

Recent Advances in Understanding Ethanol SCC of Pipelines



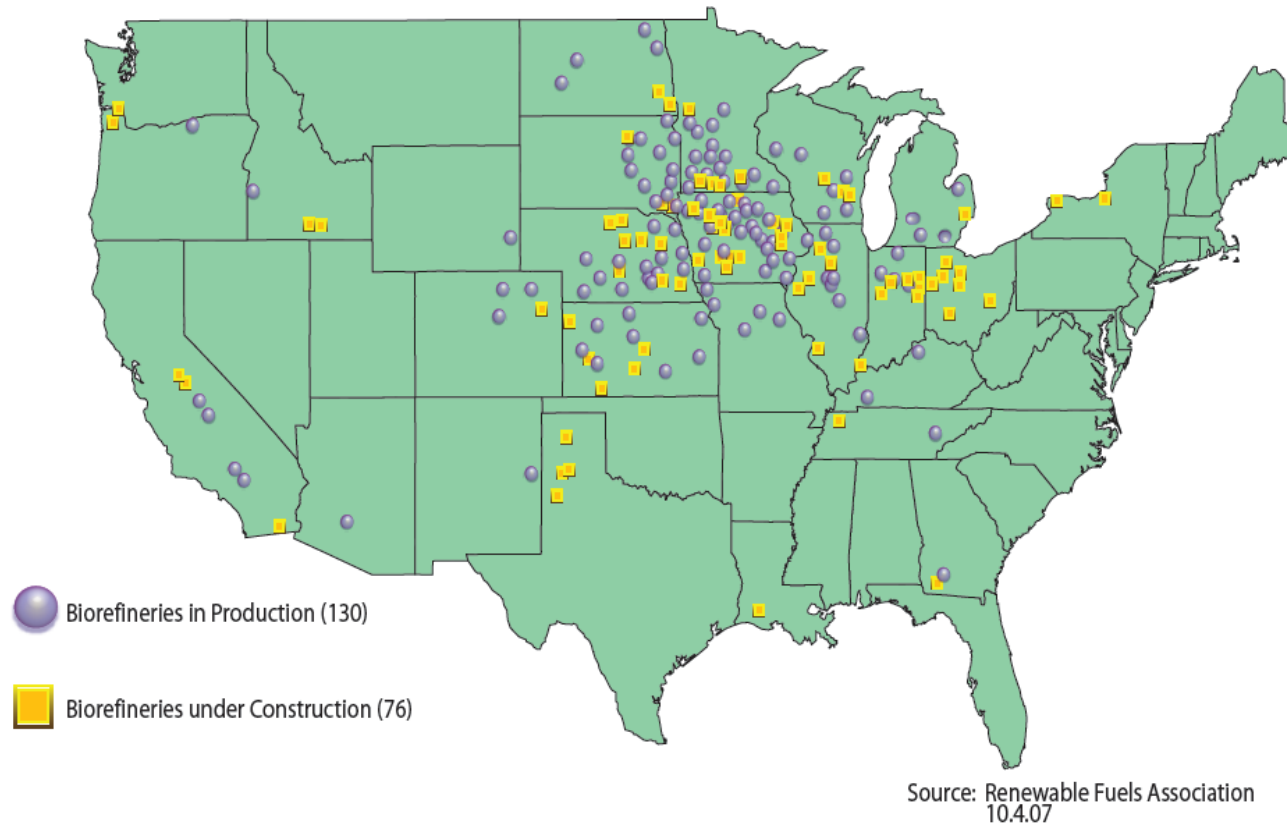
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The Problem

- Significant Interest in Ethanol
 - Oxygenating agent for gasoline
 - Alternative fuel for motor vehicles
- Biorefineries Are Not Located Near Population Centers
- Fuel Grade Ethanol (FGE) Now Transported to Blending/Distribution Facilities
 - Tanker trucks
 - Rail cars
 - Barges
- Pipelines Are the Most Efficient Method to Transport the Ethanol
- But, There are Concerns With Respect to Corrosion / Stress Corrosion Cracking (SCC)

U.S. Ethanol Production Locations



Most of the ethanol is produced in the Nation's heartland, whereas 80 percent of population lives near its coastlines

The Problem

- SCC has Been Observed in Carbon Steels in Contact with FGE
- Failures Documented Back to Early 1990s
 - User terminals
 - Storage tanks
 - Loading/unloading racks
- Majority of Cracking Found Near Welds
 - In base metal and HAZ of welds
 - Primary stress leading to SCC is residual welding stresses

Piping Failure in Distribution Terminal



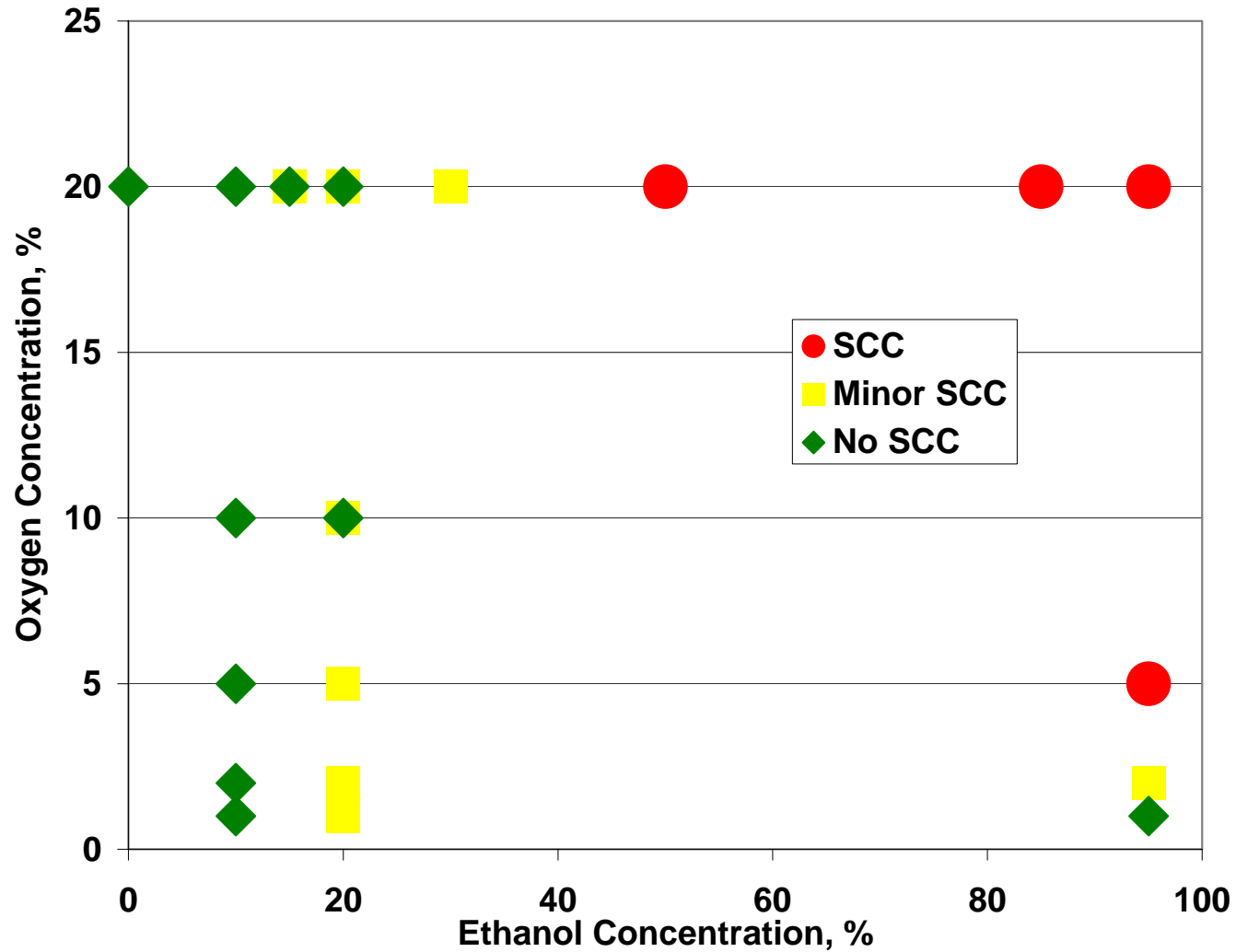
The Puzzle

- All Occurrences of SCC Were in First Major Hold Point or Downstream
 - FGE distribution terminal
 - Subsequent gas blending or distribution terminals
- No Cases Reported in:
 - Manufacturer facilities
 - Transport facilities directly following blending
 - ◆ Tanker Trucks
 - ◆ Railroad Cars
 - ◆ Barges
 - After ethanol was blended with gasoline
- No Confirmed Cases of SCC in Brazil
 - Transport hydrous (6% water) and anhydrous (<2% water) ethanol
 - Have been handling ethanol for over 30 years

Recent Findings of Slow Strain Rate Testing

- Steel metallurgical condition has a minor effect on SCC
- No SCC has been observed in E-10 under any circumstances
- No SCC has been observed in any blend ratio in the absence of dissolved oxygen
- SCC has been observed at relatively low blend ratios and in the presence of low oxygen concentration in the gas phase
 - More than 15% ethanol in ethanol-gasoline blends promoted SCC in the presence of oxygen
 - ◆ E-20 and E-85 promoted SCC
 - More than 1% oxygen in oxygen-nitrogen sparging gas promoted SCC in potent blends
- But, SSR Test is Very Aggressive
 - SCC in a SSR test does not necessarily indicate that SCC will occur in service

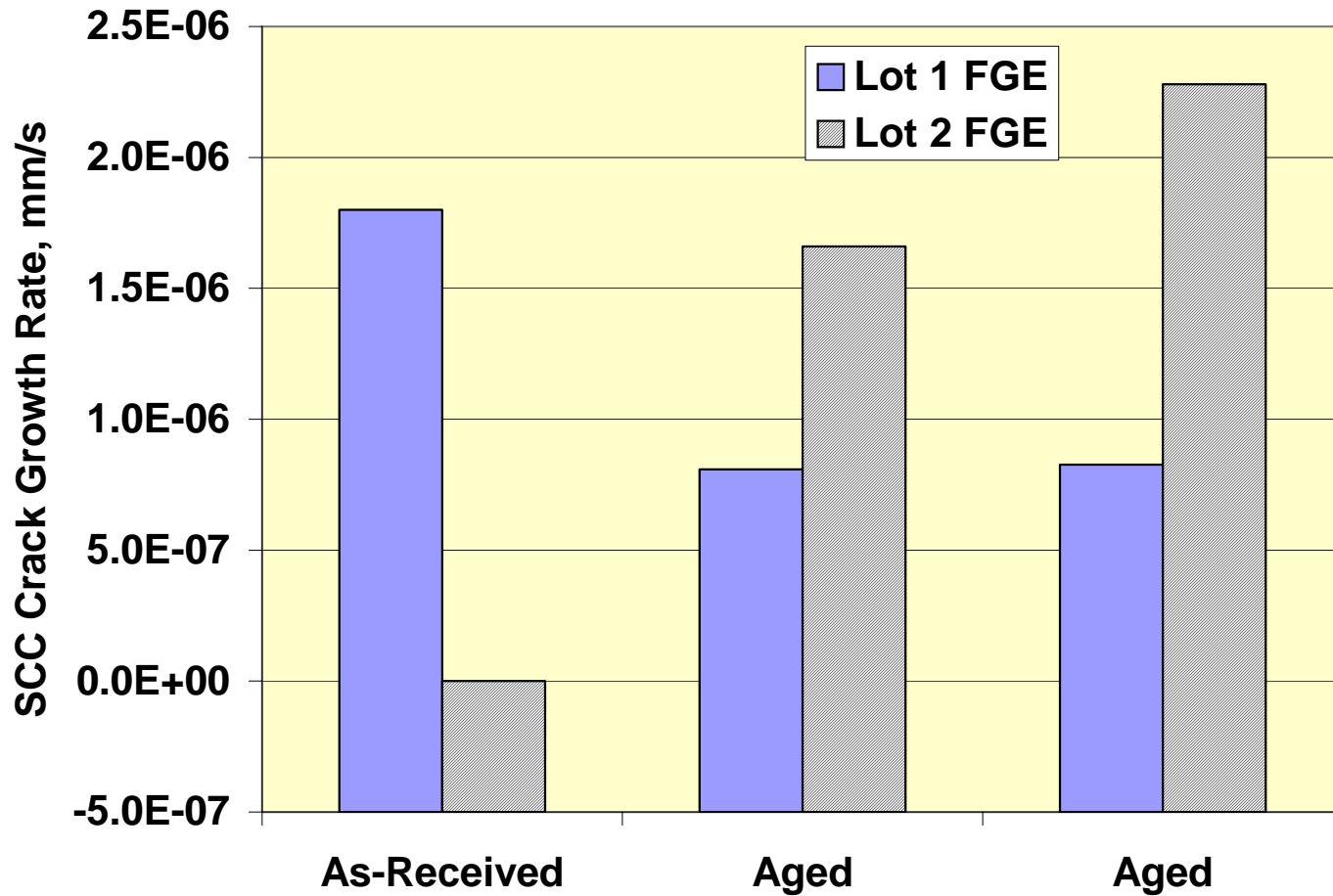
Effects of Blend Ratio and % O₂ in Gas Phase



Recent Findings

- Fuel Grade Ethanols Are Not Created Equal
 - Lot-to-lot variation in SCC potency of FGE
 - Effects of aging of FGE on SCC potency
 - ◆ Potency can increase or decrease with time

Effect of Aging on SCC Potency of FGE



Ethanol SCC Can Be Mitigated

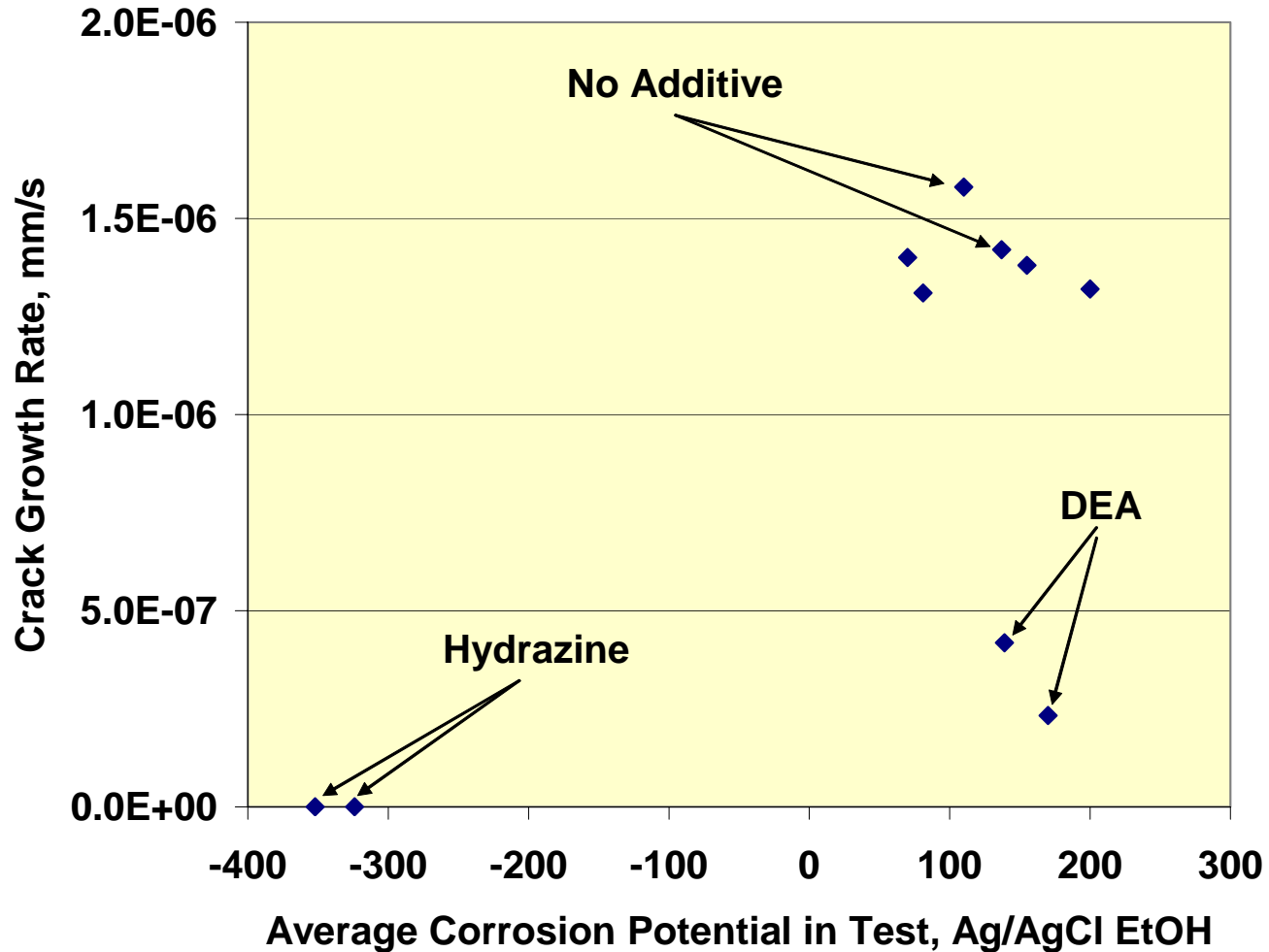
- Inhibit It
 - Diethanolamine
 - Other amines?
 - Water, but it takes a lot (4.5% to 6%)

- Get the Oxygen Out
 - Oxygen scavengers
 - Vacuum deaeration
 - Nitrogen Sparging
 - Reactive Metal

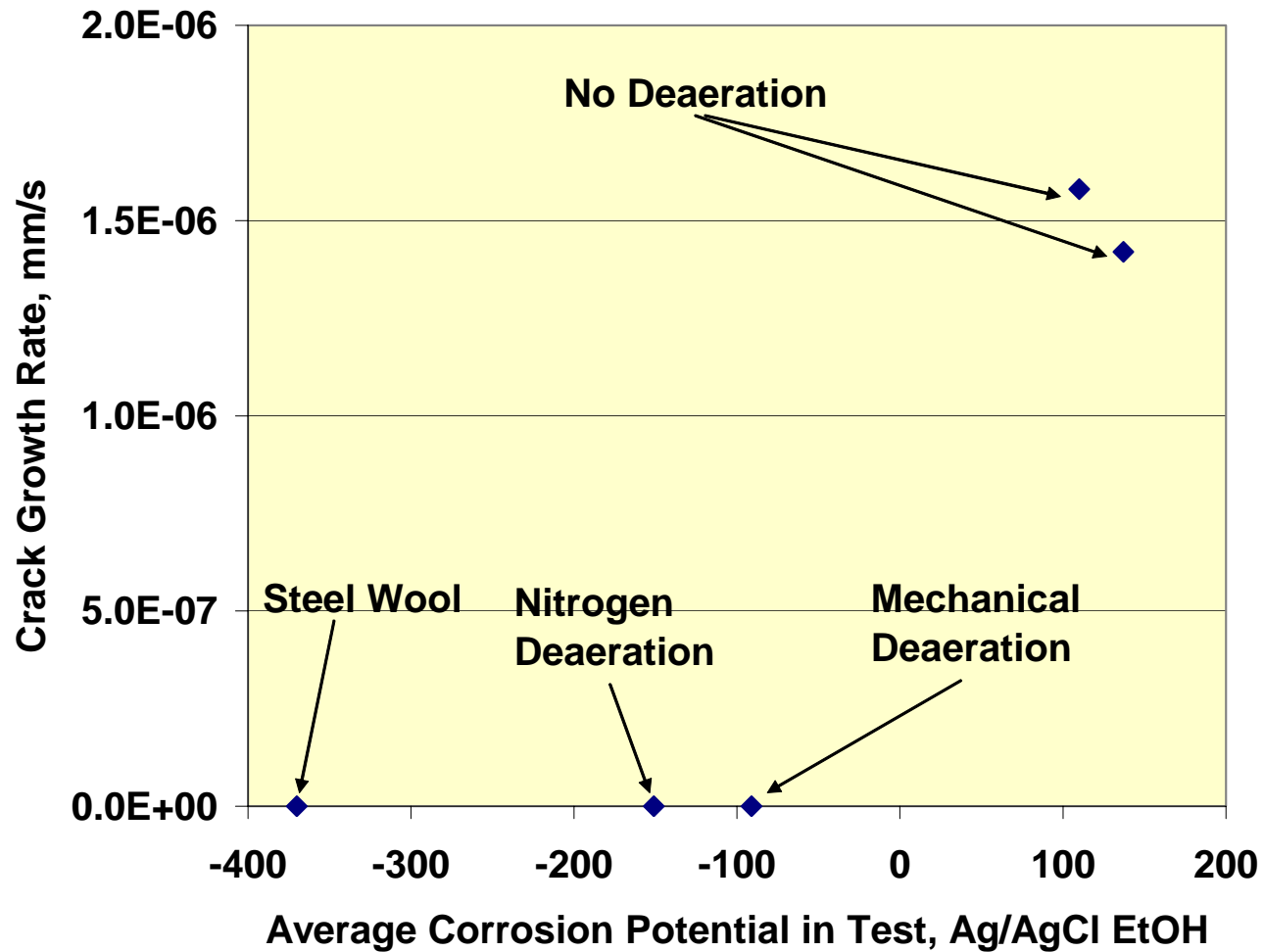
- Sacrificial Coatings to Reduce Potential
 - Untried technology
 - Impressed current CP not likely to be effective
 - ◆ Ethanol is not very conductive

- Limit Exposure Time of Ethanol to Steel
 - Time limits not known

Chemical Additives (Simulated FGE)



Other Deaeration Methods (SFGE)

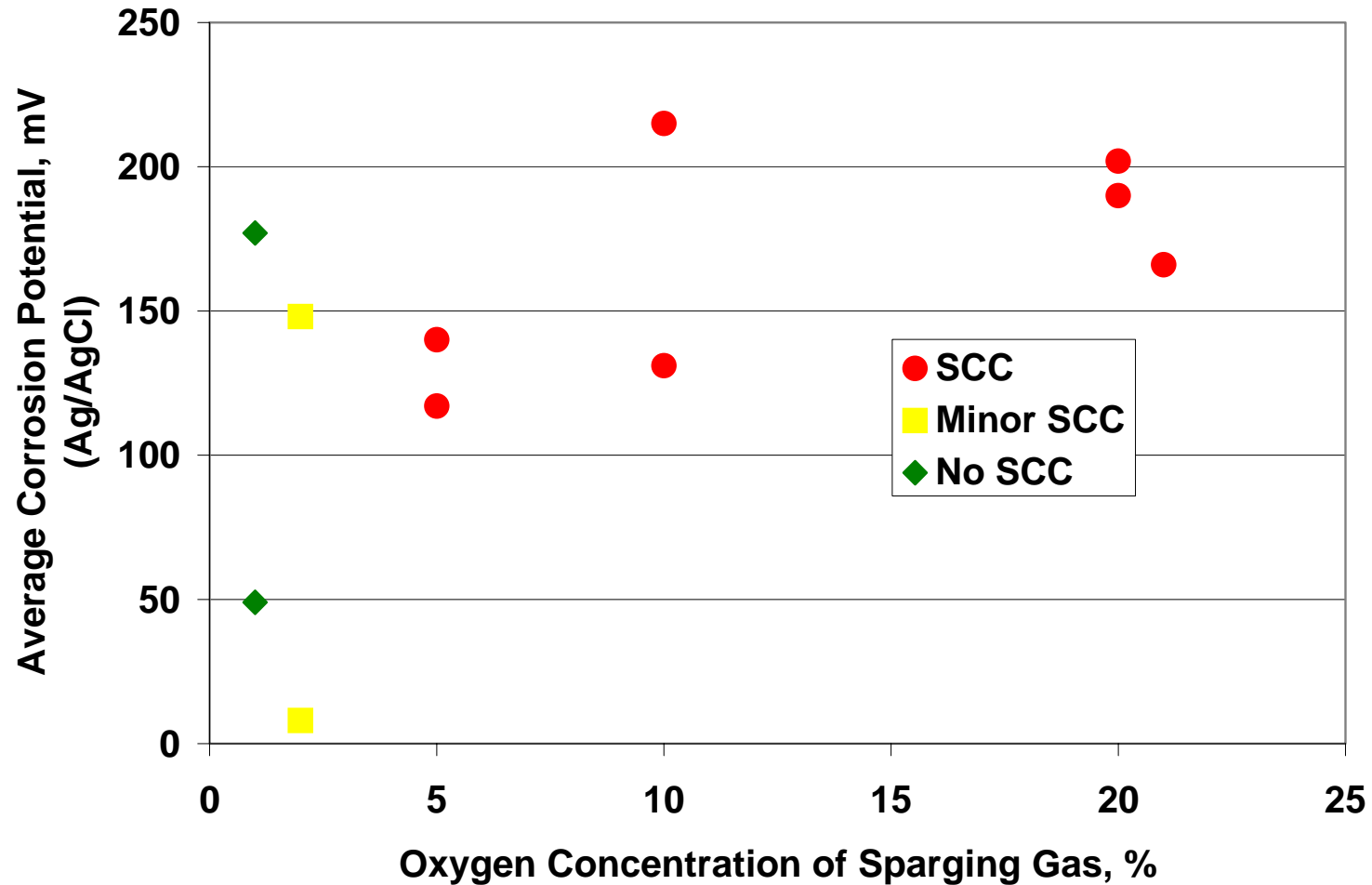


Recent Findings

- FGE and Simulated FGE Do Not Behave the Same
 - Potential Behavior
- Deaeration of SFGE Associated With Dramatic Drop in Corrosion Potential
 - SCC Mitigation
- Deaeration Also Mitigates SCC in FGE
 - Not associated with a drop in corrosion potential
- These Findings Suggest that Potential Monitoring May Not Be as Effective as Originally Thought
 - No SCC at potentials < -100 mV (still holds true)
 - May or may not have cracking at more positive potentials

Corrosion Potential vs. % Oxygen for FGE

SSR Test Results



Summary

■ We Have Learned a Lot

- ◆ Recent findings help decipher the puzzle
- Absence of SCC at biorefineries and at the front end of distribution chain likely relates to:
 - ◆ Fresh FGE characteristics (possible presence of minor organic species) and/or
 - ◆ Absence of oxygen in the ethanol
- Absence of SCC in Brazil might relate to inhibiting effects of water
- Presence of SCC further down the supply chain might be related to:
 - ◆ Aging effects and/or
 - ◆ Oxygen ingress
- Steel metallurgy does not have a big effect on SCC behavior
- Blends with higher ethanol concentrations than E-10 potentially could cause SCC
- Removing oxygen or inhibition can be effective in SCC mitigation

Summary

■ We Have a Lot to Learn

- Identifying useful inhibitors and oxygen scavengers
- Understanding the chemistry and potential behavior of FGE
- Developing field monitoring methods
- Understanding SCC behavior under more realistic loading conditions
 - ◆ The SSR test technique is very aggressive
 - ★ Great screening tool but dynamic straining does not represent field conditions
 - No SCC in test – SCC is not likely to occur in service
 - Minor to moderate SCC in test – SCC might not occur in service

Plan Forward

■ PRCI and PHMSA Funded Research

- Completed and issued an ethanol road map report
- Will complete the study of blend and metallurgical effects by June
- Initiated study of the effects of blends and batching on static and cyclic crack growth rates
- Evaluating effects of flow in pipelines on SCC
- Evaluating the effect of ethanol blends on elastomeric materials
- Will evaluate the effect of ethanol source (in collaboration with Georgia Tech and Southwest Research Institute)
- Will conduct field tests on monitoring methods (in collaboration with Aginova and Southwest Research Institute)

■ Other funded projects

- Developing monitoring and dissolved oxygen measurement methods (DNVRI)
- Developing fundamental knowledge of SCC mechanism (OSU)

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Questions?

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