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Final Report

on

Development of a Research Roadmap Related to Safe and Reliable Transportation of Ethanol in Pipelines and Storage

Milestone 2 – Roadmap

Contract PR-313-084503

Prepared for

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EXECUTIVE SUMMARY

The planned wide-spread use of ethanol as an additive to gasoline or as a supplementary fuel will require an efficient and reliable transportation and storage system that includes the existing infrastructure and new construction. Ethanol is currently being transported by a batch process involving railcars, tanker trucks, barges, and ships. However, in order to economically transport ethanol-containing fuels from producers to users on a large scale, safe and reliable transportation by pipeline is necessary. Industry experience, which has shown that stress-corrosion cracking (SCC) can occur in carbon steel exposed to fuel-grade ethanol (FGE), has led to a realization that a research program is needed to identify the specific conditions that can lead to SCC and how to avoid SCC in pipelines and storage facilities that contain ethanol or ethanol/gasoline mixtures.

The first step in the development of a research roadmap for the safe and reliable transportation of fuel-grade ethanol by pipeline was a workshop in Dublin, Ohio on October 25 and 26, 2007. That workshop identified a large number of knowledge gaps related to the subject.

The first phase of this project built upon the results of that workshop. As described in an interim report [see Attachment 1], the needs that were identified at the workshop were condensed into 15 items (Fessler, May, 2008). For those items that required research, a list of research topics was constructed and compared with past and on-going projects. Topics that were not covered in past or on-going projects were then analyzed to determine which ones could profitably be started in the near future. From that list, six projects are recommended for consideration.

In addition, it was recommended that API or some other suitable industry organization establish committees to prepare 1) a recommended practice for transporting ethanol by pipeline and 2) guidelines for integrity management of pipelines for transporting ethanol.

In this second phase of this project, which is the subject of this report, all of the research projects that were identified in the first phase were assembled into a coherent plan that addressed scheduling and resource requirements. For each project, rough estimates were made for the amount of effort (time and cost) that might be needed to complete those projects. Those estimates were not intended to be precise but merely to indicate rough order-of-magnitude numbers to be used for planning. More meaningful numbers should be based upon detailed work statements and obtained from the research organizations that propose conducting the research. Consideration also was given to interdependencies among the projects – which could be conducted simultaneously and which depended on the results of other projects – and to the relative importance or urgency of each project.

Based upon that analysis, a Gantt chart was prepared to illustrate a possible schedule for conducting the projects. A corresponding spend plan was prepared for the 27

new projects that were identified. The total estimated budget is about $4 million, of which about half is designated as high priority

For coordinating the research, which will be funded by several organizations and conducted by several more, a committee was recommended to have representatives from the pipeline industry (including the committee chair to be designated by AOPL), the Renewable Fuels Association, and the funding agencies (currently PHMSA, PRCI, and API), plus someone with a historical technical perspective of SCC in pipelines.

TABLE OF CONTENTS

INTRODUCTION

The planned wide-spread use of ethanol as an additive to gasoline or as a supplementary fuel will require an efficient and reliable transportation and storage system that includes the existing infrastructure and new construction. Ethanol is currently being transported by a batch process involving railcars, tanker trucks, barges, and ships. However, in order to economically transport ethanol-containing fuels from producers to users on a large scale, safe and reliable transportation by pipeline is necessary. Industry experience has shown that stress-corrosion cracking (SCC) can occur in carbon steel exposed to fuel-grade ethanol (FGE), and several research programs have been initiated to identify the specific conditions that can lead to SCC and how to avoid SCC in pipelines and storage facilities that contain ethanol or ethanol/gasoline mixtures.

In an effort to provide guidance to those and future research programs, a Road Mapping meeting was held in Dublin, Ohio on October 25 and 26, 2007. Participants included representatives from the pipeline and petroleum industries, research organizations, the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA), the Association of Oil Pipelines (AOPL), American Petroleum Institute (API), Renewable Fuels Association (RFA), and Pipeline Research Council International (PRCI). The primary output from the meeting was a detailed list of knowledge gaps that need to be filled and actions that need to be taken to assure safe and reliable transportation of ethanol-containing fuels by pipeline.

As a second step toward the development of a research road map, this project was initiated to develop a plan for research that will meet the needs of industry and government by addressing the critical issues in a logical sequence without duplication unless replication can provide greater phenomenological understandings or increased confidence in the use of key results in the field. This project builds on the results of the workshop that was held in October 2007 where gaps in knowledge were identified and prioritized.

The primary focus of this road-mapping project is on the technical challenges related to shipping ethanol in pipelines, including ways to prevent internal SCC in current and future pipeline systems containing FGE. Internal SCC is considered to be the primary threat to the integrity and life of such systems. Consideration also is given to quality assurance and how potential solutions to the SCC problem may affect internal corrosion, polymeric materials such as seals and gaskets, and compatibility with automotive use. Additionally, other technical issues are explored; however, issues related to the business case for transporting FGE such as market demand and price projections are beyond the scope of this project.

The deliverables from this project consist of the following:

<u>Milestone 1</u>

Identification of outstanding gaps - A preliminary report suggesting research topics that should be pursued in the near future and containing

1. An organization of the workshop results, grouping projects that are related to various potential solutions, removing overlaps, and identifying critical paths.
2. Identification of which issues from the workshop have been, or will be, addressed in past, current, or planned projects.
3. Identification of any overlaps or duplications among those projects.

Milestone 2

A final report presenting a comprehensive research plan that
1. Identifies topics that can be investigated in parallel and those that cannot because they depend on completion of others.
2. Identifies and prioritizes topics that warrant development of new research programs along with estimates of the investments required for each.
3. Suggests a structure and process for coordinating the various research efforts that are and will be conducted for various sponsors.

This report is the second deliverable and satisfies Milestone 2.

SUMMARY OF RESULTS FROM MILESTONE 1

To complete Milestone 1, the following tasks were carried out:
1. Reviewed the results of the October workshop and grouped the issues according to possible approaches to solving the problem (e.g., chemical, electrochemical, metallurgical, design, operational, etc.) for existing and future pipeline systems, identifying interdependencies among the topics.
2. Reviewed reports of relevant past research to determine how much already is known about each issue.
3. Reviewed work plans for ongoing and planned projects to determine how much additional knowledge can be expected from them.
4. Reviewed completed research that identifies E10 as transportable in pipelines without the development of SCC and provided an independent view of the findings.
5. Met with key stakeholders including principal investigators of some of the more important projects to gain insights beyond those obtainable from written reports.
6. Prepared a preliminary report in the form of a gap analysis, with recommendations for research topics that should be considered in the near future.

Condensing the needs that were identified at the workshop resulted in the following 15 items:
1. A standard (or recommended practice) for safe and reliable transport of ethanol by pipelines
2. A standard for safe and reliable storage of ethanol
3. A phenomenological understanding of the factors that cause ethanol SCC
4. Guidelines for risk assessment
5. Guidelines for fire/spill emergency response

6. A “Fingerprint” test for identifying the severity of a specific ethanol batch towards SCC of carbon steel
7. A decision-making tool for specific pipelines
8. An ethanol (biofuels) handbook
9. Tools to predict residual stresses (this is not ethanol specific)
10. A committee in API or other organization to coordinate research and tech transfer
11. A workforce training program
12. Public communication
13. A government/industry position paper on ethanol infrastructure
14. A catalogue of ongoing and completed research
15. A business case (or enterprise risk assessment) for new pipeline construction dedicated to ethanol or other biofuel transportation.

For those items that require research, a list of research topics was constructed and compared with past and on-going projects. Topics that were not covered in past or on-going projects were then analyzed to determine which ones could profitably be started in the near future. From that list, the following projects were recommended for consideration:

- Safety of Transporting Blends Containing More than 10 Percent Ethanol
- Standardized Tests for SCC in Ethanol
- Technical and Economic Feasibility of Preventing SCC Through Control of Oxygen
- Feasibility of Preventing SCC by Using Inhibitors
- Compatibility of Polymeric Materials and Non-ferrous Metals with Ethanol
- Understanding of Ethanol SCC.

In addition, it was recommended that API or some other suitable industry organization establish committees to prepare 1) a recommended practice for transporting ethanol by pipeline and 2) guidelines for integrity management of pipelines for transporting ethanol.

The complete Milestone 1 report is included as Attachment 1 to this report

APPROACH FOR MILESTONE 2

A list of research projects was created to address each of the gaps associated with each of the needs that were identified in Milestone 1. For each project, rough estimates were made for the amount of effort (time and cost) that might be needed to complete those projects. Those estimates were not intended to be precise but merely to indicate rough order-of-magnitude numbers to be used for planning. More meaningful numbers should be based upon detailed work statements and obtained from the research organizations that propose doing the research. The time and cost estimates also will be expected to change as new research results become available. Consideration also was given to interdependencies among the projects – which could be conducted simultaneously and which depended on the results of other projects – and to the relative importance or urgency of each project.

Based upon that analysis, the Gantt chart in Appendix A was prepared to illustrate a possible schedule for conducting the projects. In order to provide a complete picture of the research path, Appendix A lists the past completed projects and the on-going projects in addition to the suggested future projects. A corresponding spend plan is presented in Appendix B, where some of the projects that are considered to be of higher priority are indicated by bold print.

The following section discusses the research that may be needed to fill the knowledge gaps related to each expressed need.

RESEARCH RELATED TO EACH NEED

Standard (or Recommended Practice) for Safe and Reliable Transport of Ethanol by Pipeline

Many of the expressed needs would logically be elements in a standard (or recommended practice) for safe and reliable transport of ethanol by pipeline. Principal among those elements are the following:

- How to avoid SCC
  - Acceptable ethanol compositions
  - Materials of construction
  - Operating practices
  - Integrity assessment methods
  - Leak detection
  - Maintenance
- How to avoid pitting/general corrosion
- How to avoid deterioration of polymeric seals and gaskets
- How to maintain product quality and compatibility with automotive requirements

The most critical threat to deal with is SCC, but other possible deterioration mechanisms should not be ignored. Issues related to chemistry and electrochemistry probably are most important for integrity management and include control of oxygen content, specifying ethanol composition, use of inhibitors, and possibly control of potential. Less promising approaches are selection of resistant steel, surface treatments, and control of residual stresses.

A survey of industry experience (Project 1.1)[1] identified approximately a dozen incidences of failures produced by SCC of carbon steel in fuel grade ethanol over the past 10 years along with several more possible but unconfirmed cases (American Petroleum

[1] Project numbers refer to the lists in Appendix A and Appendix B.

Institute, 2007). The failures occurred in user terminals, storage tanks, and loading/unloading racks for fuel-grade ethanol (FGE) and involved plate steels and roof springs used in tanks, along with associated piping and vessels. There was no obvious correlation with ethanol source or process conditions. Some oxygen contamination was highly probable under all conditions, and a possible role of mill scale was suggested.

Early laboratory studies (Project 1.5) showed that SCC could be produced readily in four different carbon steels using a slow-strain-rate (SSR) test with an aerated solution containing 1% water, 4% gasoline, 0.5% methanol, and 40ppm chlorides (Brongers, 2005). The cracking rates were different in the four steels, but they did not correlated with steel composition or properties. SCC was not produced with constant-load tests at stresses between 60% and 120% of the actual yield strength.

With respect to the effects of impurities in the ethanol, other studies (Project 1.11) showed that oxygen was most important, but chlorides and methanol had some effect (Sridhar, 2006). A correlation with corrosion potential also was noted, and contact with rusty steel tended to move the potential into the range for SCC.

With SSR tests, SCC has been observed for E20 through E95, but not for E10. Especially in view of the severe nature of the SSR test as compared with service conditions, this is compelling evidence that transportation of E10 by pipeline should not pose a threat of SCC. However, from an economic standpoint, it may be desirable to transport richer blends than E10. There is most interest in E20, E30, and E95. If E95 is transported between batches of gasoline, the transmix will contain all compositions including those between E30 and E95. Although the SSR tests show that SCC is possible in blends between E20 and E95, the SSR test imposes stress and strain conditions that are much more severe than those experienced by an operating pipeline, and it is not known whether SCC would occur in those richer blends under normal operating conditions.

In an exploratory study of possible preventive measures (Project 1.6), it was found that deaeration by several methods prevented SCC, even in the severe SSR tests (Beavers, 2008). Of a number of corrosion inhibitors that were investigated, di-ethanol amine (DEA) greatly reduced the severity of SCC, but other corrosion inhibitors did not. Hydrazine, an oxygen scavenger, prevented SCC but is not considered to be a practical addition to automotive fuel.

Several funded projects that are ongoing or about to start are expected to clarify the factors that have contributed to the past SCC failures and thus suggest ways to manage the problem.

- Project 1.8, Effect of Ethanol Source on SCC of Carbon Steel – a new PHMSA-funded project at CC Technologies will characterize critical differences in ethanol from different sources and develop fingerprints.
- PRCI SCC-4-4, Determine the Requirements for Existing Pipeline, Tank and Terminal Systems to Transport Ethanol Without Cracking (Project 1.9). CCTechnologies will use SSRTs to look at various levels of

gasoline and will measure crack growth rates in static and cyclic-load tests.

- Project 1.10, Effect of Ethanol Blends and Batching on SCC of Carbon Steels -- another new PHMSA-funded project at CC Technologies will supplement the efforts in Project 1.9.

Current projects focusing on possible ways to manage the problem include the following:

- PRCI SCC-4-3, Identify Environmental and Stress Factors that Produce SCC in Existing Ethanol Pipelines and Terminals (Project 1.7). CCTechnologies will use SSRTs in a flow loop to evaluate inhibitors, oxygen scavengers, and deaeration.
- Project 1.18, an internal DNV project to develop probes to measure corrosion potential and oxygen content.
- Project 1.19, Monitoring of Conditions Leading to SCC/Corrosion – a new PHMSA-funded project at CC Technologies that will build upon Project 1.18.

Projects that may be required to answer remaining questions about the safe and reliable transport of ethanol by pipeline include the following:

- Project 1.2, Develop Lab Tests Relatable to Service Conditions
    - Rationale: As explained in the Milestone 1 report, current tests such as the SSR test impose conditions that are much more severe than those that exist on an operating pipeline and therefore might give misleading results. There is an urgent need for tests for which the results can be directly related to pipeline conditions.
    - Estimated funding: $300K
    - Estimated duration: 2 years
    - Timing: ASAP, probably 2009

- Project 1.3, Develop Rapid Field Test for Quality Assurance
    - Rationale: As explained in the Milestone 1 report, there are no current tests for monitoring the environment in an ethanol pipeline to make sure that it is not capable of causing SCC under the prevailing operating conditions. Having such a test would be a very useful way to manage the problem. Developing such a test might be in conjunction with, or part of, Project 1.2.
    - Estimated funding: $150K
    - Estimated duration: 2 years
    - Timing: ASAP, probably 2009

- Project 1.12, Feasibility of Preventing SCC by Using Inhibitors
    - Rationale: As explained in the Milestone 1 report, a number of inhibitors have been used to mitigate general corrosion and pitting corrosion of steel exposed to FGE, but, at 1000 ppm, they have

not been able to prevent SCC in SSR tests. However, other chemicals – hydrazine and DEA, in particular – have been successful at either preventing SCC or substantially reducing the severity. It is not known whether higher concentrations of the corrosion inhibitors would have been successful or if they would be successful in the less aggressive scenario of realistic pipeline operation.
    - Estimated funding: $150K
    - Estimated duration: 2 years
    - Timing: ASAP, probably 2009

- Project 1.13, Technical and Economic Feasibility of Preventing SCC Through Control of Oxygen
    - Rationale: Even with the severe SSR test, SCC has never been produced in the laboratory if oxygen has been eliminated from the system. In principle, it might be possible to keep oxygen from ever getting into the ethanol during manufacture and transport, and there are several possible ways (sparging with nitrogen, vacuum treatment, reacting with steel wool, adding an oxygen scavenger, etc.) to remove oxygen before the ethanol is put into the pipeline. An engineering study is needed to determine which, if any, of those approaches would be economically feasible and under what conditions.
    - Estimated funding: $150K
    - Estimated duration: 2 years
    - Timing: ASAP, probably 2009

- Project 1.14, Test Modern, Low-Carbon Steels to Determine if They are Less Susceptible to Ethanol SCC
    - Rationale: To date, the lab cracking tests have been conducted with vintage steels that are typical of those in service where SCC failures have occurred. Those steels have relatively high carbon contents compared with modern low-carbon steels. There is a small amount of circumstantial evidence that these low-carbon steels might be more resistant to ethanol SCC, but there is not enough data to be sure. If they are more resistant, future facilities might be constructed with them.
    - Estimated funding: $200K
    - Estimated duration: 2 years
    - Timing: Could be started any time -- suggest 2009

- Project 1.15, Determine Compatibility of Aluminum, Brass, and Any Other Non-Ferrous Metals That Might be Used in Ethanol Pipelines
    - Rationale: Aluminum, brass, and possibly other non-ferrous metals are used in many systems that could be considered for

transporting or storing ethanol. It will be important to be sure that corrosion of those metals will not be a problem.
  - Estimated funding: $100K
  - Estimated duration: 2 years
  - Timing: Could be started any time -- suggest 2009

- Project 1.16, Evaluate Effectiveness of Internal Coatings at Preventing Ethanol SCC and Effect of Ethanol on Internal Coatings
  - Rationale: Although it probably is not feasible to protect an entire pipeline with an internal coating, coatings might be considered for some storage and handling facilities. Research is needed to determine what kinds of coatings are compatible with ethanol and whether it is feasible to produce an internal coating with sufficient integrity to be reliable.
  - Estimated funding: $150K
  - Estimated duration: 2 years
  - Timing: Could be started any time but less urgent than many other projects -- suggest 2011

- Project 1.17, Evaluate the Effect of Pressure on Ethanol SCC
  - Rationale: Documented ethanol SCC failures to date have occurred in systems with relatively low internal pressures; the failures have been attributed to high residual stresses. Pipelines transporting ethanol probably will be operated at high internal pressure which will produce relatively high hoop stresses, even in the absence of residual stresses. It will be important to know if such hoop stresses will be high enough to produce internal SCC.
  - Estimated funding: $200K
  - Estimated duration: 2 years
  - Timing: Could be started any time but less urgent than many other projects -- suggest 2011

- Project 1.20, Fundamental Study to Determine How SCC Relates to Corrosion Potential, Polarization Curve, and Other Basic Electrochemical Parameters
  - Rationale: As explained in the Milestone 1 report, the research to date has made remarkable progress at pointing toward possible ways to manage the problem, but there are still many aspects of the phenomenon that are not understood. A more thorough understanding of the factors that cause ethanol SCC may suggest better ways to manage the problem. Additionally, they could provide a higher level of assurance that proposed solutions will, in fact, be successful in the long term.
  - Estimated funding: $275K
  - Estimated duration: 3 years
  - Timing: ASAP, 2008 if possible

- Project 1.21, Develop Guidelines for ILI for Internal SCC
    - Rationale: The ILI technologies that have been developed for external SCC probably will be readily adaptable to internal SCC, but interpretation of signals may be somewhat different.
    - Estimated funding: $150K
    - Estimated duration: 2 years
    - Timing: Could be started any time but less urgent than many other projects -- suggest 2011

- Project 1.22, Develop Method for Predicting Where Internal SCC is Most Likely
    - Rationale: Having a method to predict where internal SCC is most likely will be very important as a guide as to where preventive or mitigative measures should be applied. It also will be essential if direct assessment is chosen as the integrity-management approach.
    - Estimated funding: $150K
    - Estimated duration: 2 years
    - Timing: Depends on results of several current projects investigating the causes of internal SCC -- suggest 2011

- Project 1.23, Develop NDE Method to Detect and Measure Internal Cracks from the Outside
    - Rationale: If the presence of internal cracks is indicated by ILI or other means, it will be important to verify the indication and determine or validate the size.
    - Estimated funding: $200K
    - Estimated duration: 3 years
    - Timing: Could be started any time -- suggest 2009

- Project 1.24, Develop Method to Detect Ethanol Leaks
    - Rationale: Leak detection is an important part of an integrity management plan.
    - Estimated funding: $100K
    - Estimated duration: 2 years
    - Timing: Could be started any time but less urgent than many other projects -- suggest 2010

- Project 1.25, Repair Criteria and Methods for Ethanol SCC
    - Rationale: Although repair methods for internal SCC probably would be similar to those developed for external SCC, some might not be appropriate or feasible.
    - Estimated funding: $75K

- Estimated duration: 1 year
  Timing: Could be started any time but less urgent than many other projects -- suggest 2011

- Project 1.26, Develop Welding Guidelines for Avoiding Harmful Residual Stresses
  - Rationale: Many of the ethanol SCC occurrences have been associated with residual stresses from welding. Eliminating such high residual stresses may be important for preventing future failures.
  - Estimated funding: $150K
  - Estimated duration: 2 years
  - Timing: Could be started any time but less urgent than many other projects -- suggest 2012

- Project 1.27, Develop Guidelines for Avoiding Pitting or General Corrosion
  - Rationale: Although SCC is considered the major potential threat, pitting or general corrosion also is possible in ethanol and obviously should be avoided. It is especially important to be sure that whatever is done to prevent SCC will not exacerbate pitting corrosion.
  - Estimated funding: $200K
  - Estimated duration: 3 years
  - Timing: Probably should not be started until preventive measures for SCC have been determined -- suggest 2011

- Project 1.28, Evaluate Proposed SCC Solutions for Compatibility with Automotive Requirements
  - Rationale: It obviously is essential that whatever is done to prevent SCC does not make the product incompatible with automotive requirements
  - Estimated funding: $100K
  - Estimated duration: 2 years
  - Timing: Should not be started until preventive measures for SCC have been determined -- suggest 2012

Standard for Safe and Reliable Storage of Ethanol

Although anything that is done to prevent ethanol SCC in a pipeline also would be expected to be suitable for storage systems, there might be other options for storage systems since they are operated at much lower pressures. Therefore, the following project is recommended to consider this issue.

- Project 2.1, Determine Any Differences in Guidelines for Storage Versus Transportation of Ethanol

- Rationale: There might be less expensive options for storage only.
- Estimated funding: $100K
- Estimated duration: 2 years
- Timing: Should not be started until preventive measures for SCC have been determined -- suggest 2012

Phenomenological Understanding of the Factors that Cause Ethanol SCC

A thorough understanding of the causes of ethanol SCC will be important both for suggesting possible ways to manage the problem and for assuring that a proposed solution will be reliable under all operating scenarios. The electrochemical issues will be investigated in Project 1.20, to be started in 2008. That project should be supplemented with the following project to include stress and metallurgical factors.

- Project 3.1, Determine the Relationships Among Cracking Behavior and Environmental, Stress, and Metallurgical Factors
    - Rationale: SCC will occur under only limited conditions of environment, stress, and steel metallurgy.
    - Estimated funding: $275K
    - Estimated duration: 3 years
    - Timing: Should be added to Project 1.20, starting in 2009

Guidelines for Risk Assessment

Risk is defined as the probability that a failure will occur times the probable consequences of such a failure. Many of the previously mentioned projects will provide information to help determine probability of occurrence. Possible consequences include factors such as harm to humans, damage to nearby structures, loss of product, environmental damage, cost of repair, inconvenience to the customer, etc. and will have to be determined on a case-by-case basis. The following project is suggested to consolidate the information related to probability of occurrence and outline the considerations with respect to consequences.

- Project 4.1, Develop Guidelines for Risk Assessment
    - Rationale: An assessment of risk will be necessary to determine the types and urgency of mitigative or preventive actions to be taken.
    - Estimated funding: $100K
    - Estimated duration: 2 years
    - Timing: Should not be started until causes of ethanol SCC are well understood – suggest 2012

Guidelines for Fire/Spill Emergency Response

Companies that currently store or transport ethanol probably have guidelines for responding to fire or spill emergencies. A project such as the following to survey the industry, analyze the findings, and write an industry guideline would be useful.

- Project 5.1, Develop Guidelines for Fire/Spill Emergency Response
  - Rationale: Ethanol spills and fires have unique characteristics that may not be familiar to companies that previously transported only petroleum products.
  - Estimated funding: $50K
  - Estimated duration: 1 year
  - Timing: Could be started any time but less urgent than many other projects -- suggest 2010

“Fingerprint” Test for Ethanol

There is some evidence to suggest that certain batches of ethanol are much more likely to cause SCC than other batches, but the reasons are not yet known. A test to determine the source of ethanol and its propensity to cause SCC would be very useful. Development of such a test is included in Project 1.8. However, there is very little currently available information for designing such a test, and much more probably will be developed in several of the research projects to be conducted over the next few years. Therefore, a project late in the program may be useful for improving the test.

- Project 6.2, Refine Method to Characterize Critical Differences in Ethanol from Different Sources
  - Rationale: Future research projects are expected to develop information that might be the basis for a more reliable fingerprint test.
  - Estimated funding: $75K
  - Estimated duration: 1 year
  - Timing: Should not be started until causes of ethanol SCC are well understood – suggest 2012

Decision-Making Process for Specific Pipelines

On-going and future research into the causes of ethanol SCC should be helpful for making decisions about transporting ethanol by pipeline. The following project to organize such information with respect to decisions to be made could be useful.

- Project 7.1, Develop List of Issues to be Considered by a Company Regarding Transport of Ethanol
  - Rationale: Future research projects are expected to develop information that will be helpful to guide decisions.
  - Estimated funding: $50K
  - Estimated duration: 1 year
  - Timing: Should not be started until causes of ethanol SCC are well understood – suggest 2012

Ethanol (Biofuels) Handbook

A maual summarizing the practical implications of the research would be useful.

- Project 8.1, Write a Handbook on Transportation and Storage of Ethanol and Other Biofuels
    - Estimated funding: $150K
    - Estimated duration: 2 years
    - Timing: Should not be started until most of the research has been completed – suggest 2014

Tools to Predict Residual Stresses

Whether or not the structure is subjected to high internal pressures, residual stresses may be a significant factor in determining if SCC will occur. Although the scientific literature contains much material on this subject, a review of that material in terms of pipeline and tank structures could be useful.

- Project 9.1, Develop Tools to Predict Residual Stresses
    - Estimated funding: $225K
    - Estimated duration: 3 years
    - Timing: Could be started any time but less urgent than many other projects -- suggest 2010

Committee to Coordinate Tech Transfer

Typically, committees of this sort are made up of volunteers from various companies who do not require additional financial support. However, experience with such committees suggests that it may be useful to have a paid outside person to facilitate the efforts. Some funding for that purpose might be considered.

- Project 10.1, Support Participation of Technical Expert in Committee Activities
    - Estimated funding: $180K
    - Estimated duration: 6 years
    - Timing: 2009 through 2014

Workforce Training Program

Some organization or consultant might choose to develop a workforce training program at its own expense and then charge for presenting it. If not, the industry may decide to fund such a development. To account for that possibility, the following project is suggested.

- Project 11.1, Develop Workforce Training Program
    - Estimated funding: $60K

- Estimated duration: 2 years
- Timing: Should not be started until a significant amount of the research has been completed – suggest 2011

Possibility of Modifying or Combining Projects

The previous pages describe 27 new projects that would be required to meet the needs that were expressed in the October 2007 meeting. As time goes on, it may be decided that some of the projects should be undertaken by individual companies, some may no longer be needed, or new needs may arise. For ease of administration, it also would be possible to combine several projects into single projects. For example, Projects 1.21, 1.22, and 1.23, which relate to ILI, direct assessment, and measuring crack size, could be combined into a single project on assessment. Those three projects also could be combined with Project 1.25 on repair methods. Other combinations also are possible, but each topic has been kept separate in this document for clarity.

COORDINATING THE RESEARCH

It is anticipated that several organizations may decide to fund some of the projects. Currently PRCI, API, and PHMSA are doing so. In order to make sure that important issues are not being missed and to avoid unnecessary duplication of effort, a committee should be established to coordinate the activities. Such a committee also could provide advice on the research topics and approaches as well as provide suggestions for appropriate research organizations from which to solicit proposals. The committee should have members with the following affiliations or backgrounds:

- The pipeline industry. An organization such as the Association of Oil Pipelines (AOPL) could provide these members, one of which should chair the committee.
- The Renewable Fuels Association (RFA)
- The funding organizations – PHMSA, PRCI, API, and others as appropriate
- Someone with a historical technical perspective on SCC of pipelines.

Monthly teleconferences could be held to review research progress and to address planning issues as they arise. Key researchers would be invited to participate in these meetings and provide a brief update on their progress. Face-to face meetings could be held occasionally, either hosted by one of the committee members or at one of the labs that would have significant results or many items for discussion.

WORKS CITED

American Petroleum Institute (May 2007). R. D. Kane, D. Eden, N. Sridhar, J. Maldonado, M. P. Brongers, A. K. Agrawal, and J.A. Beavers, API Technical Report 939-D, *Stress Corrosion Cracking of Carbon Steel in Fuel-Grade Ethanol: Review, Experience Survey, Field Monitoring, and Laboratory Testing.* American Petroleum Institute, Washington, DC.

Beavers, J. A., M. P. Brongers, A. K. Agrawal, and F. A. Tallarida (2008). “Prevention of Internal SCC in Ethanol”, *CORROSION 08* (Paper 08153). New Orleans: NACE.

Brongers, M. P., J. A. Beavers, and A. K. Agrawal (2005). Final Report on GRI Project 8774, PRCI Catalogue No. L52229.

Fessler, R. R. (May 2008). *Development of a Research Roadmap Related to Safe and Reliable Transportation of Ethanol in Pipelines and Storage : Milestone 1 – Gap Analysis,* PRCI Catalogue No. L5XXXX.

Sridhar,N., K. Price, J. Buckingham, and J. Dante (2006). “Stress corrosion Cracking of Carbon Steels in Ethanol”, *Corrosion, Vol 62* , pp 687 – 702.

APPENDIX A. GANTT CHART FOR ETHANOL SCC ROADMAP

Deliverable	Project	Pre-2007	2007	2008	2009	2010	2011	2012	2013	2014	
1. Standard for Safe and Reliable Transport of Ethanol by Pipeline											
	1.1 API 939-D Part 2: Survey of Industry Experience										
	1.2 Develop Lab Tests Relatable to Service Conditions										
	1.3 Develop Rapid Field Test for Quality Assurance										
	1.4 PRCI SCC-4-5 Requirements for New Pipeline Systems										
	1.5 GRI-04/0128, SCC Avoidance in Ethanol Pipelines										
	1.6 PRCI SCC-4-1 Prevention of Internal SCC in Ethanol P/Ls										
	1.7 PRCI SCC-4-3 Identify Environmental and Stress Factors that Produce SCC in Existing Ethanol Pipelines and Terminals										
	1.8 PHMSA new start: Effect of Ethanol Source on SCC of Carbon Steel										
	1.9 PRCI SCC-4-4. Determine the Requirements for Existing Pipeline, Tank and Terminal Systems to Transport Ethanol without Cracking										
	1.10 PHMSA new start. Effect of Ethanol Blends and Batching Operations on SCC of Carbon Steels										
	1.11 API/SwRI SCC in Fuel Ethanol										
	1.12 Feasibility of Preventing SCC by Using Inhibitors										
	1.13 Technical and Economic Feasibility of Preventing SCC Through Control of Oxygen										
	1.14 Test Modern, Low-Carbon Steels to Determine if They are Less Susceptible to Ethanol SCC										
	1.15 Determine Compatibility of Aluminum, Brass, and Any Other Non-Ferrous Metals That Might be Used in Ethanol Pipelines										
	1.16 Evaluate Effectiveness of, and Effect on, Internal Coatings										
	1.17 Evaluate Effect of Pressure on SCC										
	1.18 DNV Internal Project to Develop Probes to Measure Corrosion Potential and Oxygen Content										
	1.19 PHMSA new start. Monitoring of Conditions Leading to SCC/Corrosion										

Deliverable	Project	Pre-2007	2007	2008	2009	2010	2011	2012	2013	2014	
	1.20 Fundamental Study to Determine How SCC Relates to Corrosion Potential, Polarization Curve, and Other Basic Electrochemical parameters										
	1.21 Develop Guidelines for ILI for Internal SCC										
	1.22 Develop Method for Predicting Where Internal Ethanol SCC is Most Likely										
	1.23 Develop NDE Method to Detect and Measure Cracks from Outside										
	1.24 Develop Method to Detect Ethanol Leaks										
	1.25 Repair Criteria and Methods										
	1.26 Develop Welding Guidelines for Avoiding Harmful Residual Stresses										
	1.27 Develop Guidelines for Avoiding Pitting or General Corrosion										
	1.28 Evaluate Proposed SCC Solutions for Compatibility with Automotive Requirements										
2. Standard for Safe and Reliable Storage of Ethanol											
	2.1 Determine Any Differences in Guidelines for Storage Versus Transportation										
3. Phenomenological Understanding of the Factors that Cause Ethanol SCC											
	3.1 Determine the Relationships Among Cracking Behavior and Environmental, Stress, and Metallurgical Factors										
4. Guidelines for Risk Assessment											
	4.1 Develop Guidelines for Risk Assessment										
5. Guidelines for Fire/Spill Emergency Response											
	5.1 Develop Guidelines for Fire/Spill Emergency Response										
6. "Fingerprint" Test for Ethanol											
	6.1 Develop Method to Characterize Critical Differences in Ethanol from Different Sources in Terms of SCC Propensity (Included in Project 1.8)										

Deliverable	Project	Pre-2007	2007	2008	2009	2010	2011	2012	2013	2014	
	6.2 Refine Method to Characterize Critical Differences in Ethanol from Different Sources										
7. Decision-Making Process for Specific Pipelines											
	7.1 Develop List of Issues to be Considered by a Company Regarding Transport of Ethanol										
8. Ethanol (Biofuels) Handbook											
	8.1 Write a Handbook on Transportation and Storage of Ethanol and Other Biofuels										
9. Tools to Predict Residual Stresses											
	9.1 Develop Tools to Predict Residual Stresses										
10. Committee to Coordinate Tech Transfer											
	10.1 Support Participation of Technical Expert in Committee Activities										
11. Workforce Training Program											
	11.1 Develop Workforce Training Program										

APPENDIX B. TENTATIVE FUNDING PLAN FOR ETHANOL SCC ROADMAP

a = Completed project
b = Currently funded project
Higher priority future projects are indicated in **bold** print.

Deliverable	Project	Estimated Funding, $000									
		Pre-2007	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
1. Standard for Safe and Reliable Transport of Ethanol by Pipeline											
	1.1 API 939-D Part 2: Survey of Industry Experience	a	a								
	1.2 Develop Lab Tests Relatable to Service Conditions				**150**	**150**					**300**
	1.3 Develop Rapid Field Test for Quality Assurance				**75**	**75**					**150**
	1.4 PRCI SCC-4-5 Requirements for New Pipeline Systems			b	b	b					
	1.5 GRI-04/0128, SCC Avoidance in Ethanol Pipelines	a									
	1.6 PRCI SCC-4-1 Prevention of Internal SCC in Ethanol P/Ls	b	b	b							
	1.7 PRCI SCC-4-3 Identify Environmental and Stress Factors that Produce SCC in Existing Ethanol Pipelines and Terminals			b	b						
	1.8 PHMSA new start: Effect of Ethanol Source on SCC of Carbon Steel				b						
	1.9 PRCI SCC-4-4. Determine the Requirements for Existing Pipeline, Tank and Terminal Systems to Transport Ethanol without Cracking			b	b						
	1.10 PHMSA new start. Effect of Ethanol Blends and Batching Operations on SCC of Carbon Steels			b	b						
	1.11 API/SwRI SCC in Fuel Ethanol	a									
	1.12 Feasibility of Preventing SCC by Using Inhibitors				**75**	**75**					**150**
	1.13 Technical and Economic Feasibility of Preventing SCC Through Control of Oxygen				**75**	**75**					**150**
	1.14 Test Modern, Low-Carbon Steels to Determine if They are Less Susceptible to Ethanol SCC				100	100					200
	1.15 Determine Compatibility of Aluminum, Brass, and Any Other Non-Ferrous Metals That Might be Used in Ethanol Pipelines				50	50					100
	1.16 Evaluate Effectiveness of, and Effect on, Internal Coatings						75	75			150
	1.17 Evaluate Effect of Pressure on SCC						100	100			200

Deliverable	Project	Estimated Funding, $000									
		Pre-2007	2007	2008	2009	2010	2011	2012	2013	2014	Total
	1.19 PHMSA new start. Monitoring of Conditions Leading to SCC/Corrosion				b	b					
	1.20 Fundamental Study to Determine How SCC Relates to Corrosion Potential, Polarization Curve, and Other Basic Electrochemical Parameters			**100**	**100**	**75**					**275**
	1.21 Develop Guidelines for ILI for Internal SCC						75	75			150
	1.22 Develop Method for Predicting Where Internal Ethanol SCC is Most Likely						**75**	**75**			**150**
	1.23 Develop NDE Method to Detect and Measure Cracks from Outside				**50**	**100**	**50**				**200**
	1.24 Develop Method to Detect Ethanol Leaks					50	50				100
	1.25 Repair Criteria and Methods for Ethanol SCC						75				75
	1.26 Develop Welding Guidelines for Avoiding Harmful Residual Stresses							75	75		150
	1.27 Develop Guidelines for Avoiding Pitting or General Corrosion						**75**	**75**	**50**		**200**
	1.28 Evaluate Proposed SCC Solutions for Compatibility with Automotive Requirements							**50**	**50**		**100**
2. Standard for Safe and Reliable Storage of Ethanol											
	2.1 Determine Any Differences in Guidelines for Storage Versus Transportation							50	50		100
3. Phenomenological Understanding of the Factors that Cause Ethanol SCC											
	3.1 Determine the Relationships Among Cracking Behavior and Environmental, Stress, and Metallurgical Factors				**100**	**100**	**75**				**275**
4. Guidelines for Risk Assessment											
	4.1 Develop Guidelines for Risk Assessment							50	50		100
5. Guidelines for Fire/Spill Emergency Response											
	5.1 Develop Guidelines for Fire/Spill Emergency Response					50					50

Deliverable	Project	Estimated Funding, $000									
		Pre-2007	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
6. "Fingerprint" Test for Ethanol											
	6.1 Develop Method to Characterize Critical Differences in Ethanol from Different Sources in Terms of SCC Propensity (Included in PHMSA new start: Effect of Ethanol Source on SCC of Carbon Steel)				b						
	6.2 Refine Method to Characterize Critical Differences in Ethanol from Different Sources							75			75
7. Decision-Making Process for Specific Pipelines											
	7.1 Develop List of Issues to be Considered by a Company Regarding Transport of Ethanol							50			50
8. Ethanol (Biofuels) Handbook											
	8.1 Write a Handbook on Transportation and Storage of Ethanol and Other Biofuels									75	75
9. Tools to Predict Residual Stresses											
	9.1 Develop Tools to Predict Residual Stresses					75	75	75			225
10. Committee to Coordinate Tech Transfer											
	10.1 Support Participation of Technical Expert in Committee Activities				30	30	30	30	30	30	180
11. Workforce Training Program											
	11.1 Develop Workforce Training Program						30	30			60
Subtotal, higher priority				100	625	650	200	275	100		1950
Subtotal, normal priority					180	355	510	685	205	105	2040
Total				**100**	**805**	**1005**	**710**	**960**	**305**	**105**	**3990**

ATTACHMENT 1. MILESTONE 1 REPORT

Catalog No. L5XXXX

Technology for Energy Pipelines

Development of a Research Roadmap Related to Safe and Reliable Transportation of Ethanol in Pipelines and Storage

Milestone 1 – Gap Analysis

Contract PR-313-084503

Prepared for

Pipeline Research Council International, Inc.

Prepared by

BIZTEK Consulting, Inc.

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Publication Date:
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EXECUTIVE SUMMARY

The first step in the development of a research roadmap for the safe and reliable transportation of fuel-grade ethanol by pipeline was a workshop in Dublin, Ohio on October 25 and 26, 2007. That workshop identified a large number of knowledge gaps related to the subject.

This project built upon the results of that workshop by grouping and condensing the list of gaps, indicating which were being addressed by current or planned research, and which required new research projects. This interim report summarizes the results of that analysis and presents recommendations for new projects that could profitably be started in the near future. Additional work will be conducted to produce a final report that will contain a roadmap of all of the future projects that have been identified.

Condensing the needs that were identified at the workshop resulted in the following 15 items:

1. A standard (or recommended practice) for safe and reliable transport of ethanol by pipelines
2. A standard for safe and reliable storage of ethanol
3. A phenomenological understanding of the factors that cause ethanol SCC
4. Guidelines for risk assessment
5. Guidelines for fire/spill emergency response
6. A “Fingerprint” test for identifying the severity of a specific ethanol batch towards SCC of carbon steel
7. A decision-making process for specific pipelines
8. An ethanol (biofuels) handbook
9. Tools to predict residual stresses (this is not ethanol specific)
10. A committee in API or other organization to coordinate research and tech transfer
11. A workforce training program
12. Public communication
13. A government/industry position paper on ethanol infrastructure
14. A catalogue of ongoing and completed research
15. A business case (or enterprise risk assessment) for new pipeline construction dedicated to ethanol or other biofuel transportation

For those items that required research, a list of research topics was constructed and compared with past and on-going projects. Topics that were not covered in past or on-going projects were then analyzed to determine which ones could profitably be started in the near future. From that list, the following projects are recommended for consideration:

- Safety of Transporting Blends Containing More than 10 Percent Ethanol
- Standardized Tests for SCC in Ethanol
- Technical and Economic Feasibility of Preventing SCC Through Control of Oxygen
- Feasibility of Preventing SCC by Using Inhibitors
- Compatibility of Polymeric Materials and Non-ferrous Metals with Ethanol

- Understanding of Ethanol SCC

In addition, it was recommended that API or some other suitable industry organization establish committees to prepare 1) a recommended practice for transporting ethanol by pipeline and 2) guidelines for integrity management of pipelines for transporting ethanol.

TABLE OF CONTENTS

INTRODUCTION

The planned wide-spread use of ethanol as an additive to gasoline or as a supplementary fuel will require an efficient and reliable transportation and storage system that includes the existing infrastructure and new construction. Ethanol is currently being transported by a batch process involving railcars, tanker trucks, barges, and ships. However, in order to economically transport ethanol-containing fuels from producers to users on a large scale, safe and reliable transportation by pipeline is necessary. Industry experience has shown that stress-corrosion cracking (SCC) can occur in carbon steel exposed to fuel-grade ethanol (FGE), and several research programs have been initiated to identify the specific conditions that can lead to SCC and how to avoid SCC in pipelines and storage facilities that contain ethanol or ethanol/gasoline mixtures.

In an effort to provide guidance to those and future research programs, a Road Mapping meeting was held in Dublin, Ohio on October 25 and 26, 2007. Participants included representatives from the pipeline and petroleum industries, research organizations, the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA), the Association of Oil Pipelines (AOPL), American Petroleum Institute (API), Renewable Fuels Association, and Pipeline Research Council International (PRCI). The primary output from the meeting was a detailed list of knowledge gaps that need to be filled and actions that need to be taken to assure safe and reliable transportation of ethanol-containing fuels by pipeline.

As a second step toward the development of a research road map, this project was initiated to develop a plan for research that will meet the needs of industry and government by addressing all of the critical issues in a logical sequence without duplication unless replication can provide greater phenomenological understandings or increased confidence in the field use of key results. The project builds on the results of the workshop that was held in October 2007 where gaps in knowledge were identified and prioritized.

The primary focus of this project is on the technical challenges related to shipping ethanol in pipelines, including ways to prevent internal stress-corrosion cracking (SCC) in current and future pipeline systems containing FGE. Internal SCC is considered to be the primary threat to the integrity and life of such systems. Consideration also is given to quality assurance and how potential solutions to the SCC problem may affect internal corrosion, polymeric materials such as seals and gaskets, and compatibility with automotive use. Additionally, other technical issues are explored; however, issues related to the business case for transporting FGE such as market demand and price projections are beyond the scope of this project.

The deliverables from this project consist of the following:

Milestone 1

Identification of outstanding gaps - A preliminary report suggesting research topics that should be pursued in the near future and containing

4. An organization of the workshop results, grouping projects that are related to various potential solutions, removing overlaps, and identifying critical paths.
5. Identification of which issues from the workshop have been, or will be, addressed in past, current, or planned projects.
6. Identification of any overlaps or duplications among those projects.

<u>Milestone 2</u>

A final report presenting a comprehensive research plan that

4. Identifies topics that can be investigated in parallel and those that cannot because they depend on completion of others.
5. Identifies and prioritizes topics that warrant development of new research programs along with estimates of the investments required for each.
6. Suggests a structure and process for coordinating the various research efforts that are and will be conducted for various sponsors.

This report is the first deliverable and satisfies Milestone 1.

APPROACH FOR MILESTONE 1

To complete Milestone 1, the following tasks were carried out:

7. Reviewed the results of the October workshop and grouped the issues according to possible approaches to solving the problem (e.g., chemical, electrochemical, metallurgical, design, operational, etc.) for existing and future pipeline systems, identifying interdependencies among the topics.
8. Reviewed reports of relevant past research to determine how much already is known about each issue.
9. Reviewed work plans for ongoing and planned projects to determine how much additional knowledge can be expected from them.
10. Reviewed completed research that identifies E10 as transportable in pipelines without the development of SCC and provided an independent view of the findings.
11. Met with key stakeholders including principal investigators of some of the more important projects to gain insights beyond those obtainable from written reports.
12. Prepared this preliminary report in the form of a gap analysis, with recommendations for research topics that should be planned in the near future.

CONSOLIDATION OF NEEDS

By sorting the several hundred needs that were identified in the October workshop into logical groups and eliminating duplicates from the various lists, all of the items were grouped into the following 15 industry needs:

1. Many of the expressed needs would logically be elements in a *standard (or recommended practice) for safe and reliable transport of ethanol by pipeline*. Principal among those elements are the following:

   - How to avoid SCC
     - Acceptable ethanol compositions
     - Materials of construction
     - Operating practices
     - Integrity assessment methods
     - Leak detection
     - Maintenance
   - How to avoid pitting/general corrosion
   - How to avoid deterioration of polymeric seals and gaskets
   - How to maintain product quality and compatibility with automotive requirements

   The most critical threat to deal with is SCC, but other possible deterioration mechanisms should not be ignored. Issues related to chemistry and electrochemistry probably are most important for integrity management and include control of oxygen content, specifying ethanol composition, use of inhibitors, and possibly control of potential. Less promising approaches are selection of resistant steel, surface treatments, and control of residual stresses.

2. A *standard for safe and reliable storage of ethanol,* which would be similar to that for transporting ethanol, but certain approaches might be more appealing because of the accessibility of storage facilities and lower operating pressures.

3. A *phenomenological understanding of the factors that cause ethanol SCC*, which will be important for suggesting ways to manage the problem and for assuring that proposed solutions will be successful in the long run. It is recognized that a fundamental, mechanistic understanding of SCC in ethanol, just as in other SCC phenomena, may not be attainable within the time frame of interest, but an understanding of the driving forces will place any engineering actions on a firmer footing.

4. *Guidelines for risk assessment*, which could be developed after the causes and potential impact of ethanol SCC are better understood.

5. *Guidelines for fire/spill emergency response*, which probably should be developed by each pipeline company. Existing guidelines for storage

facilities probably can be adapted, but the remote nature of pipelines needs to be considered. The inclusion of other stakeholders, such as the National Association of Fire Marshalls, will be important in developing emergency response procedures.

6. A *"Fingerprint" test* to screen incoming ethanol for propensity to cause SCC, which will require a better understanding of the effects of subtle differences in the composition of ethanol or the discovery of a correlation between SCC propensity and some other measurable property of ethanol.

7. A *decision-making process for specific pipelines* involving both technical and economic issues. The technical issues should follow readily from the previous items. The economic issues may be specific to each company.

8. An *ethanol (biofuels) handbook* (compilation of existing and new information available at the time), which should not require any more research than is needed for the previous items.

9. *Tools to predict residual stresses*, which may or may not be important depending upon the research results; several techniques are available (hole boring and X-ray among others) and they are not unique to the ethanol problem.

10. A *committee in API, or other organization to coordinate research and tech transfer* related to transport and storage of FGE in pipeline systems, which would be important for maximizing the efficiency of the research.

11. A *workforce training program*, which can be developed after more is learned about ethanol SCC and ethanol product handling.

12. *Public communication*, which will be important to assure the public of the safety of ethanol pipelines, but it does not, in itself, require research.

13. A *government/industry position paper on ethanol infrastructure*, which would be an important part of public communication. The coordinating committee should develop a strategy for this activity.

14. A *catalogue of ongoing and completed research*, which will essentially be produced by this project for non-proprietary research conducted to date. Consideration should be given for a mechanism to keep it current.

15. Development of a *business case*, which obviously is important but is beyond the scope of this project.

GAP ANALYSIS

Appendix A contains the results of an analysis of each of the above 15 needs to identify missing pieces of information that are required to fill those needs. The first column breaks down each need into its elements. The second column lists research projects that have or could develop such information. Many of the items are being addressed in current projects and some have been covered in previous projects. Of the remainder, the most urgent have been highlighted in red. Those are discussed in the following sections of this report. The projects that are less urgent or that depend on the results of current projects will be treated in the second milestone report.

SUGGESTED PROJECTS FOR NEAR FUTURE

Safety of Transporting Blends Containing More than 10 Percent Ethanol

With slow strain rate (SSR) tests, SCC has been observed for E20 through E95, but not for E10. Although there is only one published data point for E10, in a recent presentation to API, several additional proprietary data points for E10 and one for E15 (all with no SCC) were reported. Especially in view of the severe nature of the SSR test as compared with service conditions, this is compelling evidence that transportation of E10 by pipeline should pose no threat of SCC. However, skeptics may want more data.

From an economic standpoint, it may be desirable to transport richer blends than E10. There is most interest in E20, E30, and E95. If E95 is transported between batches of gasoline, the transmix will contain all compositions including those between E30 and E95.

Some pipeline companies might prefer to surround the ethanol batch with something other than gasoline – for example, jet fuel. The effect of those other products has not been investigated.

Although the SSR tests show that SCC is possible in blends between E20 and E95, the SSR test imposes stress and strain conditions that are much more severe than those experienced by an operating pipeline. The SSR test is useful as a rapid screening tool for environments. A different test or alternative analysis techniques for the SSR test are needed for a more realistic evaluation of environmental conditions, or a reliable correlation needs to be developed to relate the results of SSR tests to performance under realistic pipeline conditions.

Suggested Research. Using a test that does not impose macroscopic plastic strain on the specimen but represents relatively severe but realistic conditions, conduct SCC tests in blends from E20 through E95 to determine which blends are capable of causing SCC under service conditions. Concentrate on E20, E30, and E95, but conduct some tests with intermediate blends as well. Determine what products other than gasoline might be used to surround the batch of ethanol, and include blends of those as well.

Also, conduct SSR tests with blends between E10 and E20 to determine the maximum ethanol content that will not produce SCC, even under those unrealistic stress conditions. These tests will help to substantiate the safety of E10.

Standardized Tests for SCC in Ethanol

In order to fully understand SCC of steel in ethanol, it is necessary to consider crack initiation, growth of short cracks, and growth of large cracks. In addition, it would be useful to have a rapid screening test to determine if a given blend is or is not capable of causing SCC under the most severe possible operating conditions. It may be necessary to employ several different tests to meet all of those requirements.

Most of the ethanol SCC experiments to date have used the slow strain rate (SSR) test. That was a reasonable choice because the SSR test provides a relatively rapid and inexpensive way to screen environments. However, the SSR test utilizes stress and strain conditions that are much more severe than those experienced by an operating pipeline in order to obtain crack initiation in a short period. Therefore, this method may produce unrealistically conservative results. It also may not be appropriate for evaluating the susceptibility of steels because the imposed strain in the SSR test overrides the steel's resistance to creep and the effects of residual stresses that might be produced with surface treatments. While the SSR test may be retained as a rapid screening tool for environments, a range of tests is needed for a more realistic evaluation of environmental conditions and steel susceptibility.

Notched tension or pre-cracked compact tension specimens subjected to small fluctuating loads superimposed on a mean load would be useful for measuring crack growth rates and for developing threshold fracture-toughness data for ethanol SCC. However, a fracture-mechanics analysis is not valid for very short cracks and not useful for studying initiation. Traditional fracture mechanics would predict impossibly high stresses for initiation and for growth of very small cracks. Furthermore, it also is not useful for evaluating the effects of surface treatments. Therefore, other kinds of specimens, such as a tapered tensile specimen, also should be considered.

While fracture mechanics tests should be considered for laboratory experiments directed at providing of the causes or mechanism of SCC, they are not often of benefit for quick, quality assurance testing due to their complexity and sophistication of analyses. Therefore, a simpler and more rapid test for quality assurance also would be desirable.

Furthermore, it would be desirable to have published standards for each type of test to ensure that different testing labs produce data that are compatible and comparable.

Suggested Research. Develop one or more tests that represent more realistic service conditions that a pipeline might experience. Consider initiation, growth of small cracks, and growth of large cracks. Consider ways to accelerate crack growth and how to extrapolate the results of accelerated tests to realistic field conditions. For example, determine whether higher temperatures accelerate growth, and whether high-temperature data can be related to lower temperatures through an Arrhenius relation or other method? Also determine the feasibility of using more severe stress conditions or control of potential to accelerate cracking in a predictable way? For each type of test, recommend a standard procedure for preparing the specimens and conducting the tests.

Also develop a procedure for rapid screening of environments in the field. The procedure may involve a cracking test, but consideration also should be given to a chemical analysis or other characterization approach including combination approaches for maximum reliability in prediction of field ethanol SCC behavior. This approach also should involve correlations between laboratory and field behavior.

Technical and Economic Feasibility of Preventing SCC Through Control of Oxygen

Even with the severe SSR test, SCC has never been produced in the laboratory if oxygen has been eliminated from the system. In fact, this is the only approach that has consistently prevented SCC. In principle, it might be possible to keep oxygen from ever getting into the ethanol during manufacture and transport, and there are several possible ways (sparging with nitrogen, vacuum treatment, reacting with steel wool, adding an oxygen scavenger, etc.) to remove oxygen before the ethanol is put into the pipeline. One also needs to be sure that there is no source of oxygen in the pipeline and that oxygen is not re-introduced during pumping or related handling in facilities terminals.

Control of oxygen also is important in the production and transport of methanol and ammonia. It is possible that some of the approaches that have been developed for those industries might be modified and adapted for ethanol.

Suggested Research. Conduct an engineering study to evaluate the technical and economic feasibility of various ways of eliminating oxygen from the ethanol. Consider ways to prevent contamination by oxygen during production and transport as well as removing oxygen before introducing the ethanol into the pipeline. Also, develop a rapid way to monitor the oxygen content. Such research has been started under the PRCI SCC 4-3 project, but its scope may need to be extended.

Feasibility of Preventing SCC by Using Inhibitors

A number of inhibitors have been used to mitigate general corrosion and pitting corrosion of steel exposed to FGE, but, at 1000 ppm, they have not been able to prevent SCC in SSR tests. However, other chemicals – hydrazine and DEA, in particular – have been successful at either preventing SCC or substantially reducing the severity. It is not known whether higher concentrations of the corrosion inhibitors would have been successful or if they would be successful in the less aggressive scenario of real pipeline operation.

Inhibition can be accomplished by several mechanisms, each of which has certain limitations. For example, some inhibitors form a passive film on the surface of the metal, but an insufficient concentration could lead to localized breakdown of the passive film, which might result in SCC or severe pitting compared to less serious uniform corrosion in the absence of the inhibitor. Other inhibitors may shift the potential out of the critical range for SCC, but sources of stray current such as galvanic coupling to another metal or to corroded steel might shift the potential back. It is interesting that DEA inhibits SCC without shifting the potential, while Octel DCI-11 shifts the potential but does not inhibit SCC.

Suggested Research. Conduct a systematic study of candidate inhibitors at various concentrations in FGE with various oxygen contents. Include commercial inhibitors but avoid chemicals that are specifically not allowed in gasoline. Use SSR tests initially to screen inhibitors along with various electromechanical tests to evaluate the mechanisms. For chemicals that produce partial inhibition, use a less severe cracking test to evaluate their effectiveness under typical pipeline operating conditions.

For inhibitors that appear to be successful at preventing SCC, evaluate their compatibility with automotive requirements.

Compatibility of Non-ferrous Metals with Ethanol

Although SCC of carbon steel is the primary concern with transport and storage of ethanol, the effect of ethanol on other metals and alloys that are in current pipeline and storage systems or might be used in future systems should not be ignored. Apparently, pitting has been experienced with aluminum floaters.

Suggested Research. Conduct an inventory of non-ferrous metals that might be exposed to ethanol in storage and pipeline systems containing ethanol. Determine which of those materials currently are being used in ethanol storage facilities and whether the ethanol has caused any problems with them. For materials with no service record, conduct exposure tests of them in ethanol.

Phenomenological Understanding of Ethanol SCC

Although research to date has made remarkable progress at pointing toward possible ways to manage the problem, there are still many aspects of the phenomenon that are not understood. A more thorough understanding of the factors that cause ethanol SCC may suggest better ways to manage the problem. Additionally, they could provide a higher level of assurance that proposed solutions will, in fact, be successful in the long term.

There are large, unexplained differences in the propensity to produce SCC of different samples of ethanol from the field. It is not known how or if those differences are related to impurity levels or processing history. There also are large differences in corrosion potential of different samples of ethanol. There is strong evidence that the corrosion potential is an important factor; SCC has not been observed at potentials more negative than –200 mV (Ag/AgCl), but it does not always occur at more positive potentials.

Limited investigations of steel susceptibility and a review of field SCC failures have not revealed large differences in cracking susceptibility of various steel grades and compositions, but those investigations were limited to relatively old ferrite-pearlite steels and were done with slow strain rate (SSR) tests, which can mask some of the critical effects. It would be important to know whether modern, low-carbon steels exhibit any different levels of susceptibility. Furthermore, the effect of yield strength of steel on SCC is currently unknown because of the limited range of steel grades tested. Specifically, the effect of using high-strength grades (e.g., X100) is not known.

Incidents of ethanol SCC that have been discovered in the field to date have been associated with high residual and/or applied stresses. Internal pressures have been very low. Pipelines that transport ethanol are expected to operate at relatively high internal pressures, which will cause hoop stresses that may approach 72 % of the specified minimum yield strength. It is not known whether stresses of that level are sufficient to cause SCC. It also is not known whether fluctuations of the stress have an effect, as they do for external SCC. Field experience for ethanol SCC in facilities suggest that this may be the case in tank roof plates and springs and tank bottom plates.

Suggested Research. Develop a phenomenological understanding of the factors that cause ethanol SCC by conducting a systematic study of environmental, stress, and metallurgical factors. Determine relationships among the cracking behavior, electrochemical properties, chemical composition of the environment, stress conditions, and steel composition and properties.

OTHER RECOMMENDED ACTIONS

It is anticipated that the results of the research will be most useful if they are incorporated into documents such as a recommended practice for transporting ethanol by pipeline and guidelines for integrity management of pipelines for transporting ethanol. Suggested contents of a recommended practice are included in Appendix A. Integrity management guidelines should address issues such as monitoring, risk management, in-line inspection, hydrostatic testing, and direct assessment.

It is recommended that API or some other suitable industry organization establish committees or direct existing committees to prepare those documents. For example, API might develop an overall or umbrella standard, which would refer to other standards to be developed by other organizations, such as NACE for corrosion control and monitoring, ASTM for testing, etc.

Although it will not be possible to complete those documents before the research is finished, work can be initiated on guidelines, which will evolve and become better defined with available research data and field experience, for faster transfer of technology to the industrial sector. Active committees can also help guide the ongoing research to make sure it remains focused on the critical issues or to make changes in research direction as needs of the industry change over time.

APPENDIX A. RESULTS OF GAP ANALYSIS

The following table is the basis for deciding what research projects may be needed to resolve important issues related to the safe and reliable transport and storage of FGE or ethanol/gasoline blends in pipeline systems. The first column lists the 15 needs that were defined in the October 2007 workshop, and it breaks each item down into the issues that are implied by each need. The second column indicates which issues may require research to resolve them and whether those projects have been completed, are in progress, or have not been started or funded. The third column provides comments related to the status of past and current projects and the urgency of future projects.

Research Addressing Ethanol Industry Needs

Bold: completed project
Italics: on-going project
Red: Suggestion for immediate start
Other: To be considered for future

Need	Research Project/Report	Status/Comments
1. Standard for safe and reliable transport of ethanol by pipeline	**1a API 939-D Part 2: Survey of industry experience. Wide variation in occurrences but no obvious correlation with source or process conditions. Some oxygen contamination highly probable under all conditions. Suggested possible role of mill scale.**	**1a Project complete. Consider re-visiting after lab work points to issues of interest.**
1.1. Avoid SCC	1.1. Develop suitable lab test How to accelerate and relate to service conditions Temperature? Stress? Potential? Solution concentration? Crack growth	1.1 Urgently needed. Could be started now.

Need	Research Project/Report	Status/Comments
	Limits on applicability of fracture mechanics Short crack behavior Crack initiation Surface condition (mill scale, decarb) Short crack behavior **U-bends not adequate (API 939-D)**	
	1.1-a PRCI SCC-4-5 Requirements for new pipeline systems	1.1-a RFP ready to send out
	1.1-b GRI-04/0128, SCC Avoidance in Ethanol Pipelines, CCTech, 2005. Readily produces SCC in SSRTs with aerated solution containing 1% water, 4% gasoline, 0.5% methanol, and 40ppm chlorides. Did not produce SCC with constant load.	**1.1-b Project complete. Used only one environment.**
	1.1-c PRCI SCC-4-1 Prevention of Internal SCC in Ethanol Pipelines. CCTech. Apparent effect of potential, but DEA inhibitor effective without shifting potential. Oxygen removal prevented SCC. Dipping in diesel fuel did not.	**1.1-c. Project complete; final report in review.**
	1.1-d PRCI SCC-4-3 Identify Environmental and Stress Factors that Produce SCC in Existing Ethanol Pipelines and Terminals, CCTech. Will use SSRTs in flow loop to evaluate inhibitors, oxygen scavengers, deaeration.	1.1-d Project started recently.
1.1.1. Acceptable compositions	*1.1.1-a PHMSA new start: Effect of Ethanol Source on SCC of Carbon Steel. Will characterize critical differences in ethanol from different sources and develop finger prints.*	*1.1.1-a Will start soon. Need to be sure that many actual samples from the field will be used.*

Need	Research Project/Report	Status/Comments
1.1.1.1. Gasoline content (E10, E20, … E98)	*1.1.1.1-a PRCI SCC-4-4. Determine the Requirements for Existing Pipeline, Tank and Terminal Systems to Transport Ethanol without Cracking, CCTech. Will use SSRTs to look at various levels of gasoline. Will measure crack growth rates in static and cyclic-load tests.* 1.1.1.1-b PHMSA new start. Effect of Ethanol Blends and Batching Operations on SCC of Carbon Steels. Scope very similar to 1.1.1.1-a	*1.1.1.1-a Preliminary indication no SCC in E10; SCC in E20 – E95 with (severe) SSRT. Need more tests at E15 and E10.* 1.1.1.1-b About to start. Should consider short and long ethanol batches between gasoline batches.
1.1.1.2. Impurities, acceptable levels and how to control 1.1.1.2.1. Oxygen 1.1.1.2.2. Water 1.1.1.2.3. Chlorides 1.1.1.2.4. Other	**1.1.1.2-a API/SwRI SCC in Fuel Ethanol. Found oxygen most important; correlates with potential. Affected by rust. Chlorides and methanol have some effect.** **1.1.1.2-b PRCI SCC-4-1 Prevention of Internal SCC in Ethanol Pipelines. Deaeration by several methods prevented SCC in SSRTs.**	**1.1.1.2-a Project complete. Eliminating oxygen stands out as most reliable way to prevent SCC. Consider project to evaluate technical and economic feasibility of oxygen removal by various methods.**
1.1.1.3. Denaturant	1.1.1.3 Evaluate Effects of Various Denaturants	1.1.1.3 Probably not worth doing because gasoline is the only practical denaturant.
1.1.1.4. Effects of aging	*1.1.1.4 Characterize changes with aging*	1.1.1.4 *Part of new PHMSA project*
1.1.1.5. Inhibitor	**1.1.1.5 See 1.1.1.2-b PRCI SCC-4-1 Prevention of Internal SCC in Ethanol Pipelines. DEA greatly reduces severity of SCC. Other corrosion inhibitors**	1.1.1.5 Might need follow-on to look at more inhbitors

Need	Research Project/Report	Status/Comments
	did not. Hydrazine, an oxygen scavenge, prevented SCC.	
	1.1.1.5 Being addresses in 1.1-c, but only to limited extent	
1.1.2. Materials of construction 1.1.2.1. Pipe 1.1.2.1.1. Grade	**1.1.2.1-a GRI-04/0128 (See 1.1a) Produced SCC in 4 different steels. Cracking rates were different but not correlated with steel composition or properties.**	**1.1.2.1-a Project complete. Apparently minor variations in steel susceptibility not explained. SSRT may not be sensitive to steel properties.**
	1.1.2.1-b Test modern, low-carbon steels to determine if they are less susceptible to ethanol SCC and use other than SSRT	1.1.2.1.1-b Could be started soon.
1.1.2.1.2. Welding	*1.1.2.1.2. Being addressed in 1.1.1.1-a (PRCI SCC-4-4)*	*1.1.2.1.2 In progress.*
1.1.2.2. Fittings	*1.1.2.2 Castings being addressed in 1.1.1.1.-a*	*1.1.2.2 In progress*
1.1.2.3. Non-ferrous metals	1.1.2.3 Determine compatibility of aluminum, brass, and any other non-ferrous metals that might be used in ethanol pipelines	1.1.2.3 Could be started soon.
1.1.2.4. Internal coatings	1.1.2.4 Evaluate effectiveness of, and effect on, internal coatings.	1.1.2.4 Low priority.
1.1.3 Operating practices		

Need	Research Project/Report	Status/Comments
1.1.3.1.Mixing sources	1.1.3.1 (See 1.1.1-a) Will look at mixing from different sources.	
1.1.3.2.Batching	1.1.3.2-a PRCI SCC-4-4 (See 1.1.1.1-a) Some tests will involve alternate exposure to FGE and gasoline	1.1.3.2-a Project recently started. May require follow-on to investigate more conditions.
1.1.3.3.Pressure	1.1.3.3 Evaluate Effect of Pressure on SCC	1.1.3.3 Low priority.
1.1.3.4.Pressure fluctuations	1.1.3.4-a PRCI SCC-4-4 (See 1.1.1.1-a) Some tests will involve cyclic loading	1.1.3.4-a Project recently started. May require follow-on to investigate more conditions
1.1.3.5.Flow rates and stagnation	*1.1.3.5-a PRCI SCC-4-3 (See 1,1-c) Will do SSRTs in flow loop.*	
1.1.4. Quality assurance		
1.1.4.1.Ethanol composition		
1.1.4.1.1. Chemical sensors	*1.1.4.1.1-a DNV Internal Project to develop probes to measure corrosion potential and oxygen content*	*1.1.4.1.1-a Initial results for oxygen look promising*
	1.1.4-a PRCI SCC-4-3 (See 1.1-c) Will develop field procedures to measure inhibition and oxygen content.	*1.1.4-a Project just starting*
	1.1.4-b PHMSA new start. Monitoring of Conditions Leading to SCC/Corrosion. Scope similar to 1.1.4-a	*1.1.4-b About to start.*
1.1.4.1.2. Cracking tests	1.1.4.2 Develop in-line SCC test	1.1.4.1.2 Probably not practical.

Need	Research Project/Report	Status/Comments
1.1.4.2. Potential		
1.1.4.2.1. Acceptable ranges	**1.1.4.2.1 Determined in 1.1.1.2 (API/SwRI Project), but recent data on FGE raised question.** **Also, DEA inhibits without changing potential and Octel DCI-11 changes potential but does not inhibit SCC.** 1.1.4.2.1-a Fundamental study to determine how SCC relates to corrosion potential, polarization curve, and other basic electrochemical parameters.	1.1.4.2.1 Needs to be re-visited. 1.1.4.2.1-a Should be started soon.
1.1.4.2.2. Sensor	*1.1.4.2.1 Being addressed in 1.1.4.1.1*	*1.1.4.2.1 In progress.*
1.1.5. Integrity assessment methods	*1.1.5-a PRCI SCC-4-4 (See 1.1.1.1-a) Will measure crack growth rates (as basis for establishing inspection intervals).*	*1.1.5-a In progress*
1.1.5.1. In-line inspection		
1.1.5.1.1. Accuracy, sensitivity, discrimination	1.1.5.1.1 Develop guidelines for ILI for internal SCC	1.1.5.1.1Probably not unique to ethanol.
1.1.5.1.2. Intervals	*See 1.1.5-a*	
1.1.5.2. Hydrostatic testing		
1.1.5.2.1. Pressures and times	1.1.5.2.1 Develop guidelines for hydrostatic testing for internal SCC	1.1.5.2.1 Probably can use known technology
1.1.5.2.2. Intervals	*See 1.1.5-a*	
1.1.5.3. Direct assessment		
1.1.5.3.1. Method	1.1.5.3.1 Develop method for predicting where internal ethanol SCC is most likely.	1.1.5.3.1 Would be good, but probably premature in view of limited understanding

Need	Research Project/Report	Status/Comments
1.1.5.3.2. Intervals	*See 1.1.5-a*	
1.1.5.4. NDE Method to detect and measure cracks from outside	1.1.5.4 Evaluate various methods	1.1.5.4 Could be done now, but not urgent
1.1.5.5. Early detection of SCC	1.1.5.5 Develop method for early detection	1.1.5.5 Don't know if feasible. What approach?
1.1.6. Leak detection	1.1.6 Develop method to detect leaks	1.1.6 What approach?
1.1.7. Maintenance 1.1.7.1. Welding 1.1.7.1.1. Procedures 1.1.7.1.2. Post-weld heat treatment	1.1.7.1 Develop guidelines for welding	1.1.7.1 Might not be critical for pipelines since internal pressure may be enough.
1.2. Avoid pitting/general corrosion 1.2.4. Acceptable compositions 1.2.4.1. Gasoline content 1.2.4.2. Impurities 1.2.4.2.1. Oxygen 1.2.4.2.2. Water 1.2.4.2.3. Chlorides 1.2.4.2.4. Other 1.2.4.3. Denaturant 1.2.4.4. Inhibitor	1.2 Develop guidelines for avoiding pitting or general corrosion	1.2. Important, but probably should wait for SCC research to identify indicate issues. Researchers doing SCC tests should take note of corrosion rates.
1.3. Avoid deterioration of polymeric seals and gaskets	*1.3-a PRCI SCC-4-4 (See 1.1.1.1-a) Will do literature survey and experiments with various gasket and seal*	*1.3-a Project just started.*

Need	Research Project/Report	Status/Comments
1.3.4. Acceptable compositions 1.3.4.1. Gasoline content 1.3.4.2. Impurities 1.3.4.2.1. Oxygen 1.3.4.2.2. Water 1.3.4.2.3. Chlorides 1.3.4.2.4. Other 1.3.4.3. Denaturant 1.3.4.4. Inhibitor	*materials in various environments.* *1.3-b PHMSA new start. Scope similar to 1,1,1,1-a and 1.3-a*	 *1.3-b About to start.*
1.3.5. Materials of construction 1.3.5.1. Seals 1.3.5.2. Gaskets		
1.4. Avoid corrosion of non-ferrous material in the system	1.4 Expose materials such as aluminum and brass to ethanol and ethanol/gasoline blends and monitor for corrosion	1.4 Could be started soon.
1.5. Maintain compatibility with automotive requirements 1.5.1 Acceptable compositions 1.5.1.1Impurities 1.5.1.1.1 Oxygen 1.5.1.1.2 Water 1.5.1.1.3 Chlorides 1.5.1.1.4 Other 1.5.1.2 Denaturant 1.5.1.3 Inhibitor	 1.5.1 Evaluate proposed approaches for avoiding SCC in terms of automotive requirements	 1.5.1 Need to wait for SCC results

Need	Research Project/Report	Status/Comments
2 Standard for safe and reliable storage of ethanol 2.5 Avoid SCC	**2a Survey of industry experience** 2.1 Develop recommended practice for avoiding SCC in storage tanks	 2.1 Much of work on transportation of FGE should be relevant.
2.1.1. Acceptable compositions 2.1.1.1.Gasoline content 2.1.1.2.Impurities 2.1.1.2.1. Oxygen 2.1.1.2.2. Water 2.1.1.2.3. Chlorides 2.1.1.2.4. Other 2.1.1.3.Denaturant 2.1.1.4.Inhibitor	2.1.1 Determine safe composition limits to avoid SCC in storage tanks	2.1.1 Any composition that is safe for a pressurized pipeline should be safe for storage. Because of lower pressures, limits might be relaxed, but not relevant if product will be put into a pipeline.
2.1.2. Materials of construction (existing and new) 2.1.2.1.Piping and tanks 2.1.2.1.1. Grade 2.1.2.1.2. Welding 2.1.2.2.Fittings	2.1.2 Develop guidelines for selecting materials of construction for storage tanks.	2.1.2 Results to date do not indicate any critical materials issues.
2.1.3. Operating practices 2.1.3.1.Mixing sources 2.1.3.2.Batching 2.1.3.3.Pressure	2.1.3 Results from pipeline work should be relevant and sufficient.	2.1.3 Probably no need for anything beyond pipeline work.
2.1.4. Quality assurance 2.1.4.1.Ethanol composition 2.1.4.1.1. Chemical sensors 2.1.4.1.2. Cracking tests	2.1.4 Results from pipeline work should be relevant and sufficient.	2.1.4 Probably no need for anything beyond pipeline work.

Need	Research Project/Report	Status/Comments
2.1.4.2.pH 2.2. Avoid pitting/general corrosion 2.2.1. Acceptable compositions 2.2.1.1.Gasoline content 2.2.1.2.Impurities 2.2.1.2.1. Oxygen 2.2.1.2.2. Water 2.2.1.2.3. Chlorides 2.2.1.2.4. Other 2.2.1.3.Denaturant 2.2.1.4.Inhibitor	2.2 Results from pipeline work should be relevant and sufficient.	2.2 Probably no need for anything beyond pipeline work.
2.3. Avoid deterioration of polymeric seals and gaskets 2.3.1. Acceptable compositions 2.3.1.1.Gasoline content 2.3.1.2.Impurities 2.3.1.2.1. Oxygen 2.3.1.2.2. Water 2.3.1.2.3. Chlorides 2.3.1.2.4. Other 2.3.1.3.Denaturant 2.3.1.4.Inhibitor 2.3.2. Materials of construction 2.3.2.1.Seals **2.3.2.2.**Gaskets 2.3.3. Quality assurance 2.3.3.1.Ethanol composition 2.3.3.1.1. Chemical sensors 2.3.3.1.2. Corrosivity tests 2.3.3.2. pH	2.3 Results from pipeline work should be relevant and sufficient	2.3 Probably no need for anything beyond pipeline work.

Need	Research Project/Report	Status/Comments
3. Phenomenological understanding of the factors that cause ethanol SCC	3 Systematic study of the relationships among cracking behavior and environmental, stress, and metallurgical factors	3 Should be initiated as soon as possible
4. Guidelines for risk assessment 4.1. Assessing threats 4.1.1. SCC 4.1.2. Internal corrosion 4.2. Comparison of ethanol SCC risks to other current risks 4.3. Potential failure scenarios 4.4. Consequences 4.4.1. Damage 4.4.2. Clean-up costs	4 Develop guidelines for risk assessment	4 Must wait for results of 1
5. Guidelines for fire/spill emergency response	5 Develop guidelines for fire/spill emergency response	5 Who should fund?
6. "Fingerprint" test 6.1. Production process 6.2. Operating variables 6.3. Raw materials	6 *Covered in 1.1.1-a PHMSA new start: Effect of Ethanol Source on SCC of Carbon Steel. Will characterize critical differences in ethanol from different sources and develop finger prints.*	*6. In progress. Ambitious goal.*
7. Decision-making process for specific pipelines	7 Will depend on results from 1	7 Must wait for results from 1
8. Ethanol (biofuels) handbook	8 Write handbook	8 Not clear what should be included. Probably must wait for results from above.
9. Tools to predict residual stresses	9 Develop tools to predict residual stresses.	9 Needs better definition
10. Committee in NACE, ASTM API, or other to coordinate tech transfer 10.1. Also include RFA, EPI,(UNICA Brazil), SAE, AOPL, ASME,	10 Organizational issue; not a research issue.	10 Not a subject for research.

Need	Research Project/Report	Status/Comments
PRCI, DOT, CRC, DOE, USDA, DOD, EPA, Biodiesel Board, NFPA, other international organizations 10.2. Annual forum 10.3. Compare Brazilian and US practices		
11. Workforce training program	11. Develop training program	11 Premature. Must wait for research results
12. Public communication 12.1. Value of using ethanol 12.2. Safety of ethanol transportation	12 Not a research issue.	
13. Government/industry position paper on ethanol infrastructure	13 Write paper.	13 Premature. Must wait for research results
14. Catalogue of ongoing and completed research	*14 Will be accomplished in this project.*	14 Should consider mechanism for updating.
15. Business case 15.1. Pipeline transportation 15.2. Cost/benefit analysis 15.3. Optimum delivery system **15.3.1.** Capacity **15.3.2.** Length **15.3.3.** Realistic limit on quantity available for fuel	*15.2-a PRCI SCC-4-3 (See 1.1-c) Will assess cost effectiveness of inhibitors and deaeration.*	15 Outside scope of this project.