually gasoline, and is added prior to shipping. The second largest can be inhibitors added to limit corrosion and these can include ethyl tertiary butyl ether (ETBE) and methyl tertiary butyl ether (MTBE) and various aliphatic ethers. Other potential impurities can be a by-product of production and can include: lactic and acetic acid, water, and sulfur dioxide. Other chemical reactions with deleterious effects are reactions of ethanol with phosphoric and sulfuric acid to form phosphate and sulfate esters.

The chemical structure of ethanol also offers some potential incompatibilities with other materials. Ethanol is made up of carbon, hydrogen and oxygen. The oxygen content provides no BTU value, but it is the oxygen content that imparts very different properties to an alcohol, when compared to gasoline. The oxygen is present as a hydroxyl group (-OH), the same functional group found in water. Since the hydroxyl group is attached to the end of the molecule, it makes the alcohol molecule very polar. This also results in a high heat of vaporization as the molecule is very susceptible to hydrogen bonding, as opposed to very volatile gasoline.

Common impurity specifications can be found in ASTM D5798 (Table 4 on page 23 of this report). The parent standard for fuel grade ethanol is ASTM D4806. This and all other international standards were researched and compiled into a single list presented in Table 6 on page 25 of this report. With the help of the steering committee and industrial partners, a detailed survey was constructed and distributed relating to ethanol production. With the results from this survey and the literature search it was decided to focus on the current fuel grade standards as a starting place for ethanol fuel chemistry.

The project steering committee requested that this project focus on the bulk thermoplastic pipe for the materials selection and compatibility analysis. However, a small work effort was completed to list out all the current joining practices and with which thermoplastic resins that can and are being used today. The joining methods include: solvent cementing, butt fusion, socket fusion (heat and electro-fusion), threading, flanging, bell-ring-gasket joining, compression insert joints, and grooved-end mechanical joints. The advantages and disadvantages of all joining methods were studied and listed.

All commercially available thermoplastic pipe products (by common resin type) were investigated. This included researching the literature and contacting the major plastic pipe resin manufacturers. The most common material types (all commercially available in pipe form) included: polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), polypropylene (PP), polyamide (PA), ethylene chlorotrifluoroethylene (ECTFE), polyvinylidene fluoride (PVDF), and polyvinylidene chloride (Saran™). Chemistry, structure, and availability (in pipe form) were all researched and summarized. Several excellent polymers were considered unsuitable for ethanol gathering lines because they are not made in pipe form and/or are cost prohibitive. These included: Polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP), perflouoralkoxy (PFA), ethylene tetrafluoroethylene (ETFE), and chlorotrifluoroethylene.

After narrowing down the viable thermoplastic resins, a chemical compatibility analysis/study was conducted. Before collecting "chemical compatibility charts", a more fundamental study on the environmental effects of solvents on thermoplastics was undertaken. This included: general chemical resistance properties of polymers, permeability and swelling issues, crazing and cracking, superimposed stress (affects of) for structural components and environmental stress cracking, hydrogen bond destruction, and solvent leaching of additives. This information allowed further narrowing of some subclasses of the polymer resins to those that would be less susceptible to some degradation mechanisms (like environmental stress cracking) in ethanol.

An exhaustive search of published chemical resistance data was undertaken to determine suitability of the polymer resins for use in ethanol. As noted in PPI TR-17, much if not all of the published data from many sources is for compatibility in the unstressed state and/or short term (e.g., splash) exposure. However, the data is still extremely useful because it allows one to preclude resins for long term use if they are not suitable for short term use.

Based on the chemical compatibility data and fundamental chemical principles noted above, an initial list of thermoplastics was decided upon. In several cases there were temperature restrictions on the materials use in ethanol which also precluded the use of that particular pipe resin. This list was restricted to a subset of those materials currently listed in the latest edition of PPI TR-3 (which are currently commercially available and have passed a rigid ASTM/PPI qualification standard procedure). The resins of interest available in pipe form are: High Density PE, Crosslinked PE (PEX), Polyvinylidene Fluoride (PVDF), and Polyamide (PA).

GTI then contacted all the manufacturers with intent to obtain any chemical compatibility testing of these resins in ethanol. First priority was on pressurized testing in ethanol, followed by pressurized testing in a similar alcohol (e.g., methanol), then unpressurized (i.e., no stress) testing in ethanol, and finally unpressurized testing in a similar alcohol.

Manufacturers did provide detailed testing data on: PA12 in methanol which generally showed good resistance; multilayered materials with PA12 also showed good overall resistance to methanol exposure; PVDF which showed outstanding resistance to ethanol (CE85 and CE50 grades) and good mechanical strength retention (with some degradation) when exposed to ethanol under pressure/stress. One manufacturer also submitted ECTFE compatibility test data in ethanol which showed it was even more resistant than PVDF.

Although the focus of the research was placed on bulk thermoplastic pipe, a composite piping review was included and focused on systems comprised of a thermoplastic pipe wrapped with a high strength material. This high strength material, usually fibers, is then shielded by an outside layer of thermoplastic. Composite piping has and continues to be used for flow lines, oil and gas production, water disposal and injection, and subsea applications.

Product literature on eleven (11) thermoplastic piping products used for rehabilitation or replacement of steel pipelines was reviewed. Each was evaluated for their potential use in ethanol transportation based on application, availability, material, size, and pressure. Three (3) products were for rehabilitation of steel only and were removed from consideration. The eight (8) remaining products were divided into two categories based on likeliness to be compatible.

In ranking, preference was given to stainless steel and plastic connectors and PE, PEX, PVDF, and PP liners (PP was not selected for bulk thermoplastic pipe since it is readily available in only the liner form). Only the materials in direct contact were considered. The pressure ratings given for the products were not based on ethanol therefore; manufacturers should be consulted before using these products for pressurized ethanol transport.

In addition to the composite pipe review, fifteen (15) fiberglass piping products were investigated for use with ethanol. They were rated by likeliness to be compatible with fuel ethanol. The rating system was set up from "1-Cannot be used" to "4 - Can be used", where a rating of 3 is more likely to be compatible with ethanol than a product rated 2.

Three products received ratings of 4 as they are currently used for piping ethanol and are listed by UL 971 “Nonmetallic Underground Piping for Flammable Liquids.” UL 971 demands a compatibility tests with methanol and ethanol at 100% for a minimum of 270 days with a 50% maximum loss in strength. Additionally, there is a maximum permeation level if 2 g/m^2/day in a 180 day test. Eleven were assigned a rating of 3 because chemical compatibility data for those products specified compatibility with “Ethyl Alcohol” or “E95-100”. The remaining product was rated 2 because there was no evidence to support or disprove compatibility with ethanol.

Ethanol compatibility data gaps were documented and summarized into three areas where very limited to no direct data could be found:

- Long term strength testing with ethanol,
- Permeability testing at operating pressures, and
- Erosion resistance with ethanol flow.

To better determine the necessary pipe requirements (sizing, hoop stress, joining, fittings, etc.), a base line system was established. It was designed around a flat theoretical corn producing region. This pipeline was designed to transport ethanol from several production plants to a class 1 railroad. The calculations to design the pipeline system were based on the *U.S. Army Corps of Engineers – Liquid Process Piping, Engineer Manual* and data supplied by the pipe manufactures. The calculations were performed to determine the pressure drop across the pipe system and the flow capacity of the pipe sections. Four pipe systems were selected for comparison:

- High Density Polyethylene (HDPE),
- Polyamides (PA12),
- Epoxy Resin Pipe (Red Thread II), and
- Composite Pipe (Flexpipe).

With all assumptions taken into account, all four systems produced a theoretical system that could gather/transport ethanol as desired.

These four systems were further explored for economic viability with Carbon Steel as a baseline material of construction. This presented a difficult task, as raw material costs, such as resins and steel, are constantly changing over time and can have significant variability. This variability made it impractical to perform a long term evaluation of pipeline system costs, and subsequently any monetary calculations within this analysis should be considered a “snap-shot in time” and periodically updated. To account for this variability in material pricing, a dynamic economical model was developed to provide the base requirements with price as the only variable input. To ensure a relative economic comparison and minimize operational related cost variability, two test case scenarios were developed. First, a basic set of parameters were used to perform a test case cost scenario: a single gathering line (Segment B) was selected. Given the amount of cost information available for selected materials, the test case scenario included Carbon Steel (a baseline material of construction), HDPE, and PA12 in 4"diameter pipe. The Segment B test case exhibited a 7% increase in cost (from steel) when PA12 was used and 64% reduction in cost when HDPE was used.

A second test case scenario was developed utilizing the same materials of construction with the addition of RED THREAD II and designed around operational and economical requirements of the theoretical ethanol gathering pipeline system. Using the cost of a carbon steel system as the baseline, this test case scenario resulted in:

- A 61% reduction in total cost when using HDPE,
- A 43% reduction in total cost when using RED THREAD II, and
- A 41% increase in total cost when using PA12.

The materials compatibility, manufacturing testing to date, and theoretical gathering system and associated economic analysis undertaken in this project has initially demonstrated that polymer pipe is a feasible choice for ethanol gathering lines. However, as the gap analysis also indicated, full-size and pressurized testing of this concept is recommended as the next step to validate/substantiate the findings for this report.

Recommendations for Next Steps

A pilot study with one or both of the HDPE and composite pipes mentioned above would provide real world empirical data to validate some of the conclusions of this report. As discussed in this report's section, "Ethanol Compatibility Data Gaps", there were identified data gaps related to the lack of direct testing that would mimic the operating conditions of a typical ethanol gathering service pipeline.

In summary, the three major informational gaps are:

1. Long term strength testing with ethanol (under pressure),
2. Permeability testing at operating pressures, and
3. Ethanol flow erosion resistance.

Sound engineering judgment is necessary to determine whether it is appropriate to use laboratory-based long term strength testing data and short term chemical compatibility tests discussed in this report to provide a safe and reliable ethanol gathering system that will provide long term physical and chemical integrity in the field. However, the laboratory testing is often performed on unstressed resin materials and for relatively "short" time frames.

A properly monitored field installation would validate the findings of this report and provide the information necessary to make sound engineering judgments on ethanol gathering pipeline selection. It is unlikely that operators would consider full implementation of recommended polymer piping systems from this report without such field validation testing.

The polymer piping systems recommend in this report offer a host of advantages over steel pipelines, including: lower cost, greatly improved resistance to external corrosion, chemical stability in nearly all installation environments, ease of joining and tapping for system expansions and reconfigurations. These desirable features would lower the life cycle costs of ethanol gathering systems and facilitate the expansion of this renewable source of fuel. It is also unlikely that without support from DOT/PHMSA, pipeline manufactures of feasible systems, and at least one ethanol production facility that such a field validation will be conducted.

GTI therefore recommends that the next logical step is a full-scale pilot installation of a polymer gathering line in an ethanol production facility. A resin choice of PE 4710 (bimodal HDPE) would be a good first candidate. It would also be desirable to test the material under different formulations of ethanol if possible.

A manufacturing participant in this project, LyondellBasell Industries (Equistar Chemical), has generously offered to provide access to an ethanol plant as well as provide the PE 4710 pipe in various lengths and diameters. Specifics of the HDPE resin and the ethanol blends for potential exposure are listed in Appendix D.

The following scenario is available for a follow on, full scale pilot installation:

- Resin type: HDPE which meets the following standards:
  - Plastics Pipe Institute (PPI) PE 4710.
  - PE 100 per PPI TR-4.
  - ASTM D 3350 Cell Classification 445574C and 445576C.
  - Chemical Resistance per ASTM D 2513
  - NSF Standard 14 and Standard 61 for Potable Water Pipe and Fittings.
- Line length roughly 1000 feet in total,
- Pipe diameter: 3 inch and 1.5 inch, and
- The line would "T" from existing pipe, with block valves to assure the plant does not violate any sales agreements with customers that have certified and approved the plant's operation and require an MOC notification (the plant could switch back to CS lines by switching a valve.)

The below list contains possible test configurations and order:

1. 190 Ethanol

- 150 feet of 1.5 inch line currently two "T" connections, eight 90 degree elbows, two filters with two tri-clover filter connections,
- 60 - 70 feet of 3-inch line with currently one end line filter and five 90 degree elbows, and
- Throughput ~ 25-30M gal per month.

2. Denatured Ethanol (SDA 2B) 200 proof material

- Containing 0.5% toluene or rubber hydrocarbon solvent,
- 100 to 125 feet of 3-inch line, six to eight 90 degree elbows , minimum of one 4-bolt flange (300 lb) and one filter, and
- Throughput ~ 35 - 50M gal per month.

3. Denatured Ethanol (SDA 3A) 200 proof material

- Containing ~ 5% methyl alcohol,
- 100 to 125 feet of 3-inch line, six to eight 90 degree elbows , three 4-bolt flanges (300 lb) and three filters, and
- This line also has a pump at ~ 60-80 psig / 175-200 gal per minute throughput which varies by season.

4. Pure 190 Ethanol

- Roughly 200 feet of 3-inch line to tank from rail siding to pump into a tank (may be able to switch this to 4-inch) fittings would be based on installation,
- Along pipe tank to the meter room could place in another 275 – 300 feet of 3-inch (again may be able to swap out to 4-inch line), with several flanges, and elbows as well, and
- Throughput ~ 56 to 85M gal per month in flow, and a similar amount of out flow out.

Another manufacturing participant in this project, Prime Flexible Products - FlexSteel, has generously offered to provide composite pipe (FlexSteel product) for a potential follow on pilot study.

List of Acronyms

Acronym	Description
ANSI	American National Standards Institute
API	American Petroleum Institute
CPVC	Chlorinated Polyvinyl chloride
CTFE	Chlorotrifluoroethylene
E10	Ethanol 10
E20	Ethanol 20
E95	Ethanol 95
ECTFE	Ethylene Chlorotrifluoroethylene
EA	Ethyl Alcohol
ETFE	Ethylene Tetrafluoroethylene
EVOH	Ethylene vinyl alcohol
FEP	Fluorinated Ethylene Propylene
FRP	Fiber Reinforced Plastic
GRE	Glassfiber Reinforced Epoxy
HDPE	High Density Polyethylene
PA	Polyamide
PB	Polybutylene
PBT	Polybutylene terethalate
PE	Polyethylene
PEI	Polyetherimide
PEX	Cross-linked Polyethylene
PET	Polyethylene terephthalate
PFA	Perflouoralkoxy
POM	Polyoxymethyle
PP	Polypropylene
PPA	Polyphtalamide
PPS	Polyphenylene Sulfide
PVC	Polyvinyl chloride
PVDF	Polyvinylidene Fluoride
PTFE	Polytetrafluoroethylene
PUR	Polyurethane
RTP	Reinforced Thermoplastic Pipe
TCF	Thermoplastic Composite Flowline

Appendix A – Data Provided by Evonik

Test Results of Vestamid L2124 with exposure to ASTM Fuel C and Methanol mixtures for 25 days

The test data does not identify the temperature for the duration of the exposure.

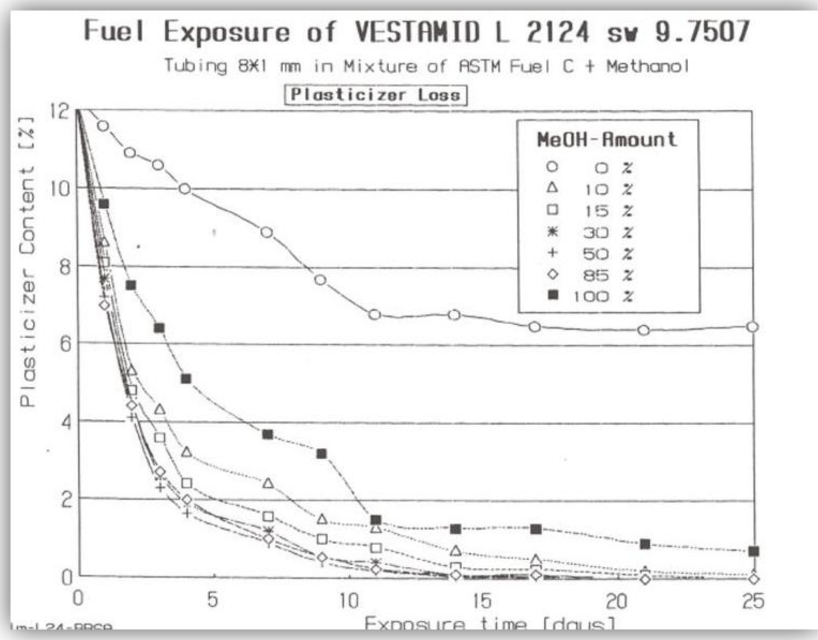


Figure 2: Vestamid L 2124 - Plasticizer Loss vs. Exposure Time Plot.

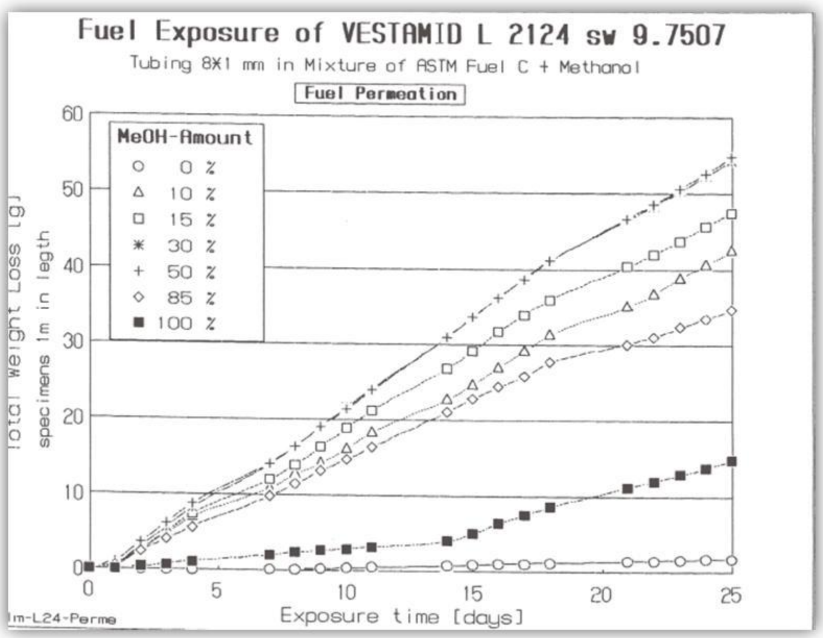


Figure 3: Vestamid L 2124 - Fuel Permeation vs. Exposure Time Plot.

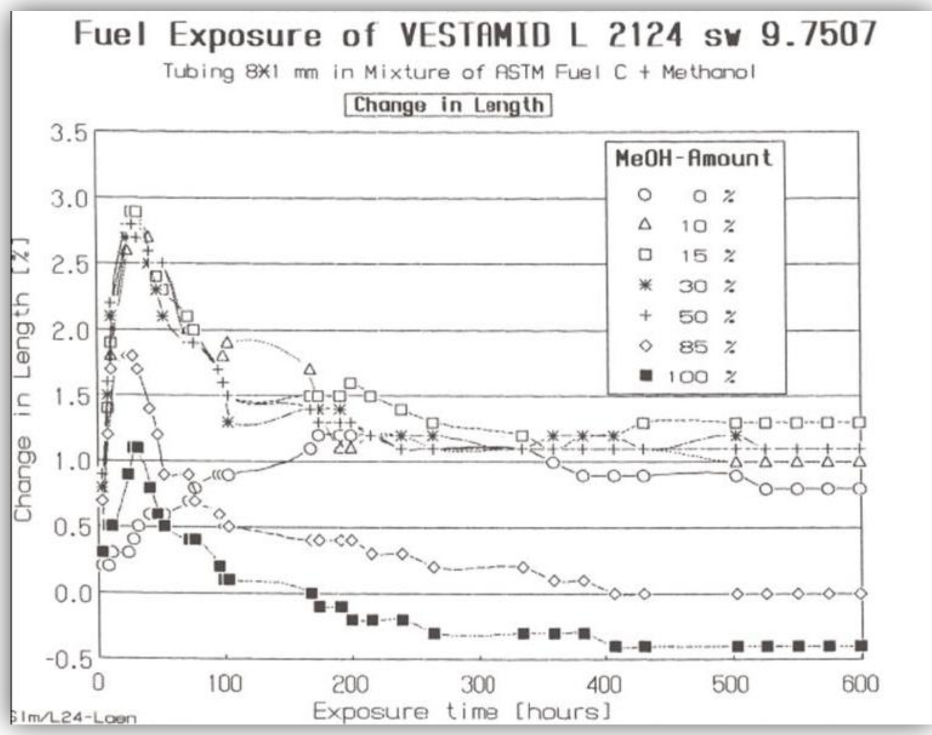


Figure 4: Vestamid L 2124 - Change In Length vs. Exposure Time Plot.

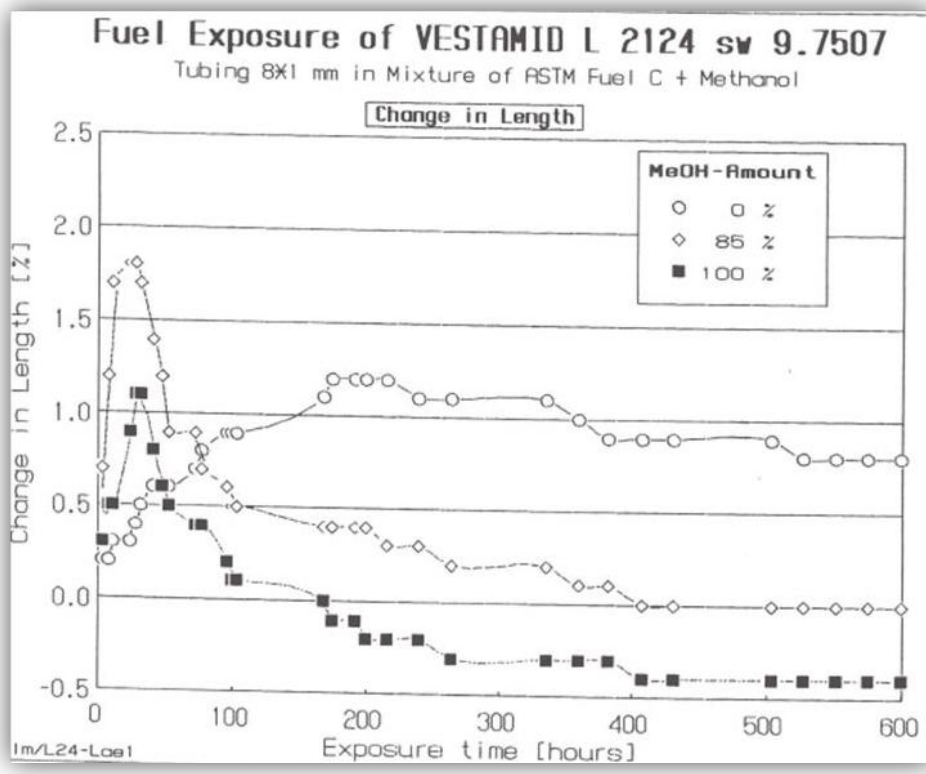


Figure 5: Vestamid L 2124 - Change In Length vs. Exposure Time Plot.

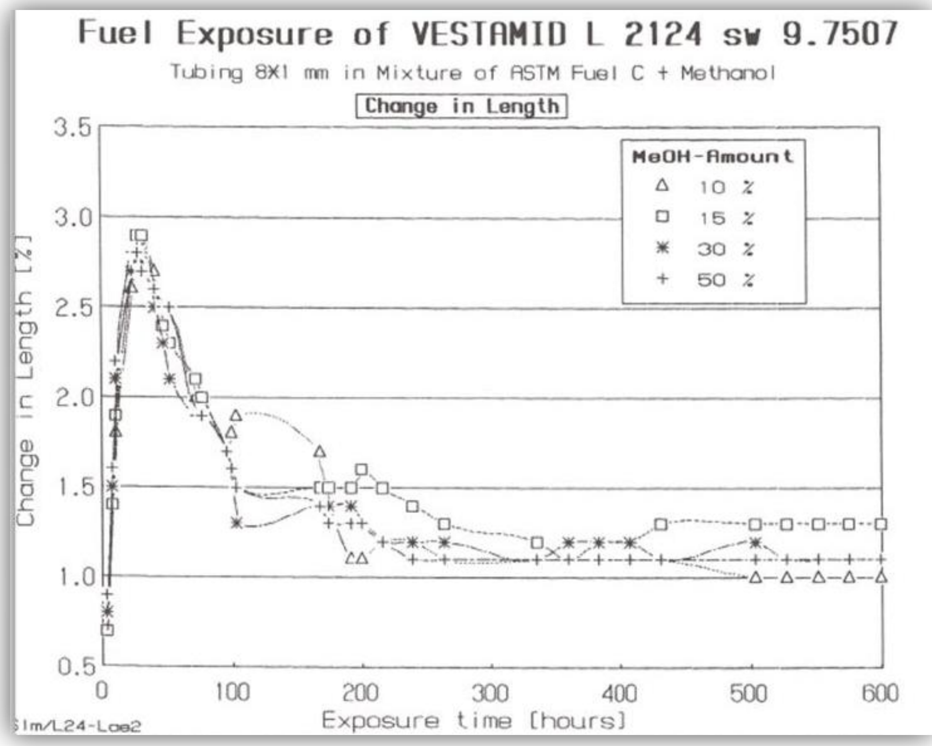


Figure 6: Vestamid L 2124 - Change In Length vs. Exposure Time Plot.

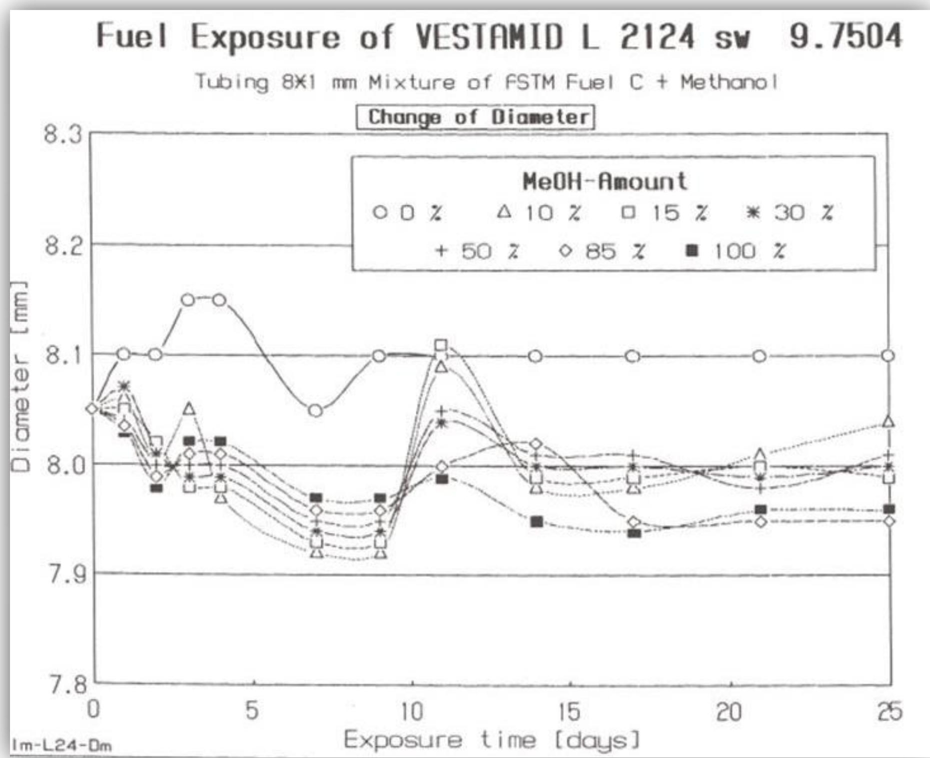


Figure 7: Vestamid L 2124 - Change In Diameter vs. Exposure Time Plot.

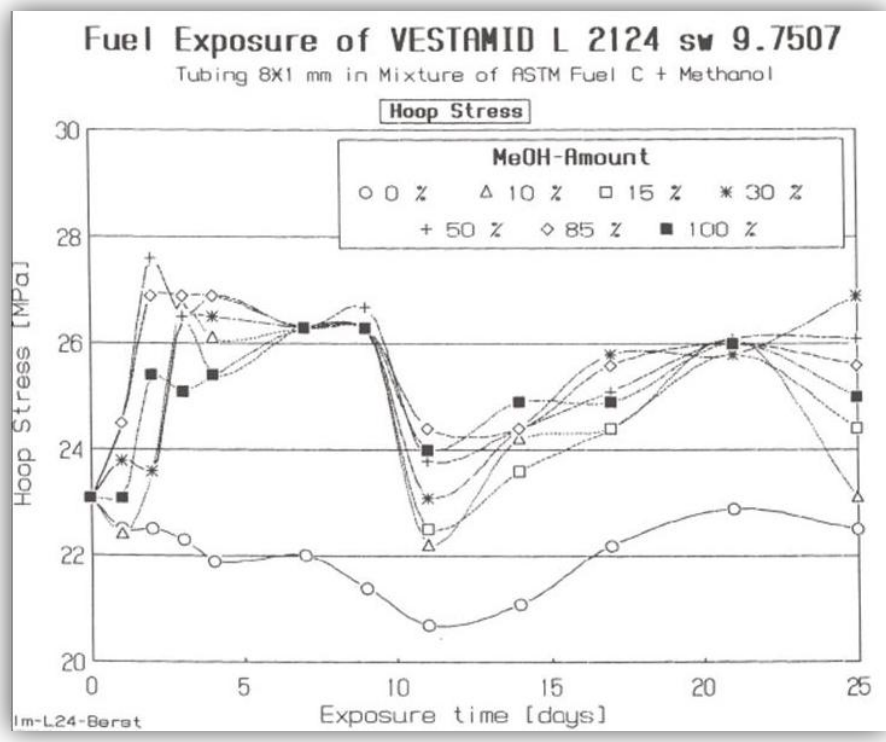


Figure 8: Vestamid L 2124 - Hoop Stress vs. Exposure Time Plot.

Fuel Exposure of 25 days of VESTAMID L 2124 sw 9.7507
Tubing 8*1 mm in Mixture of ASTM Fuel C + Methanol

			Content of Methanol [%]						
Properties	Unit	Control Sample	0	10	15	30	50	85	100
Plasticizer content after 25 days of exposure	% %	12,4	6,5	0,10	0	0	0	0	0,7
Permeation	g/m*d g/m²*d		0,10 4,5	1,69 77	1,91 87	2,20 100	2,20 100	1,44 65	0,98 45
Change in length maximum equilibrium	% %		1,2 0,8	2,9 1,0	2,9 1,2	2,8 1,1	2,8 1,1	1,8 0,0	1,1 -0,4
Tubing diameter after 25 days of exposure	mm mm	8,05 8,05	8,10	8,05	8,00	8,00	8,00	7,95	7,95
Hoop stress after 25 days of exposure	MPa MPa	23	23	23	24	27	26	26	26
Cold impact at -40°C acc. to SAE J844d after 25 days of exposure	* *	no break	1	0	0	0	0	0	0

*) Note: The number of breaks out of 7 tested Specimens are listed.

Figure 9: Vestamid L 2124 - Summary Data Table.

Test Results of Vestamid L2121 with exposure to ASTM Fuel C and Methanol mixtures for 30 days

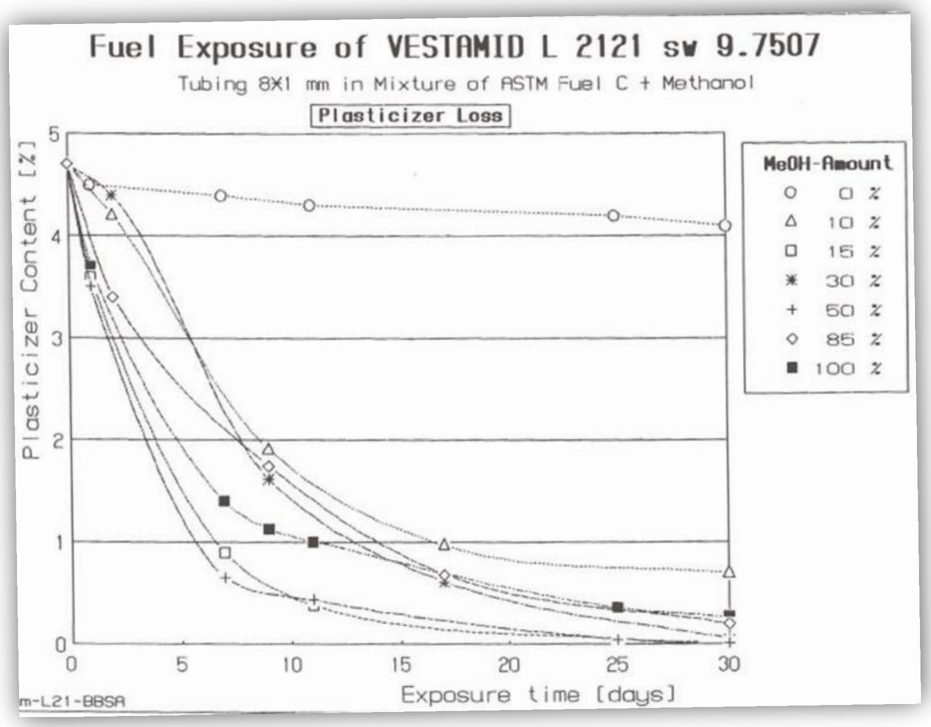


Figure 10: Vestamid L 2121 - Plasticizer Loss vs. Exposure Time Plot.

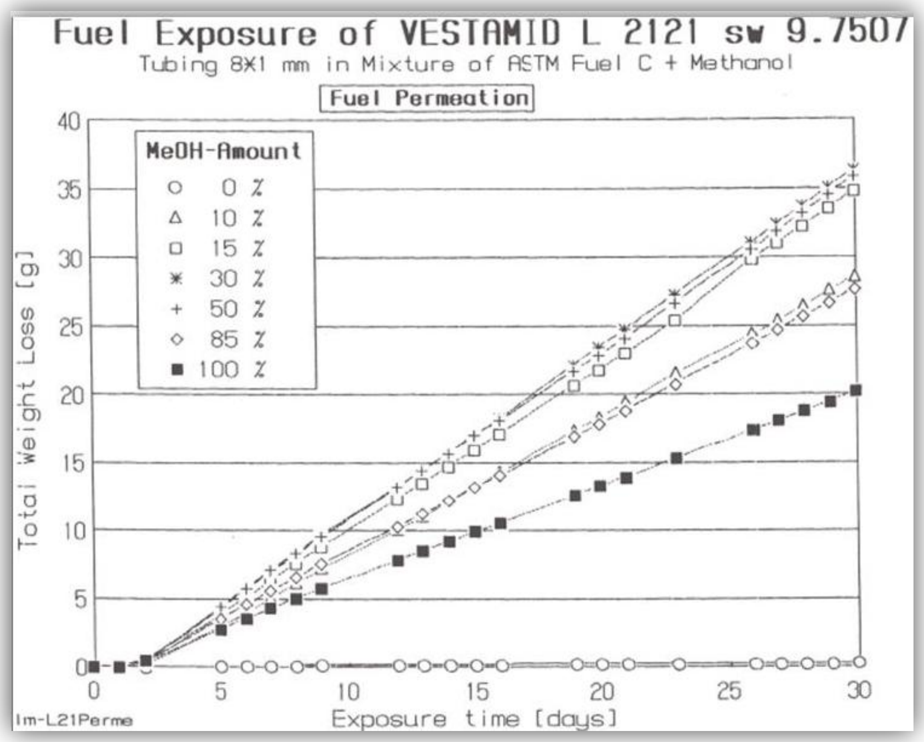


Figure 11: Vestamid L 2121 - Fuel Permeation vs. Exposure Time Plot.

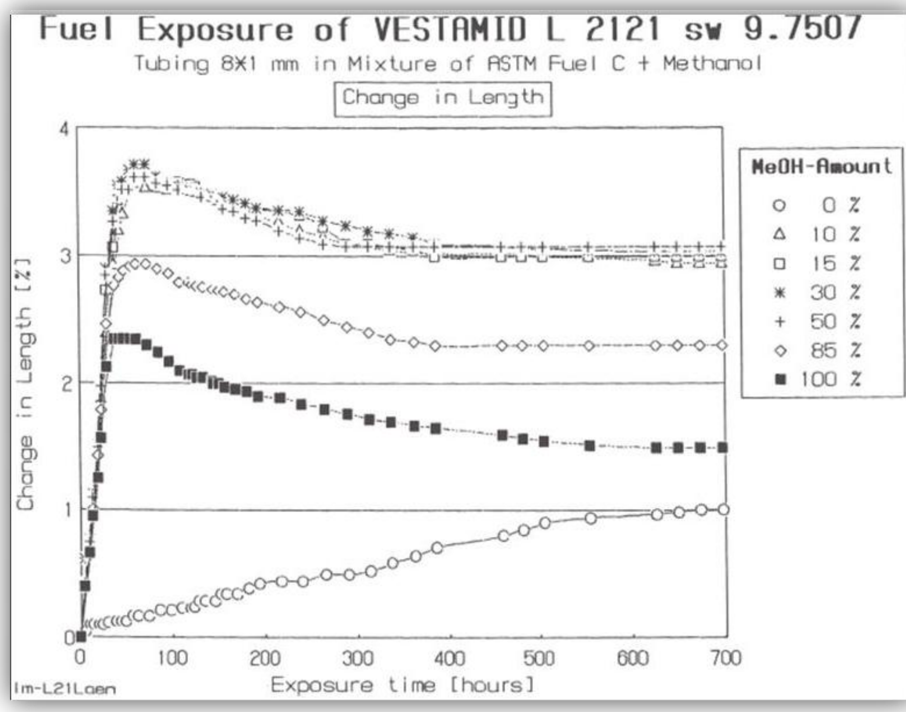


Figure 12: Vestamid L 2121 - Change In Length vs. Exposure Time Plot.

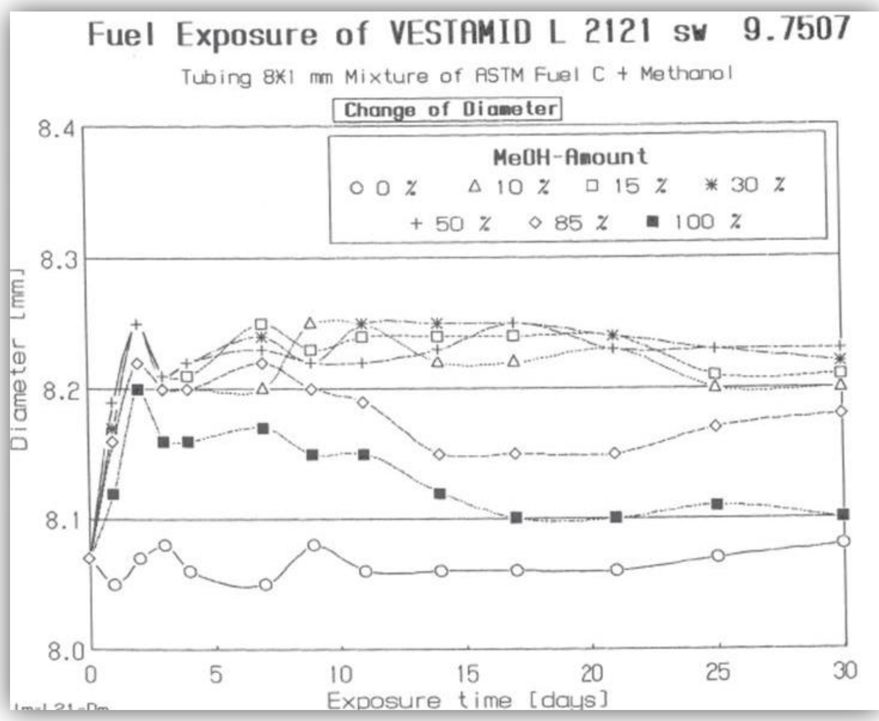


Figure 13: Vestamid L 2121 - Change In Diameter vs. Exposure Time Plot.

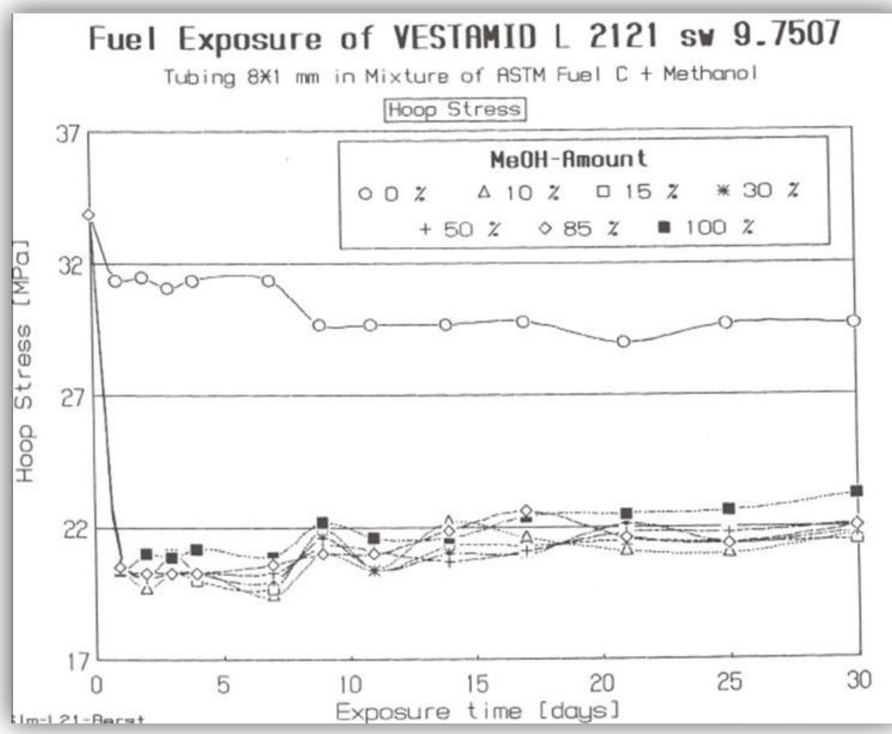


Figure 14: Vestamid L 2121 - Hoop Stress vs. Exposure Time Plot.

Fuel Exposure of 30 days of VESTAMID L 2121 sw 9.7507
Tubing 8*1 mm in Mixture of ASTM Fuel C + Methanol

Properties	Unit	Control Sample	Content of Methanol [%]						
			0	10	15	30	50	85	100
Plasticizer content after 30 days of exposure	% %	4,7	4,1	0,7	0	0	0	0,2	0,3
Permeation	g/m*d g/m²*d		<0,5 <3	1,03 47	1,23 56	1,27 58	1,26 57	0,96 44	0,70 32
Change in length maximum equilibrium	% %		1,0 1,0	3,6 3,0	3,7 3,0	3,7 3,0	3,6 3,1	2,9 2,3	2,4 1,5
Tubing diameter after 30 days of exposure	mm mm	8,07	8,08	8,20	8,20	8,25	8,25	8,20	8,10
Hoop stress after 30 days of exposure	MPa MPa	34	30	22	22	22	22	22	22
Cold impact at -40°C acc. to SAE J844d after 30 days of exposure	* *	no break	0	0	0	0	0	0	0

*) Note: The number of breaks out of 7 tested Specimens are listed

Figure 15: Vestamid L 2121 - Summary Data Table.

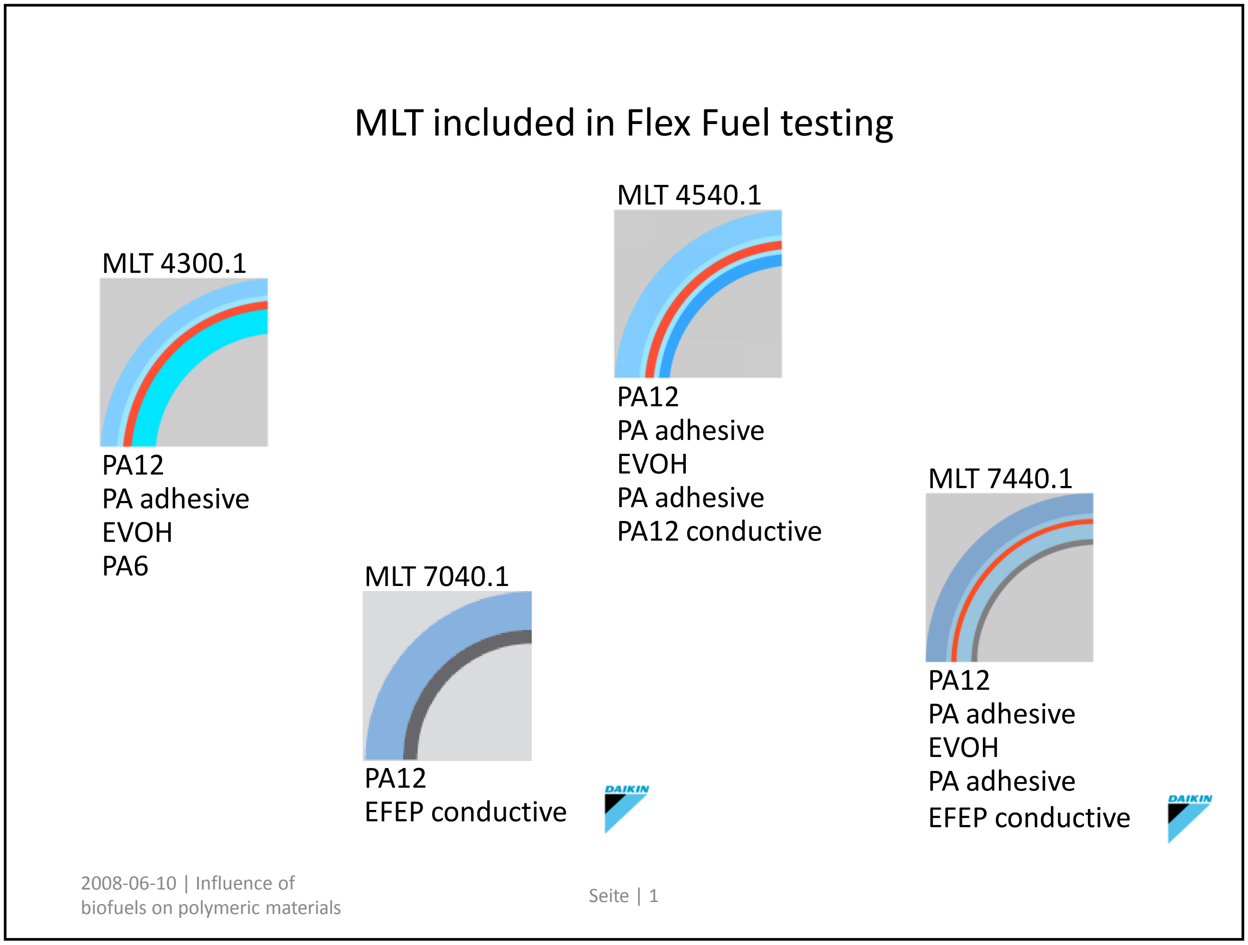


Figure 16: Multilayered Tubing Configurations with PA12.

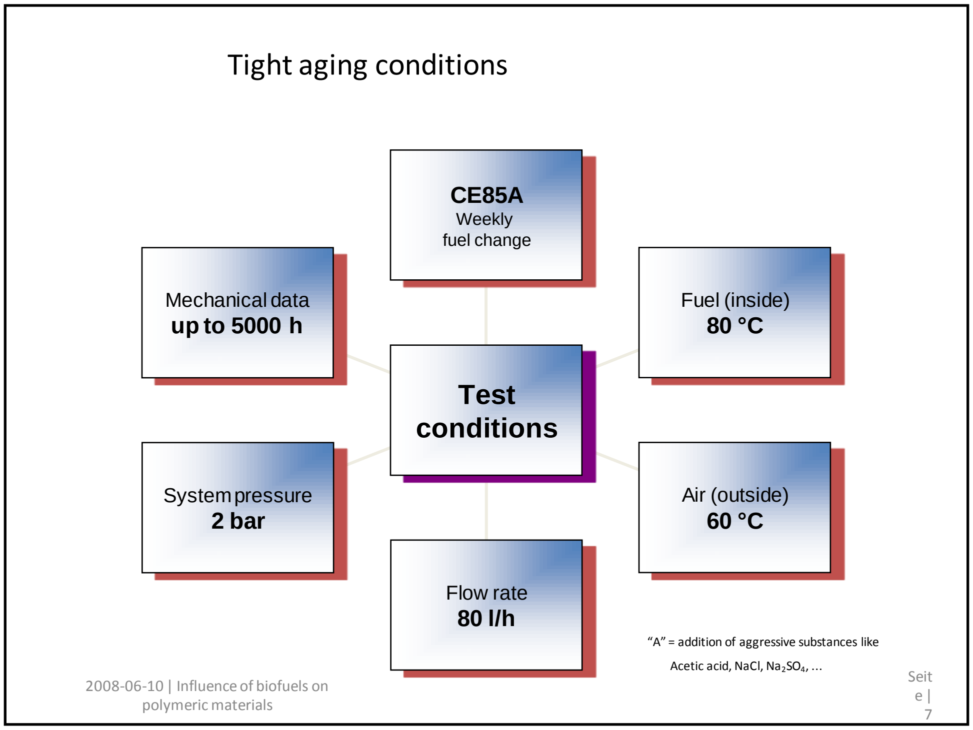


Figure 17: Multilayered Tubing Aging Test Conditions.

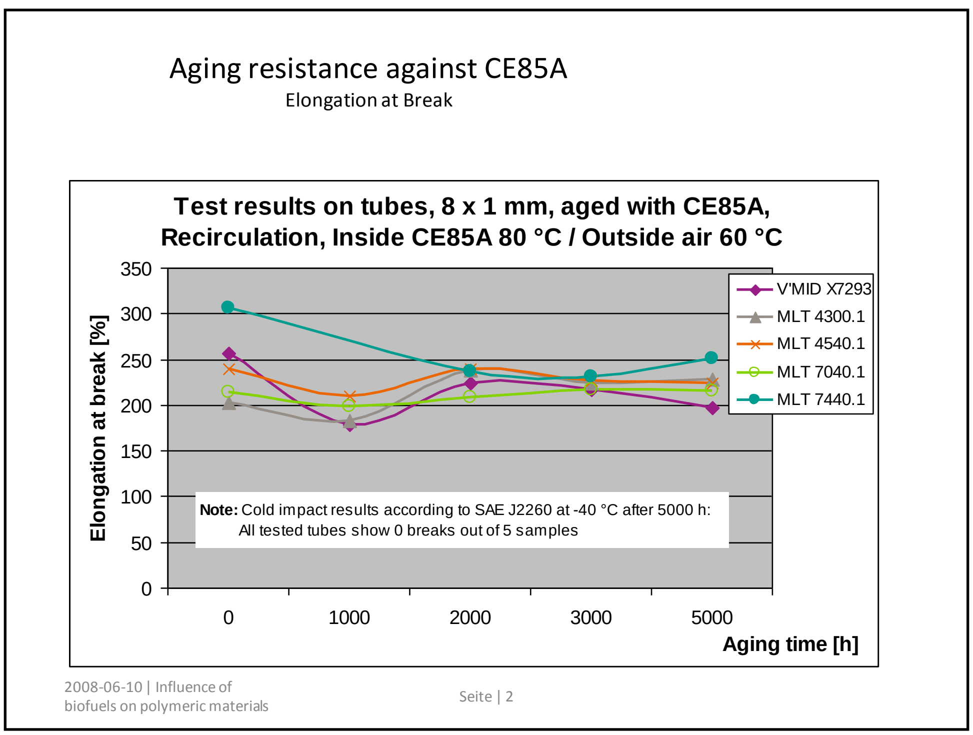


Figure 18: Multilayered Tubing Elongation at Break Aging Resistance Against CE85A.

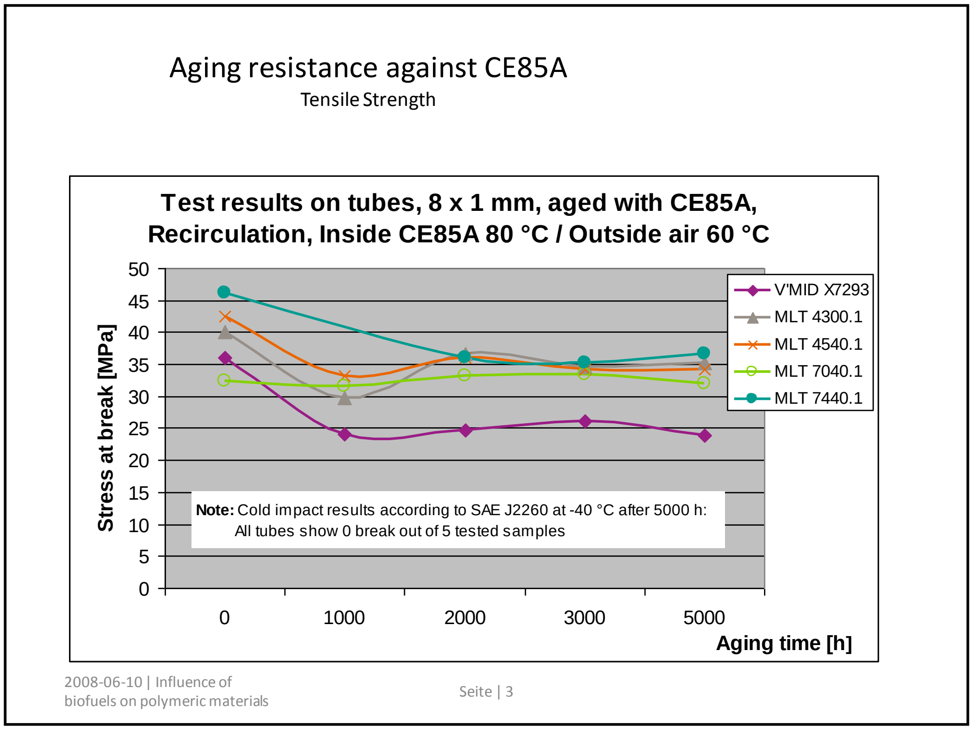


Figure 19: Multilayered Tubing Tensile Strength Aging Resistance Against CE85A.

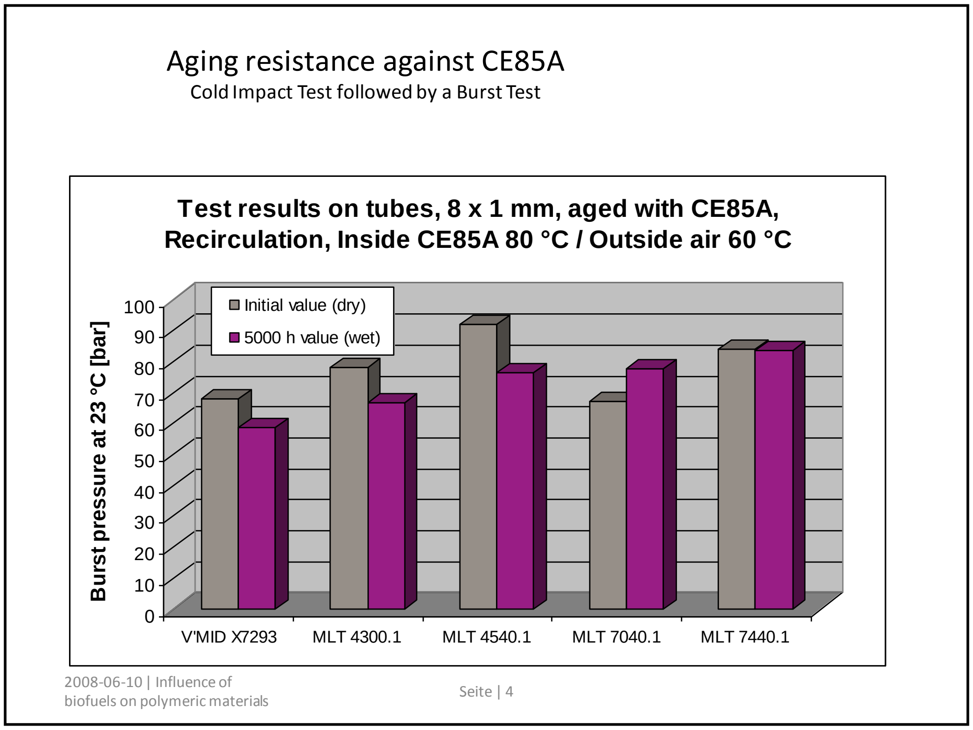


Figure 20: Multilayered Tubing Cold Impact/Burst Test Aging Resistance Against CE85A.

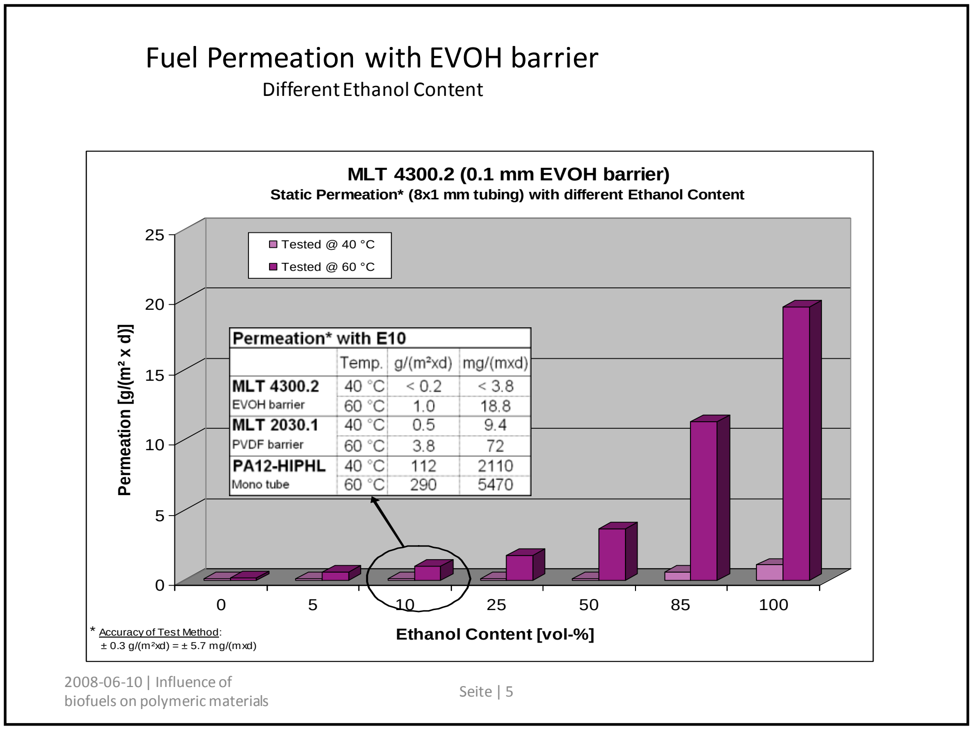


Figure 21: Multilayered Tubing Permeation vs. Ethanol Content.

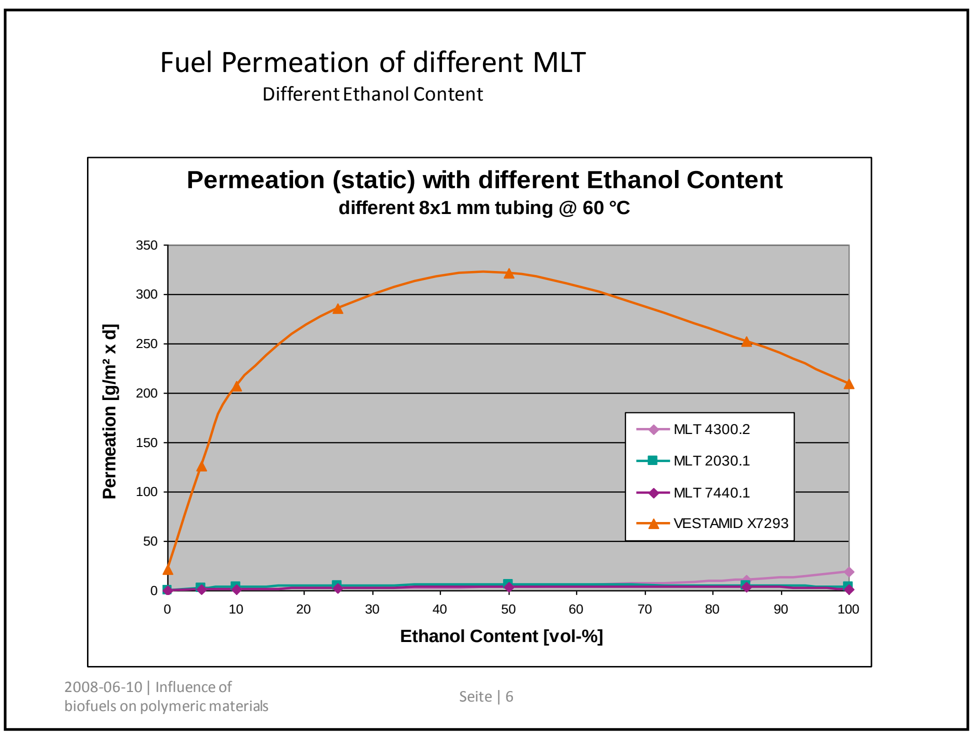


Figure 22: Multilayered Tubing Permeation vs. Ethanol Content.

Appendix B – Data Provided by Solvay Solexis

SOLVAY SOLEXIS

CHEMICAL RESISTANCE DATA OF SOLEF PVDF AND HALAR ECTFE TO ETHANOL

1. Solef PVDF

1.1. Immersion tests

Immersion tests have been performed in ethanol at 50 and 100% concentration and at temperatures of 50°C and 78°C (boiling point):

Concentration	Temperature	Immersion Time (days)		Δweight (%)
		Equilibrium	Measurement	
100 %	50 °C	50	60	+ 1.2
	78 °C (b.p.)	10	80	+ 1.8
50 %	50 °C	50	60	+ 0.5
	78 °C (b.p.)	20	60	+ 0.7

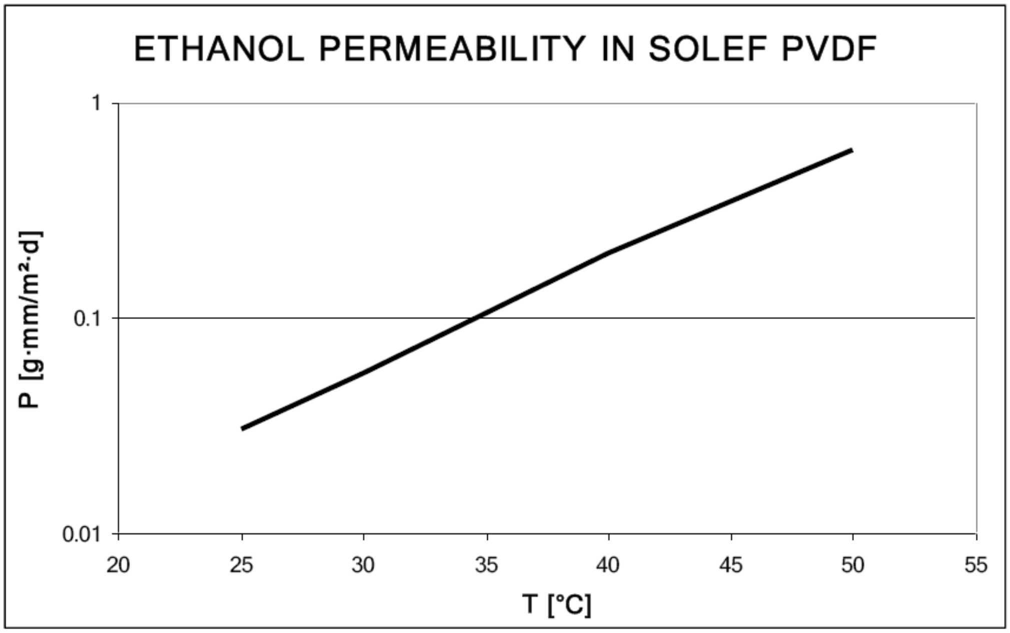
1.2. Bursting tests

We performed bursting tests and the data concerning the Solef PVDF internal pressure resistance measured on pipes filled with ethanol are listed in the following table:

Trial temperature	Conc.	Hoop stress σ max [MPa]	Time before rupture [h]	σ max H_2O without rupture [MPa]
50°C	100 %	23	6	23.5
		21	23	
		19	50	
		18	80 *	
		16	167 **	
		14	1053	
		12	16300 (stopped)	
		10	16300 (stopped)	
100°C	100 %	12	0.8	12.5
		10	6.6	
		9	8.7	
		8	29 *	
		7	16250 (stopped)	
		6	15300 (stopped)	

1.3. Permeation tests

Permeability to ethanol of Solef homopolymer was measured as a function of temperature:



2. Halar ECTFE

2.1. Immersion tests

Immersion tests were performed in ethanol on 0.3 mm thick compression moulded Halar samples:

Conc.	Temperature	Duration	Weight change	Modulus change	Yield stress change	Stress at break change	Strain at break change	Colour change
100 %	50 °C	28 days	+ 0.3 %			I	I	None
	100 °C	30 days	+ 0.8 %			I	I	None
	120 °C	30 days	+ 0.8 %	I	I	I	I	None
	140 °C	30 days	+ 1.6 %			I	I	None

Property change code: I: insignificant; A: property altered by 25-50%; B: property altered by 50-75%; C: property altered by more than 75%.

Appendix C – Data provided by NOV Fiber Glass Systems

Lined Aromatic Amine Cured Epoxy Pipe Testing per ASTM D 2992-96 Procedure B @ 200°F

Physical Data

Table I

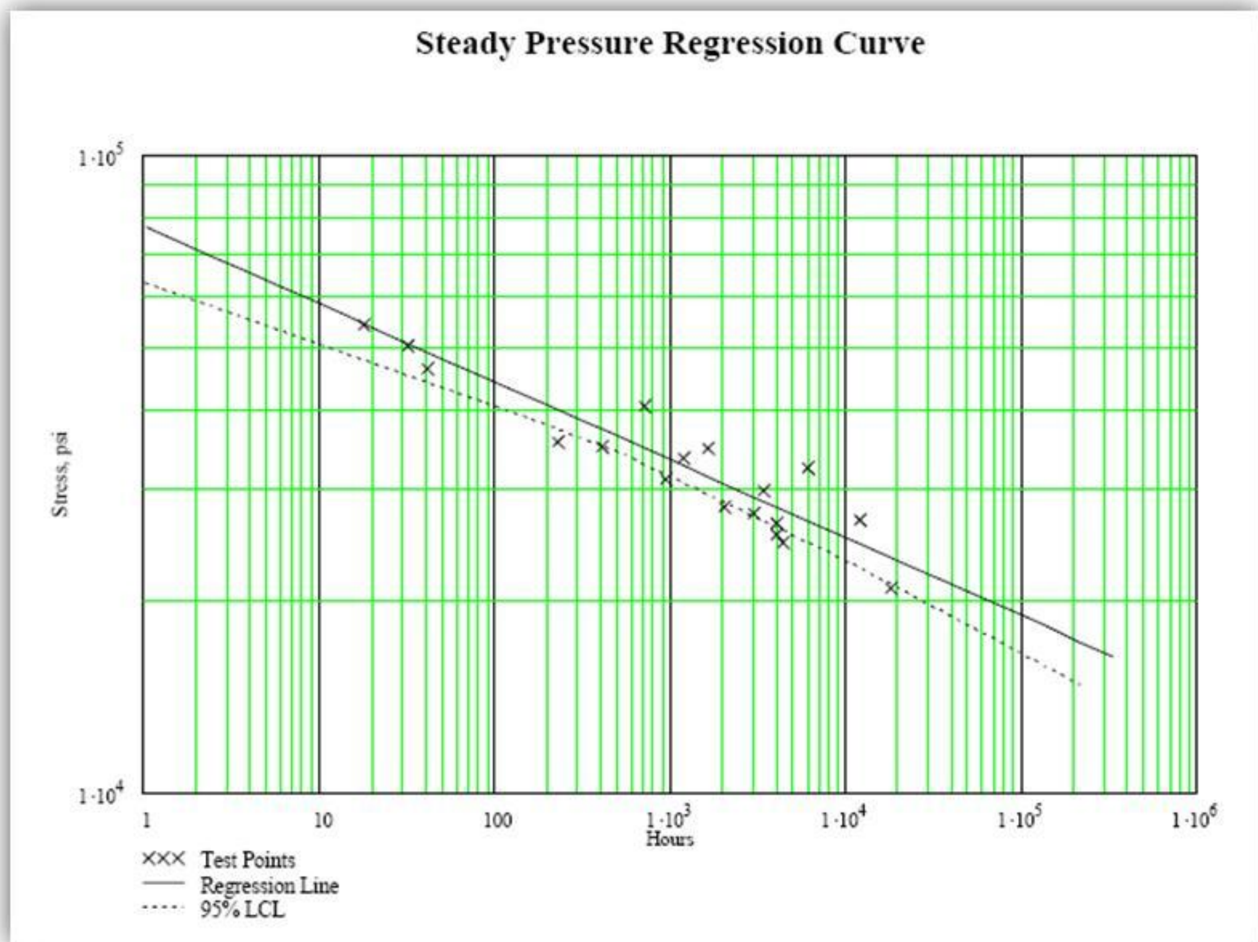
Date Test Initiated	Pipe Number	Avg. OD, in	Min Rein Wall, in	Liner, in	Tg, °C
12-11-01	2881-42	4.526	0.070	0.034	176
12-11-01	2881-37	4.532	0.071	0.039	168
12-11-01	2891-4	4.528	0.082	0.024	157
8-17-00	2170-1-1	4.518	0.069	0.029	135
7-15-00	0840-100-2	4.532	0.083	0.027	157
10-25-99	2749-12	4.528	0.077	0.027	154
7-15-00	0840-100-3	4.532	0.079	0.026	153
11-11-99	2749-31	4.535	0.080	0.031	154
8-17-00	2170-1-2	4.519	0.074	0.028	134
8-1-01	2170-1-3	4.516	0.073	0.027	126
8-17-00	2850-1-3	4.503	0.071	0.026	154
8-1-01	2840-3-2	4.512	0.060	0.028	109
4-5-00	3109-58-5B-A4	4.539	0.076	0.029	166
4-5-00	3109-58-5A5	4.544	0.088	0.020	154
7-15-00	0840-100-4	4.528	0.081	0.025	156
11-15-99	2749-30	4.546	0.083	0.030	156
4-5-00	3109-58-5-A3	4.540	0.067	0.028	160
1-13-00	3109-54-6A	4.540	0.067	0.029	161

Specimen Performance and Failure Mode

Table II

Specimen Identification	Internal Pressure psig	Hoop Stress[1] psi	Specimen Life hours	Failure Mode Description
2881-42	1,700	54109	18	Pipe Wall Weep
2881-37	1,600	50265	32	Pipe Wall Weep
2891-4	1,700	46087	41	Pipe Wall Spray
2170-1-1	1,100	35463	228	Pipe Wall Weep
0840-100-2	1,300	34842	407	Pipe Wall Burst
2749-12	1,400	40464	706	Pipe Wall Burst
0840-100-3	1,100	31002	939	Pipe Wall Weep
2749-31	1,200	33413	1,176	Pipe Wall Weep
2170-1-2	1,150	34539	1,648	Pipe Wall Burst
2850-1-3	900	27388	2,997	Pipe Wall Spray
2170-1-3	900	28090	2,021	Pipe Wall Weep
2840-3-2	800	29680	3,367	Pipe Wall Spray
3109-58-5B-A4	900	26426	4,011	Pipe Wall Weep
3109-58-5A5	1,000	25318	4,052	Pipe Wall Weep
0840-100-4	900	24706	4,348	Pipe Wall Spray
2749-30	1,200	32263	6,040	Pipe Wall Weep
3109-58-5-A3	800	26704	12,001	Pipe Wall Weep
3109-54-6A	625	20863	17,952	Pipe Wall Spray

1 Based on minimum reinforced wall thickness



Linear Regression Analysis per ASTM D2992 Procedure B
Curve gradient = -0.127571
Curve Y-intercept = 4.89796
Test Start Date: October 25, 1999
Test Completion Date: December 11, 2001

Case History of use in Fuel Applications

Fuel Research Center

Application: Blend and transfer of future fuels from the blending facility to test cars

Product: 2" and 3" Red Thread® pipe secondarily contained inside 3" and 4" pipe

Features & Benefits: In 1974, a major oil company began testing for future fuels. The product they chose to blend and transfer these fuels from the blending facility to their test cars was Red Thread® pipe and fittings. The compatibility of Red Thread pipe with aggressive future fuels used in testing made this pipe the product of choice.

In 2008, after 34 years in service, the pipe was removed and the major oil company sent much more aggressive future fuels to NOV Fiber Glass Systems for testing. These fuels were proven to be compatible with our piping, thus Red Thread was chosen to re-pipe the testing facility.

The thermosetting properties of the pipe won't soften or creep at the maximum operating temperature of 150°F and does not become brittle at temperatures as low as -40°F. The pipe is designed to meet the guidelines issued by the Environmental Protection Agency. In addition, the product has a 30-year warranty with over 40 years proven performance in the marketplace and is UL971 listed.

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Alathon

L4904

High Density Polyethylene
Pipe and Sheet Extrusion Grade
High Load Melt Index **7.0** Density **0.949**

Applications

Alathon L4904 is a bimodal, high molecular weight, high density polyethylene resin with excellent processability characteristics that meet the high performance requirements of demanding pressure pipe applications including gas distribution, industrial piping, gas gathering, municipal water service lines and sewers. L4904 is designed specifically to provide superb resistance to pipe failure by rapid crack propagation and slow crack growth mechanisms. When L4904 is compounded with an Equistar approved black at the correct loading (see page 2) this formula meets the following standards.

- Plastics Pipe Institute (PPI) PE 4710.
- PE 100 per PPI TR-4.
- ASTM D 3350 Cell Classification **445574C** and **445576C**.
- Chemical Resistance per ASTM D 2513 (see page 2)
- NSF Standard 14 and Standard 61 for Potable Water Pipe and Fittings.

Processing Techniques

Specific recommendations for processing L4904 can only be made when the processing conditions, equipment and end use are known. For further suggestions, please contact your Equistar sales representative.

Conformance

Test[1]	Nominal Value	Units	Test Method
Hydrostatic Design Basis, 73 °F (23 °C)	1,600	psi	ASTM D 2837
Hydrostatic Design Basis, 140 °F (60 °C)	1,000	psi	ASTM D 2837
Minimum Required Strength, 68 °F (20 °C)	10	MPa	ISO 12162
Creep Rupture Strength, 20 °C, 12.4 MPa	>200	hours	ASTM D 1598
Resistance to Rapid Crack Propagation, P_c @32 °F [2]	>10	bar	ISO 13477
Resistance to Rapid Crack Propagation, T_c @ 5 bar [2]	<20	°F	ISO 13477
Notched Pipe Test, 80 °C, 4.6 MPa [2]	>2,500	hours	ISO 13479

Typical Properties

Property [3]	Nominal Value	Units	Test Method
High Load Melt Index	7.0	g/10 min	ASTM D 1238
Melt Index	0.04	g/10 min	ASTM D 1238
Density	0.949	g/cc	ASTM D 1505
DSC Induction Temperature	250	°C	ASTM D 3350
2% Secant Modulus	146,000	psi	ASTM D 790
Tensile Stress @ Yield	3,500	psi	ASTM D 638
Tensile Stress @ Break	5,100	psi	ASTM D 638
Elongation @ Break	800	%	ASTM D 638
Brittleness Temperature	<-76	°C	ASTM D 746
PENT at 2.4 MPa and 80 °C	>2,000	hours	ASTM F 1473

[1] Values were obtained from L4904 compounded with an approved black masterbatch.
[2] Pipe Diameter of 4" and SDR 11
[3] Values were determined on natural resin.

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Alathon

L4904

High Density Polyethylene
Pressure Pipe Extrusion Grade
High Load Melt Index 7.0 Density 0.949

Approved Masterbatches

The following masterbatches are approved for use with *Alathon* L4904:

Manufacturer	Masterbatch Code
Ampacet	190872
Ampacet	190872A
Modern Dispersions	PE 535-42
PolyOne	2107 Black PEC
PolyOne	2107M
PolyOne	2107M-PPA
Spartech	B60054 or B60054C

Formulation

Alathon L4904 is a natural color high density polyethylene resin designed for pressure pipe applications. When L4904 is combined with an approved black concentrate and processed into a pipe, L4904 Black conforms to:

- ASTM D 3350 Cell Classification PE445574C and PE445576C
- Plastic Pipe Institute (PPI) PE 4710 at 1,600 psi HDB at 23 °C and 1,000 psi HDB at 60 °C
- Plastic Pipe Institute (PPI) PE100 at 10 MPa at 20 °C
- NSF Standard 14 and Standard 61 for potable water applications.

The L4904 Black formulary is limited to the following components and ratios:

- 100 lb L4904 Natural
- 7 lb Approved Black Masterbatch

This is approximately a 14.3:1 let-down ratio for the approved black. The above formulary yields an approximate concentration of carbon black in the final part of 2.27 wt%.

Chemical Resistance

Chemical resistance was conducted in accordance with ASTM D 2513-01a, Section 5.4 on L4904 Black. Results can be found in the table below.

	Weight Change		Change in Tensile Strength	
Reagent	% Change	Requirements	% Change	Requirements
100% Mineral Oil	0.05	0.5% max.	-5.00	± 12% max.
5% t-Butyl Mercaptan in Mineral Oil	0.04	0.5% max.	-4.91	± 12% max.
100% Ethylene Glycol	0.01	0.5% max.	-2.54	± 12% max.
15% Toluene in Methanol	0.01	1.0% max.	-1.94	± 12% max.

Equistar Chemicals, LP
1221 McKinney, Suite 700
P.O. Box 2583
Houston, Texas 77252-2583
800.615.8999
www.lyondellbasell.com

Pure Ethyl Alcohol 190 Proof

LYONDELL CHEMICAL - EQUISTAR CHEMICALS

ALCOHOL PRODUCT SPECIFICATIONS

PRODUCT ETHYL ALCOHOL 190 PROOF PURE USP

PRODUCT CODE 503004 & 503009 - BULK
508924 & 508928 - DRUM **MSDS 1100, 1105 & 1110**

FORMULATION	Wt %
Ethyl Alcohol, as 200 Proof	92.42
Water	7.58

SPECIFICATIONS	Target	Range Min.	Range Max.	Test Method
Specific Gravity: @ 60/60° F	0.8158	0.8156	0.8160	STM 101
@ 20/20° C	0.8126	0.8124	0.8128	
@ 25/25° C	0.8092	0.8090	0.8094	
Identification A	Pass	Pass		USP
Identification B	Pass	Pass		USP
Acidity			0.9ml of .02N	USP
Non Volatile Residue			1mg / 40ml	USP
Water Insoluble Substances	Pass	Pass		USP
Aldehydes and Foreign Organics	>5 Minutes	5 Minutes		USP
Amyl Alcohol & Carbonizables Sub.	Pass	Pass		USP
Acetone and Isopropyl Alcohol	Pass	Pass		USP
Methanol	Pass	Pass		USP

PROPERTIES	TYPICAL VALUE
Coefficient of Expansion: per 1° C	0.0006
Density @ 60° F	0.8150
Flash Point: Tag Closed Cup, ° F (ASTM D-56)	62
Refractive Index: nD @ 25° C	1.3619
Water Solubility: ml. water per 100 ml.	Infinite

Shelf Life - Retest after 1 year

Storage Conditions - Drummed material should be stored under ambient conditions out of direct sunlight

Ethyl Alcohol SDA 2B-3 200 Proof (Toluol)

EQUISTAR CHEMICLALS

ALCOHOL PRODUCT SPECIFICATION

PRODUCT SDA 2B-3 200 PROOF

PRODUCT CODE 503089 - BULK **MSDS** **140303** Toluol

FORMULATION							Wt %
190° Ethyl Alcohol		100.0	Gallons		679.434	Pounds	
Toluene		0.5	Gallons		3.626	Pounds	0.53

			Total	LB per GL
RESULTANT VOLUME @ 60° F	100.49	Gallons	683.060	6.797

SPECIFICATIONS	Target		Range Min.	Range Max.		Test Method
Specific Gravity: @ 60/60° F	0.7941		0.7934	0.7947		STM 101
@ 68/68° F	0.791		0.7905	0.7914		STM 101
Apparent Proof	199.8		199.5	200		STM 101
Color: Pt-Co	<5			10		STM167
Odor	Typical					STM 172
Toluene	0.5		0.45	0.55		SOP 2-1.1& SOP 5-2.1

PROPERTIES	TYPICAL VALUE
Acidity: wt / wt% as Acetic	0.0010
Coefficient of Expansion: per 1° C	0.00104
Density @ 60° F	0.8153
Flash Point: Tag Closed Cup, ° F (ASTM D-56)	61
Non-Volatile Matter: grams / 100 ml	0.0003
Refractive Index: nD @ 25° C	1.36267
Water wt%	< 0.10
Water Solubility: ml. Water per 100 ml. Product	Infinite

Shelf Life - Retest after 1 year

Storage Conditions - Drummed material should be stored under ambient conditions out of direct sunlight

Ethyl Alcohol SDA 3A-200 Proof (Toluol)

EQUISTAR CHEMICALS

ALCOHOL PRODUCT SPECIFICATION

PRODUCT SDA 3A 200 PROOF

PRODUCT CODE 503091 - BULK **MSDS 140400**
509012 - DRUM

FORMULATION Wt %

200° Ethyl Alcohol		100.0 Gallons		660.97 Pounds	95.22
Methanol		5.0 Gallons		33.15 Pounds	4.78
Total				694.12 Pounds	

RESULTANT VOLUME @ 60° F 104.99 Gallons

SPECIFICATIONS	Target		Range Min.	Range Max.		Test Method
Specific Gravity: @ 60/60° F	0.7938		0.7934	0.7944		STM 101
@ 68/68° F	0.7907		0.7902	0.7912		STM101
@ 77/77° F	0.7873		0.7869	0.7879		STM 101
Apparent Proof	199.9		199.7	200.1		STM 101
Color: Pt-Co	<5			10		STM 167
Odor	Typical		Pass			STM 172
Methanol wt%	4.78		4.30	5.26		SOP 2-1.1 & 5-2.1
Water wt%				0.1		STM155a

PROPERTIES	TYPICAL VALUE
Acidity: wt / wt% as Acetic	0.0013
Coefficient of Expansion: per 1° C	0.0011
Density @ 60° F	0.7930
Flash Point: Tag Closed Cup, ° F (ASTM D-56)	55
Non-Volatile Matter: grams / 100 ml	0.0007
Refractive Index: nD @ 25° C	1.35839
Water Solubility: ml. water per 100 ml.product	Infinite

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