NAC-10
Phase II Analysis

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Executive Summary

This document provides an analysis of the infrastructure anticorrosive coating market and oil rig anticorrosive market within which WinTec’s NAC-10 coating will compete. The analysis utilizes a multi-faceted approach to look at a wide number of key data points and assess the overall attractiveness of the various segments.

The findings and recommendations section immediately following the executive summary outlines the key points discovered in this analysis and provides strategic recommendations for future actions. Additionally, the findings and recommendations section also outlines the key areas that need to be further assessed in future studies to gain a full evaluation of this market segment.

The analysis provides a detailed analysis of eight different infrastructure segments to provide insight into the market potential for NAC-10. The eight sections provide a specific analysis of each respective opportunity and provide an evaluation of barriers to entry and market entry strategies for each.

Furthermore, the infrastructure section determines that NAC-10 has potential in nearly all nine segments and has substantial promise as an anticorrosive coating for reinforcing steel. This factory applied application would have minimal environmental impact and allow NAC-10 to exploit its superiority to traditional fusion bonded epoxies that dominate this market segment.

Finally, this analysis provides a detailed evaluation of potential for NAC-10 to act as an anticorrosive coating for oil drilling rigs. An analysis of this market size and potential is included with this document.

The body of this analysis is supported by more than twenty supporting exhibits that provide links to the data sources used to compile the main body of this analysis.
Findings and Recommendations

**Infrastructure Holds Opportunities for NAC-10**

The market for NAC-10 is robust within infrastructure. This analysis looked at infrastructure as nine distinct segments; including, highways & bridges, water & sewer, airports, natural gas distribution, pipelines, electricity, railroads, hazardous material storage tanks and waterways & ports. The need for anticorrosive protection cuts across all nine types of infrastructure. Additionally, the United States has demonstrated a willingness to commit substantial amounts of funds to addressing the woeful condition of U.S. infrastructure. In 2009, President Barack Obama signed legislation creating the $700 billion American Recovery and Reinvestment Act (ARRA) of 2009. Additionally, a forecast performed by the American Society of Civil Engineers forecasts $900 billion in infrastructure spending over the next five years, with as much as $2.2 trillion necessary to address all of the deficiencies of U.S. infrastructure. NAC-10 has the potential for use as a protective coating in many of the projects forecasted in the next five years. A 2001 study estimated the annual cost of corrosion within the United States infrastructure at nearly $30 billion.

**Insignificance of Coating Material Cost in Infrastructure Projects**

A common misconception within the infrastructure segment is that infrastructure coating materials are very costly and can significantly inflate the cost of a project. However, this analysis indicated that the actual anticorrosive coating material itself was relatively inexpensive in comparison to the total project costs. Considering the relatively insignificance of coating material costs, it should be relatively easy for WinTec to craft a sales pitch focusing on NAC-10 long-term durability and minimal increase in material costs. If NAC-10 is capable of providing a coating that can significantly increase the life expectancy of the anticorrosive coating, the overall coating costs can be significantly reduced.
For instance, on a $2 million bridge recoating project typical material coating costs are commonly around $80,000, meaning that $1.92 million of the project is same regardless of the coating system selected. Therefore if NAC-10 is able to double the useful life of the coating project from an expected life of 15 years to just 30, it is feasible to save $2 million in the next coating project. Thus, even if NAC-10 were five times the price of the current coating system at $400,000 in coating materials the 16 year cost of the NAC-10 system would be just $2.32 million as opposed to $4 million with the conventional system.

**Opportunities in Reinforcing Steel Coatings**

One of the most consistent findings of this analysis is the need for additional corrosion protection within the steel reinforcing segment of infrastructure. Steel reinforcing within infrastructure cuts across all nine segments profiled in this analysis and is currently dominated fusion bonded epoxies. The Phase I analysis discussed NAC-10 superior performance to fusion bonded epoxies and provided a basis for NAC-10 to applied to reinforcing steel applications. Currently standard FBE coated rebar has a useful life of 40 years and a cost of $0.66/kg while stainless steel rebar has a useful life of 75 to 120 years and costs $3.85/kg. The Phase I analysis, indicated that NAC-10 provided a five-fold increase in useful life when compared to FBE coatings. Applying that logic to rebar, it is easy to forecast NAC-10 coated rebar providing similar performance to stainless steel rebar, while costing considerably less.

Reinforcing steel is commonly utilized in reinforced concrete structures and will cause a failure of the concrete structure when the reinforcing steel begins to corrode. While some critical areas utilize stainless steel rebar for the superior useful life it is cost prohibitive on many applications. If NAC-10 can provide similar performance for a price in the area of $1.50/kg, it will be able to rapidly develop a reputation for quality. In addition, the rebar applications in infrastructure there are also rebar applications in many construction projects worldwide.

Additionally, considering the many environmental considerations within any market segment, there is significant potential for NAC-10 in reinforcing steel applications. The application of
protective coatings on reinforcing steel are almost exclusively performed in OEM factory situations where there is little environmental regulations regarding the discharge of controlled materials. The phosphoric acid pre-wash used in NAC-10 would be a non-issue in factory applications where appropriate controls could be built into place to allow for the safe application of the NAC-10 coating system complying to all applicable safety regulations.

U.S. Rebar Consumption
(Thousands of Tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Shipments</th>
<th>Exports</th>
<th>Imports</th>
<th>Consumption</th>
<th>Change</th>
<th>Import %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 F</td>
<td>5,892</td>
<td>525</td>
<td>480</td>
<td>5,847</td>
<td>22.60%</td>
<td>8.20%</td>
</tr>
<tr>
<td>2009 F</td>
<td>4,830</td>
<td>430</td>
<td>369</td>
<td>4,769</td>
<td>-37.20%</td>
<td>7.70%</td>
</tr>
<tr>
<td>2008</td>
<td>7,318</td>
<td>694</td>
<td>971</td>
<td>7,595</td>
<td>-20.50%</td>
<td>12.80%</td>
</tr>
<tr>
<td>2007</td>
<td>8,028</td>
<td>335</td>
<td>1,861</td>
<td>9,554</td>
<td>-1.65%</td>
<td>19.50%</td>
</tr>
<tr>
<td>2006</td>
<td>7,419</td>
<td>301</td>
<td>2,587</td>
<td>9,705</td>
<td>12.70%</td>
<td>26.70%</td>
</tr>
<tr>
<td>2005</td>
<td>7,464</td>
<td>279</td>
<td>1,424</td>
<td>8,609</td>
<td>-13.40%</td>
<td>16.50%</td>
</tr>
</tbody>
</table>

This analysis strongly recommends that WinTec consider dedicating efforts to developing NAC-10 as the premiere coating for the reinforcing steel industry segment. Reinforcing steel provides an ideal combination of market size, opportunity and strategic fit that will allow NAC-10 to flourish without having to undergo significant changes. Additionally, if NAC-10 can deliver the promised level of performance there can be significant increases to the useful life of reinforced concrete structures.

Opportunities in Bridge Coatings

Currently most typically utilized bridge coating systems provide engineers with a useful life of 15 years for structural steel bridges. The most common types of coatings utilized by modern engineers include:

- Organic zinc primer, epoxy or polyurethane intermediate coat, and aliphatic polyurethane topcoat,
- Inorganic zinc silicate primer, chemically curing epoxy or polyurethane intermediate coat, and aliphatic polyurethane topcoat,
• High-build, high solids, good-wetting epoxy primer with aliphatic polyurethane topcoat,
• Three-coat waterborne acrylic
• Three-coat, lead-free alkyd

NAC-10 has the potential to provide superior performance than virtually all of the most commonly utilized coatings in today’s infrastructure arsenal. With current epoxies provide a 15 year useful life; NAC-10 has great potential if it can provide a coating capable of lasting at least 30 years. If WinTec can price NAC-10 in a manner that will allow for it be applied to bridges at a cost of $130/ square yard applied, it has potential to quickly meet market demand.

That being said open-air applications of NAC-10 will require far more environmental clearance before it would be able to be used on exterior bridge applications. Additionally, many bridges span over waterways and water formations that will require even additional clearance of NAC-10 before it could be applied over these water formations.

**Opportunities in Water & Sewer**

As with all of the other infrastructure segments there are bountiful application opportunities for NAC-10 within the water and sewer segment as well. Within the segment there are some opportunities for NAC-10 as an exterior anticorrosive coating for water distribution lines and a protective coating for various sewer structures. However, the most promising opportunities for NAC-10 lie within water and wastewater treatment plants. There are more than 16,000 water treatment facilities and 21,564 waste water treatment plants in the United States. To gain a fuller understanding of the potential of this segment the analysis performed a site visit to the City of Youngstown Wastewater Treatment Plant to document areas of opportunity for NAC-10.

The treatment plants consist of a complicated network of steel piping and reinforced concrete structures that are frequently riddled with the negative effects of corrosion. The vast bulk of these facilities are nearing the expiration of their useful lives and requiring substantial investments to address their inadequacies. NAC-10 has the potential to be specified during
construction and significantly extend the useful life of the reinforced concrete structures, steel piping and steel pumps.

**Opportunities in Hazardous Material Storage Tanks**

Another segment of infrastructure that is a strong fit for NAC-10 is within the hazardous material storage tanks segment. There are more than 8.5 million hazardous material storage tanks in the United States with an estimate cost of corrosion of more than $7 billion annually. Additionally, within this segment nearly 65% of tank failures were as a result of exterior corrosion. With EPA regulations becoming increasingly tight beginning in 1998, there is a push for greater corrosion protection of these potentially dangerous structures. NAC-10 has potential as an exterior anticorrosive coating within this market segment. This analysis recommends that WinTec determine the relevant environmental regulations that will be applicable to allow NAC-10 to be applied in this potential market.

**Lack of Anticorrosive Coating Education**

One of the common problems plaguing the anticorrosive coating industry is a lack of education and awareness at the various agency levels. At the local level most agencies lack sufficient experience with the coating selection process and there is a common misconception that many anticorrosive coatings are cost prohibitive and fail to meet performance claims. Additionally, due to the small operating budgets at many municipalities work staff has been cut and most rely on outside engineering consultants to engineer and design various improvement projects.

This analysis recommends utilizing a pull marketing strategy where WinTec will reach out to large engineering consultants to inform them of the potential benefits and applications for NAC-10. This would provide the most cost effective way of targeting local municipalities and informing them be the products value proposition. WinTec’s objective should be to convert the engineering consultant to a coating proponent that will advocate for it to their clients. The engineering consultants would savor the opportunity to inform their clients of NAC-10 because
it helps to validate the firm as a technology leader focused on cost effective increases to project useful life.

**Slow Adoption of 3LPE & 3LPP in United States**

Three layer polyethylene and three layer polypropylene coatings are technically far superior to traditional fusion bonded epoxies. However, the traditional FBE coatings are still the dominant coating of choice for the vast majority of North American applications. This analysis attributed the slow adoption to a number of factors, but, the North American propensity to go with a short-term focus of a proven 30 year coating was one the primary reasons. The FBE coating has a proven performance track record that will last the career for a purchaser making the coating selection; making a very low risk choice. Adding to increased adoption overseas of 3LPE and 3LPP was the fact that they were largely developed overseas. 3LPE coatings were pioneered by the leading European firms where testing efforts were focused on partnering with overseas developing markets.

This analysis recommends that WinTec closely monitor the shifting FBE market in the United States. Currently, the market conditions are pushing FBE margins razor thin and perpetually driving the prices down; while applicators continue to hone and refine the FBE coating process. This is creating a situation where it makes it difficult for NAC-10 to enter the market with 3LPP and 3LPE coatings have had difficulty doing so in more than ten years. Additionally, to aid in accelerating adoption WinTec should proceed in a manner similar to the way 3LPE firms did in Europe. The coating firms partnered with leaders amongst the end-users and worked with them to design and test a coating that met their exact needs. This type of first hand interaction has significant potential to mitigate the perceived risk associated with the coating selection.

Additionally, the analysis revealed that Americans were far more likely to accept a coating that had a prequalification or met a specific industry standard. It is recommended that WinTec partner with either a respected STEM research university or a nationally recognized research institute to alleviate buyer concern. If WinTec elects to target many of the infrastructure
components outlined in this document a partnership with the Federal Highway Administration’s Turner Fairbanks Institute Material Testing Lab would be an ideal fit. Any reduction perceived risk significantly increases the marketability and potential success of NAC-10 within the market place.

**Opportunities in Oil Rig Coatings**

This analysis performed an evaluation of oil rig anticorrosive coating selection and coating process. It determined that the rig industry is fairly stagnant in the United States, however, there is potential within the offshore rig market. The offshore market carries with it a unique set of parameters making the ability to meet anticorrosive demands very difficult. The current leading coating alternative within this segment epoxy systems comply with various ISO and NACE standards.

This analysis recommends that NAC-10 focus on new projects in developing markets for potential applications of NAC-10. The best opportunities for NAC-10 lie with maintenance projects in the U.S. market specifically. WinTec has the potential to build upon the popularity of epoxy coatings and exploit their weaknesses in comparison to NAC-10 for a market entrance strategy.

It is also imperative the WinTec realize the internal coating system costs and exploit the deficiencies with the current coatings. Additionally, there is potential for NAC-10 within the market if WinTec can delve into the technical details like filler type, shape and size while becoming a part of the coatings system. It would also be greatly beneficial for WinTec to focus on NAC-10’s ability to extend coating useful life and significantly decrease the amount spent on surface preparation and surface blasting techniques. In future analysis for this section, WinTec should focus efforts on evaluating the administrative process in coating selection and develop additional research examining the most common types of corrosion protection used at these facilities.
Recommendations for Future Actions

The Phase II analysis provided an in-depth assessment in many of the areas for further consideration arising out of the Phase I work. There are additional areas that have arisen out of the Phase II document that should be considered for further evaluation in future phases. Future analysis should include:

- Assess the entry strategies to capitalize on the burgeoning reinforcing steel market potential
  - Determine what the coating process should be with the application firms
  - Clarify the end-user pull marketing strategy
  - Verify all applicable coating standards within the market segment
  - Establish relationship with STEM college or third-party testing agency to validate useful life claims of NAC-10
- Fully develop the potential for bridge coating alternatives
- Establish contacts within the wastewater and water treatment facilities to capitalize on the readily available market potential
- Develop an outreach initiative to make anticorrosive coating education a primary point for NAC-10 prospects at the local level
- Begin attempts to achieve ISO standardization for NAC-10 to avoid many of the challenges of encountered by 3LPE and 3LPP in the North American market
- Continue evaluation of oil rig coating market
  - Determine impact of environmental regulations
  - Assess potential impact of NAC-10 coating system cost savings
- Evaluate opportunities within the aerospace market segment for NAC-10
- Perform a full evaluation of supply chain inefficiencies within the oil pipe segment
- Develop market opportunities within the burgeoning nanotechnology market
  - Establish NAC-10 a high-quality innovator within nanotechnology

These action items can provide a roadmap for future evaluation as later teams working on the WinTec NAC-10 market evaluation.
Project Approach

Project History

Phase II of this analysis began in January 2011; building upon the evaluation performed over the fourth quarter of 2010. The Phase I analysis performed an evaluation of WinTec’s initiatives focusing NAC-10 opportunities within the petrochemical marketplace. The Phase I analysis focused on eight key points for evaluation:

- Evaluate the Current Issues Facing the Petrochemical Industry
- Determine and Evaluate the Regulator Requirements Regarding NAC-10
- Evaluate the Needs of End-Users of Anti-Corrosive Coatings within the Petrochemical Industry
- Determine the Competitive Landscape of Anti-Corrosive Coatings within the Petrochemical Industry
- Evaluate and Compare the Complexity of the NAC-10 Coating System with that of Competitors
- Evaluate the Impact of a Catastrophic Corrosion Failure on both the End-User and the Coating Developer
- Examine Existing Supply Chains of End-Users and Determine Potential Savings by Using NAC-10
- Utilizing the Totality of Data Gathered to Quantify the Financial Impact of Using NAC-10

The project charter for the Phase I analysis is included with this document as Exhibit One and the full Phase I project scope and approach is included as Exhibit Two. Building upon the key findings and recommendations from the Phase I analysis, a project plan was developed for the Phase II analysis.

Phase II Project Plan

As the Phase II project began to proceed, a proposed project scope was developed by the Youngstown State University team to outline the areas for further evaluation. The initial
project scope is included as *Exhibit Three*. As Phase II got underway, a slight change in focus occurred with the Tagos Group directing the YSU research team to divert resources away from petrochemical pipeline focus and instead fully evaluate the potential available within the oil rig protective coating segment. Integrating the new focus into the existing project plan developed a final strategy encompassing a multi-faceted approach to evaluate opportunities for NAC-10.

The final project scope provided an in-depth evaluation of opportunities recommended for further evaluation during Phase I. The areas of evaluation for Phase II included:

- An in-depth evaluation of opportunities available with the infrastructure market
  - Evaluation of market size, barriers to entry, market potential, regulatory oversight and market entrance strategies for each infrastructure segment
  - Infrastructure segments include: highways & bridges, water & sewer, airports, oil & gas, gas pipelines, electricity, railroads, hazardous material storage, and waterways & ports
- Evaluation of reasons for slow adoption of three layer polyethylene and three layer polypropylene coating systems in North America
  - A point of reference for the North American market’s willingness to accept new coating technologies
- Analysis and evaluation of opportunities utilizing NAC-10 as an protective coating on oil drilling rig applications
  - Areas of evaluation included: market size, market segmentation, market potential and evaluation of current coating systems
- Summary of short-comings with existing petrochemical pipeline supply chains
  - Phase I revealed inefficiencies within the existing supply chains that could be remedied by the use of NAC-10

The above summary of the Phase II actions provides only a brief overview of the work areas evaluated; *Exhibit Four* provides a finalized project scope for the Phase II analysis.
**Infrastructure Anticorrosive Coatings**

**Overview**

During the Phase I analysis of NAC-10, it became incredibly apparent that firms within the anticorrosive coating industry were beginning to shift resources and focus additional efforts on the infrastructure market. This was quickly noted and flagged as an area for further evaluation during Phase II of the project. During Phase II of the project, significant time was designated to perform a full evaluation of anticorrosive coatings for infrastructure and provide a realistic estimation of the overall potential of this marketplace.

After completing the evaluation contained further in this section, the analysis strongly recommends that WinTec continue to make efforts to capitalize on the potential of the infrastructure market. The analysis revealed substantial costs for corrosion within the infrastructure marketplace and a significant diverse selection of substrates for NAC-10 protective coatings. Additionally, with the continued growth of investment in United States infrastructure the potential of this market is forecasted to grow.

Some of the most promising areas for potential NAC-10 application within the infrastructure market can be found in traditional areas like steel bridge super structures, reinforcing bar (re-bar) and natural gas distribution lines. However, one of the most promising areas for potential applications of NAC-10 can be found in water and wastewater applications, both in collection and distribution systems and within treatment plants themselves. Additionally, research revealed a significant potential for growth within the electrical market as a protective coating within the electrical distribution grid components.

Overall, the analysis recommends that WinTec fully explore the potential of NAC-10 within the infrastructure market. There appears to be a plethora of opportunities available that NAC-10 would quickly fill and enable an immediate improvement over contemporary coatings serving the infrastructure market.
Some of the unique challenges facing entrance into the infrastructure market include significant regulatory oversight and materials testing, a diverse set of stakeholders with strong held political beliefs and the lack of an existing reputation within the infrastructure coating marketplace.

**Market Potential**

*Introduction*

This analysis looks primarily at the potential within the United States of America infrastructure market. This is being performed for several reasons; including, an increased spending on infrastructure within the USA and the perception that it may be easier for WinTec to develop a domestic reputation for NAC-10 rather than attempting to move overseas and target new markets. Additionally, the success of WinTec at attracting USA government contracts for their various ballistics and blast proof products indicates a strong ability to capitalize on the opportunities the infrastructure market has to offer.

As previously discussed, the United States has demonstrated a recent commitment to addressing current inadequacies in the condition of infrastructure. In 2009 President Barack Obama and Congress passed the American Recovery and Reinvestment Act of 2009 (ARRA). ARRA created $787 billion allocations for various projects including a significant number of infrastructure applications. $140 Billion of the allocations were earmarked by Congress for infrastructure investments\(^1\).

*Table I-1* lists the allocations by the Senate and the House of Representatives within the infrastructure investment section; while *Charts I-2* and *I-3* provide a graphical representation of the data.

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### Table I-1

ARRA 2009 - Allocations

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Billion Dollars</th>
<th>Senate</th>
<th>Percentage</th>
<th>House</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation Projects</td>
<td></td>
<td>$7.50</td>
<td>12%</td>
<td>$8.00</td>
<td>10%</td>
</tr>
<tr>
<td>Highway and Bridge Construction/Repair</td>
<td></td>
<td>$27.00</td>
<td>44%</td>
<td>$27.00</td>
<td>35%</td>
</tr>
<tr>
<td>Mass Transit &amp; Rail Projects</td>
<td></td>
<td>$11.50</td>
<td>19%</td>
<td>$12.00</td>
<td>15%</td>
</tr>
<tr>
<td>Army Corps of Engineers</td>
<td></td>
<td>$4.60</td>
<td>7%</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>Public Housing Improvements</td>
<td></td>
<td>$5.00</td>
<td>8%</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>Clean and Drinking Water Projects</td>
<td></td>
<td>$6.40</td>
<td>10%</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>Building and Repairing Federal Buildings</td>
<td></td>
<td>0%</td>
<td></td>
<td>$31.00</td>
<td>40%</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td>$62.00</td>
<td></td>
<td>$78.00</td>
<td></td>
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</table>

### Chart I-2

**Proposed Senate Spending -2009**

- Transportation Projects: 12%
- Highway and Bridge Construction/Repair: 44%
- Mass Transit & Rail Projects: 19%
- Army Corps of Engineers: 7%
- Public Housing Improvements: 0%
- Clean and Drinking Water Projects: 10%
- Building and Repairing Federal Buildings: 0%
Within the allocated funds were distributed to all levels of the government including federal agencies like the Army Corps of Engineers, State Departments of Transportations and local municipalities. The spread of allocations allowed all levels of government to spend on improvements and repairs to infrastructure, having a significant impact on the recipients of the funding allocations.

ARRA enabled local governments to address many of the immediate needs facing them and also encouraged them to focus on future investments in infrastructure and take a preventative approach to future maintenance.

Gross public spending on transportation and water and sewerage systems, including spending on new capital and operation and maintenance of existing capital, constitutes 2.4 percent of GDP according to the available most recent sources. Chart I-4 below provides a graphical representation of infrastructure spending between 1956 and 2004.
Despite the intense focus on federal earmarking and spending, the majority of infrastructure spending happens at the state and local level. State and local spending on infrastructure constitutes three-fourths of total public infrastructure spending. The remaining fourth originates at the federal level, with one-third of these federal funds in the form of direct federal spending, and two-thirds in the form of federal grants and loan subsidies to state and local governments. In addition to differing in magnitude, federal spending and state and local spending differ in their focus. Federal spending on infrastructure is focused on investment in new capital, while state and local spending is focused on operation and maintenance of existing infrastructure, especially highways and roads.

Over time spending has shifted relatively from new capacity to operation and maintenance of existing capacity. Transportation investment as a whole has undergone a shift to operation and maintenance, but new capital spending has actually risen for mass transit and aviation while falling for highways and water transportation.
This discussion clearly shows the areas of opportunity for WinTec’s NAC-10 coating. With a bulk of highways and water transportation in the need for operation and maintenance over the next few years, NAC-10 could help these structures operate smoothly and lower the maintenance costs. Also since most of the funding is provided by local and state departments, WinTec’s already existing contacts and expertise in the field of government projects could help them easily transition into the public infrastructure market.

The impact of corrosion on the United States infrastructure components is a serious problem capturing the attention of various government agencies. In 2001, the federal government sponsored an in-depth analysis of corrosion costs to gain a fuller understanding of the problems corrosion problems facing U.S. infrastructure.
In 2002, the total annual estimated direct cost of corrosion in the U.S. was estimated to be $276 billion, or about 3.1% of the nation's gross domestic product (GDP), according to a study initiated by National Association of Corrosion Engineers International (NACE).

The North American market for anticorrosion technology used in paints and coatings is estimated by ChemQuest to be approximately $210 million, with $75 million attributed to the cathodic protection technology, $70 million to barrier protection, and $65 million to inhibitors. Industrial maintenance accounts for 57% of the total, and OEM applications the remainder. The global market is valued at about $590 million by the consultancy, with barrier protection the largest segment ($270 million, 46%), followed by inhibitors ($200 million, 34%), and sacrificial additives ($120 million, 20%). "North America tends to use more sacrificial coatings than the rest of the world because the value of assets to be protected is greater and there is also more ready access to the high quality sand blasting equipment required to prepare the raw steel as compared to the rest of the world."

**Anticorrosive Coatings in Infrastructure**

*Introduction*

While examining the competing coating design firms during Phase I, it became apparent that a number of firms were electing to dedicate more resources to protective coatings for infrastructure applications. Nearly all firms evaluated were either developing or acquiring new technologies to satisfy the needs of the infrastructure markets. This can be for a number of different reasons; however, this analysis attributes it largely to the fluctuations in the industrial coatings segment.

This past year Valspar experienced a decrease in revenues of more than 22% within the industrial coating segment. Industrial firms are extremely sensitive to economic downturns and may elect to put-off industrial expenditures on new coatings that may still have a marginal
amount of useful life left. By diversifying into infrastructure coatings that are less economically dependent, WinTec will be able to generate more stable revenue streams.

Additionally, the infrastructure segment is less of a high-risk industry where it will be easier to gain penetration without an existing reputation. Within the infrastructure segment, anti-corrosive coatings are less intensive decision and there are a far greater number of coating applications available.

**Firm Specific Infrastructure Coating Information**

While examining 3M\(^2\) it became apparent that one of their primary strengths laid in the firm’s infrastructure specific coating segments. Detailed information on 3M’s product portfolio and strategic actions can be found in *Exhibit Five*. 3M’s corrosion protection products are targeted at the following six industry segments.

- Oil and Gas
- Water Infrastructure
- Building and Construction
- Utilities and Power
- Transportation Infrastructure
- Production and Manufacturing

Of the six segments, half fall within the confines of infrastructure as this analysis defines it. Water infrastructure, utilities and power, and transportation infrastructure are core components of 3M’s strategic marketing plan. Additionally, in January of 2009 3M completed a purchase of Alltech Solutions. This move signaled 3M’s shift to gain market share within the infrastructure segment of the marketplace. Alltech Solutions built a reputation based upon innovative coating products to aid in the rehabilitation of drinking water distribution pipes.

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\(^2\) Company Filings, 3M 2009 Annual Report
An examination of PPG Industries revealed similar data to the evaluation of 3M. A full analysis of PPG can be found in *Exhibit Six*. Two of PPG’s four divisions are dedicated to serving the infrastructure market defined by this analysis. PPG’s civil and infrastructure coatings segment covers anti-corrosive coatings for use in bridges, pipelines, water and wastewater treatment plants, water transmission lines and water storage tanks. PPG’s power coatings are designed for applications in fossil fuel plants, nuclear energy plants, hydroelectric generation plants, wind energy generation and power transmission towers.

Additionally, in 2008 PPG completed the acquisition of Sigma Coatings. Sigma Coatings specializes in protective coatings, specifically within the infrastructure segments. Similar to 3M this acquisition, demonstrates PPG’s commitment to the fully capitalizing on the infrastructure segment of the protective coatings.

A further review of data from the Phase I analysis of competing firms within the coating industry will reveal a further delineation of current market trends. Collectively the competing firms have made it a priority to dedicate a significant amount of resources to capturing the potential of the infrastructure marketplace. The shift has included new research and development activities, acquisition of coating leaders in the infrastructure market and restructuring of operations to allow the firm to be best situated to exploit the infrastructure anticorrosive coating market.

**Contemporary Coating Overview**

Prior to delving into the specific infrastructure segments and their respective coating needs, this analysis determined it would be prudent to provide a brief overview of some of the contemporary coating systems being utilized in the marketplace today. A detailed analysis of this section and the supporting sources can be found in *Exhibit Seven*. When examining the

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3 Reuters, *PPG Reuter's Description* and *Annual Report* p. 2, *Annual Report*
primary coatings for today’s infrastructure applications it becomes apparent that they can be placed in three separate categories; chemically induced polymerized coatings, heat induced polymerized coatings and hydrolysis induced polymerized coatings. Within each type of coatings there are a vast number of sub-categories; however, this section will provide a brief overview of some of the market leaders within each.

Chemically induced polymerized coatings consist of several prominent coatings for infrastructure applications: epoxies and polyurethanes. These versions of epoxies have developed a reputation for superior adhesion to the substrates and high-levels of chemical resistance. Additionally, polyurethanes have proven very adept at providing long-term anticorrosive coatings on steel substrates. The polyurethanes have also proven capable of providing strong aesthetic qualities, making them ideal for bridge and other highly visible applications.

The segment of heat induced polymerized coatings include the North American leading fusion bonded epoxies. FBEs have proven to be highly effective anti-corrosive coatings providing approximately 30 years of useful protection in ideal conditions. FBEs have also been prominently featured in pipeline applications and concrete rebar applications. Also falling within this category are polyester and vinyl esters that are ideal for protective tank liners due to their fiberglass characteristics. Phenolyic coatings within this segment are also well suited for protective coatings on storage tanks of highly-acidic acids and strong solvents. Silicone-based anticorrosive coatings also fall within the category of heat induced polymerized coatings. Silicone-based anticorrosive coatings are a strong fit for furnace and boiler applications where acidic or corrosive environments exist due to their superior heat resistance.

Finally, the hydrolysis induced polymerized coatings consist of some basic coatings that when paired with other contemporary coatings provide an exemplary anticorrosive coating system. For instance, inorganic zinc coatings fall within this category and are a simple, yet incredibly effective, way to protect a substrate. The inorganic zinc coating is applied to a steel substrate
where it forms a network of individual anodes that act to sacrificially protect the substrate by drawing corrosion away from it. Additionally, the inorganic zinc coatings can be topped with a chemically induced polymerized coating, like an epoxy or polyurethane, to provide a long-lasting anticorrosive protection system. This type of system is frequently used on many bridge applications.

While examining the entirety of the protective coating market it is imperative accurately segment the coating applications to adequately understand the nature of the market size and potential. According to data from the 2000 United States Census/Department of Commerce, Economics and Statistics Administration; the coating industry can be segmented into architectural coatings, OEM coatings, special-purpose coatings and miscellaneous coatings. For the purpose of this analysis the primary points of consideration are architectural coatings, OEM coatings and special-purpose (industrial) coatings. A summary of the relevant data for the segments is depicted below in the table below.

<table>
<thead>
<tr>
<th>Year</th>
<th>TOTAL</th>
<th>ARCHITECTURAL COATINGS</th>
<th>OEM COATINGS</th>
<th>SPECIAL-PURPOSE COATINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Value</td>
<td>Quantity</td>
<td>Value</td>
</tr>
<tr>
<td>1999</td>
<td>1,486.30</td>
<td>18,012.30</td>
<td>677.1</td>
<td>6,816.20</td>
</tr>
<tr>
<td>1998</td>
<td>1,443.70</td>
<td>17,298.20</td>
<td>631.6</td>
<td>6,115.20</td>
</tr>
<tr>
<td>1997</td>
<td>1,472.80</td>
<td>16,559.50</td>
<td>655.6</td>
<td>6,264.90</td>
</tr>
<tr>
<td>1996</td>
<td>1,468.20</td>
<td>16,554.70</td>
<td>640.3</td>
<td>6,246.30</td>
</tr>
<tr>
<td>1995</td>
<td>1,407.20</td>
<td>15,923.70</td>
<td>622.5</td>
<td>6,057.10</td>
</tr>
<tr>
<td>1994</td>
<td>1,431.10</td>
<td>15,645.20</td>
<td>644.8</td>
<td>5,888.30</td>
</tr>
<tr>
<td>1993</td>
<td>1,336.50</td>
<td>14,630.10</td>
<td>608.1</td>
<td>5,615.30</td>
</tr>
<tr>
<td>1992</td>
<td>1,236.00</td>
<td>13,595.10</td>
<td>575.6</td>
<td>5,294.30</td>
</tr>
<tr>
<td>1991</td>
<td>1,226.80</td>
<td>13,009.40</td>
<td>537.9</td>
<td>4,900.70</td>
</tr>
<tr>
<td>1990</td>
<td>1,281.90</td>
<td>12,898.40</td>
<td>558.4</td>
<td>4,913.60</td>
</tr>
</tbody>
</table>

Additionally, according to data from Exhibit Seven the average costs of anti-corrosive coatings can vary greatly from manufacturer-to-manufacturer. That being said, the data indicated that

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some average prices can be extracted for normal situations. The data on average coating cost are listed in the table below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Low Cost</th>
<th>High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Coatings</td>
<td>$ 30</td>
<td>$ 50</td>
</tr>
<tr>
<td>Polyurethane Coatings</td>
<td>$ 75</td>
<td>$ 100</td>
</tr>
<tr>
<td>Industrial Acrylics</td>
<td>$ 12</td>
<td>$ 15</td>
</tr>
</tbody>
</table>

It is also critical to note that the actual cost of the coating material is a relatively insignificant portion of the total coating costs. For instance, a 1999 study by the SSPC and WEH Corporation\(^6\) examined the coating costs for an above ground storage tank and found that the material coating costs consisted of only 19% of the total project costs. The graphic below provides a full breakdown of relevant costs for the coating project.

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When examining more traditional infrastructure applications, like bridge painting the insignificance of coating material cost is even more striking. In a 1995 study by the U.S. Federal Highway Administration’s Turner-Fairbanks Institute\(^7\), it was revealed that coating material costs consisted of only four percent of the total project costs to re-coat a steel highway bridge. The graphic below provides a full breakdown of project costs.

![Pie chart showing project costs distribution.]

Considering the relatively insignificance of coating material costs, it should be relatively easy for WinTec to craft a sales pitch focusing on NAC-10 long-term durability and minimal increase in material costs. If NAC-10 is capable of providing a coating that can significantly increase the life expectancy of the anticorrosive coating, the overall coating costs can be significantly reduced. For instance, on a $2 million bridge recoating project material coating costs may be only $80,000, meaning that $1.92 million of the project is same regardless of the coating system selected. Therefore if NAC-10 is able to double the useful life of the coating project from an expected life of eight years to just 16, it is feasible to save $2 million in the next coating project.

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Thus, even if NAC-10 were five times the price of the current coating system at $400,000 in coating materials the 16 year cost of the NAC-10 system would be just $2.32 million as opposed to $4 million with the conventional system.

**Infrastructure Market Segmentation**

As previously discussed in this analysis, the market for anticorrosive coatings in the infrastructure market cuts across multiple segments; for the purpose of this analysis the segments have been defined to include nine distinct market segments.

- Highways & Bridges
- Water & Sewer
- Airports
- Natural Gas Distribution
- Electricity
- Railroads
- Hazardous Material Storage
- Waterways & Ports

A detailed analysis of each market segment is included below.

**Highway & Bridges**

According to data from *Exhibit Eight* the annual direct cost of corrosion for United States highway bridges is estimated between $6 and $10 billion\(^8\). Of that amount $500 million is spent on steel bridge painting annually. Additionally, with concrete bridge structures nearly $6 billion is spent annually on superstructure and substructure maintenance and replacement. Combining all costs across concrete and steel bridge applications, a realistic estimate of $8.29 billion is spent addressing bridge corrosion in the United States. Additionally, over a five year period from 1995 to 1999 the cost to replace an average bridge has increased 12%.

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Bridges fall into three main categories which will be explored individually to determine the likely NAC-10 applications for each. A detailed evaluation of each can be found in *Exhibit Eight*. The bridge categories include:

- Reinforced Concrete
- Prestressed Concrete
- Steel

Reinforced concrete bridges typically fail as a result of the corrosion of the steel reinforcing within the concrete structure. As the concrete contracts during curing, small fissures and cracks develop allowing water to work into the structure down to the reinforcing steel enabling corrosion. In cold climates, roadway salt will be washed away by water and into the fissures. Once the saltwater reaches the steel reinforcing, corrosion rates are accelerated causing further damage. As the corrosion continues the rebar expands causing additional cracking and spalling of the concrete structure. The attached exhibit below depicts the concrete failure.

![Diagram of chloride-induced macrocell corrosion on top rebar, expansion of corrosion product produces tensile stresses in concrete, and tensile stresses in concrete lead to cracking/spalling.]

It is virtually impossible to avoid this type of corrosion in existing reinforced concrete structures. However, contemporary construction is shifting toward using low sump concrete mixtures and protective coatings on the rebar to avoid surface corrosion once the water reaches the steel.
The currently the standard protective coating is an FBE coated rebar to mitigate corrosion abilities. Current construction practices have extended the useful life of these types of structures to 75 to 120 years under ideal conditions. In terms of opportunity for NAC-10, the coating would basically only have an opportunity as a factory applied OEM coating for rebar on these applications.

Prestressed concreted bridges utilize a system of reinforcing the perpetually holds the concrete structure in a state of compression, therefore significantly increasing efficiency. The advent of prestressed concrete bridges is a relatively recent development in bridge construction, resulting in many of the structures being relatively young. However, these types of structures are more susceptible to rebar corrosion causing serious structural problems. Any degradation of the structural tensioning and reinforcing steel can cause a catastrophic bridge failure, making the need for adequate corrosion protection imperative.

The bulk of corrosion protection in these structures is performed through high-performance concretes and cathodic protection to increase useful life. The tensioning of the structure components make it difficult for the use of protective coatings in these structures which results in many currently turning to stainless steel reinforcing.

Steel bridges typically fail as result of the structural steel becoming exposed to atmospheric elements. Any corrosion points are greatly increased as the surface is exposed to salt spray from roadway salt. The only way to adequately protect these structures is through a barrier coating protecting the surface from corrosion. United States Environmental Protection Agency (EPA) requirements have greatly changed the approach to bridge coating. Prior to the mid 1970s the bulk of structures were protected with lead based coatings. Due to substantial costs to adequately remove the lead based coatings that cover the bulk of the U.S. bridges, the vast majority of applications elect to simply overcoat the lead-based coating to avoid costly removal and remediation costs. Prior to the advent of stricter environmental standards, bridge recoating could be performed for approximately $18 per square meter of steel. However, with
the increased regulation and requirements that numbers have increased tenfold. The table below lists the relevant regulations affecting the coating process.

<table>
<thead>
<tr>
<th>IMPACTING REGULATION</th>
<th>EFFECT ON COATING OPERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA; Resource Conservation and Recovery Act (RCRA), 1976</td>
<td>Regulates the handling, storage, and disposal of lead- (and other heavy metal) containing waste. Can increase the cost of disposal of waste from bridge paint removal by a factor of 10.</td>
</tr>
<tr>
<td>EPA; Title X, Residential Lead-Based Paint Reduction Act of 1992</td>
<td>Mandates training and supervision requirements for workers associated with lead-containing paint removal.</td>
</tr>
<tr>
<td>EPA; Comprehensive Environmental Response Compensation and Liability Act (CERCLA 1980 and Superfund 1986)</td>
<td>Assigns ownership of and responsibility for hazardous waste to the generator “into perpetuity.”</td>
</tr>
<tr>
<td>EPA; Clean Water Act, 1972</td>
<td>Regulates discharge of materials into waterways.</td>
</tr>
<tr>
<td>EPA; Clean Air Act Amendments, 1970</td>
<td>Mandates restrictions on allowable VOC content of paints and coatings. Regulates discharge of dust into air from bridge painting operations.</td>
</tr>
</tbody>
</table>

Overall there is significant potential for coatings within the bridge market. According to a 1997 study by the Federal Highway administration found more than 93,119 bridges structurally deficient in the United States. The table below breaks down that data based upon the bridge construction types previously discussed9.

<table>
<thead>
<tr>
<th>CONVENTIONAL REINFORCED CONCRETE</th>
<th>PRESTRESSED CONCRETE</th>
<th>STEEL</th>
<th>OTHER</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges in Inventory</td>
<td>235,151</td>
<td>107,666</td>
<td>200,202</td>
<td>40,395</td>
</tr>
<tr>
<td>Structurally Deficient</td>
<td>21,164</td>
<td>3,230</td>
<td>54,054</td>
<td>14,671</td>
</tr>
<tr>
<td>Percent Deficient</td>
<td>9</td>
<td>3</td>
<td>27</td>
<td>36</td>
</tr>
</tbody>
</table>

9 The Status of the Nation’s Highway Bridges: Highway Bridge Replacement and Rehabilitation Program (HRRRP) and National Bridge Inventory, FHWA, Thirteenth Report to the United States Congress, May 1997.
As witnessed from the above data the most striking number is that 27% of the steel bridges are structurally deficient requiring immediate replacement or remediation. The case studies indicated that one of the primary reasons for the deficiencies has to do with a focus on maintaining only what budgets allowed instead of performing maintenance as the life-cycle analysis recommended. Additionally, most agencies perceive anticorrosive coatings as very expensive and elect to forego them without even considering the options fully.

**Anticorrosive Rebar**

To confront the challenges of corrosion in bridge and highway applications there are a number of alternative providing cost effective ways to increase useful life. In *Exhibit Nine* the analysis provided a detailed overview of the differing types of rebar available today and the effects on useful life. The table below provides a summary of the impacts that the differing types of rebar have on useful life and project costs\(^{10}\). The types of rebar included in this analysis include: black steel, epoxy coated\(^ {11}\), stainless steel\(^ {12}\), stainless steel clad, calcium nitrate and silica fume.

<table>
<thead>
<tr>
<th>CORROSION CONTROL PRACTICE</th>
<th>COST OF BAR</th>
<th>BAR WEIGHT PER DECK AREA</th>
<th>COST PER DECK AREA</th>
<th>INCREASE IN COMPARISON TO BASELINE</th>
<th>PERCENT INCREASE</th>
<th>ESTIMATED SERVICE LIFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black steel (baseline)</td>
<td>$0.44 kg</td>
<td>26.4 kg/m²</td>
<td>$11.60/m²</td>
<td>NA</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>2-layer epoxy-coated rebar</td>
<td>$0.65 kg</td>
<td>26.4 kg/m²</td>
<td>$17.40/m²</td>
<td>$5.80</td>
<td>1.2%</td>
<td>40</td>
</tr>
<tr>
<td>2-layer solid SS rebar</td>
<td>$3.85 kg</td>
<td>26.4 kg/m²</td>
<td>$101.64/m²</td>
<td>$90.04</td>
<td>18.6%</td>
<td>75 - 120</td>
</tr>
<tr>
<td>2-layer SS-clad rebar</td>
<td>$1.54 kg</td>
<td>26.4 kg/m²</td>
<td>$40.66/m²</td>
<td>$29.00</td>
<td>6.0%</td>
<td>50</td>
</tr>
<tr>
<td>Calcium Nitrite CIA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$5.40</td>
<td>1.1%</td>
<td>30</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$4.30</td>
<td>0.9%</td>
<td>20</td>
</tr>
</tbody>
</table>

Examining the table above presents a series of opportunities for NAC-10 within the rebar market segment. Bench tests of NAC-10 discussed in the Phase I analysis revealed that the

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coating system was providing five times the anti-corrosive protection of FBE coatings. Applying that logic to the rebar data above, NAC-10 should be able to achieve an estimated service life of 200 years. That sounds like a bit of an outlandish claim that many end-users would instantly discredit because of its preposterous sound. However, if the bench test are accurate it is very feasible to believe that an NAC-10 coated piece of rebar will be at least capable of performing comparably to stainless steel rebar (75-120 years). If NAC-10 is proven to meet that useful life projection, WinTec will be able to command a premium for it within the marketplace.

**U.S. Rebar Consumption**

(Thousands of Tons)

<table>
<thead>
<tr>
<th>Year</th>
<th>Shipments</th>
<th>Exports</th>
<th>Imports</th>
<th>Consumption</th>
<th>Change</th>
<th>Import %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010F</td>
<td>5,892</td>
<td>525</td>
<td>480</td>
<td>5,847</td>
<td>22.60%</td>
<td>8.20%</td>
</tr>
<tr>
<td>2009F</td>
<td>4,830</td>
<td>430</td>
<td>369</td>
<td>4,769</td>
<td>37.20%</td>
<td>7.70%</td>
</tr>
<tr>
<td>2008</td>
<td>7,318</td>
<td>694</td>
<td>971</td>
<td>7,595</td>
<td>-</td>
<td>12.80%</td>
</tr>
<tr>
<td>2007</td>
<td>8,028</td>
<td>335</td>
<td>1,861</td>
<td>9,554</td>
<td>-1.65%</td>
<td>19.50%</td>
</tr>
<tr>
<td>2006</td>
<td>7,419</td>
<td>301</td>
<td>2,587</td>
<td>9,705</td>
<td>12.70%</td>
<td>26.70%</td>
</tr>
<tr>
<td>2005</td>
<td>7,464</td>
<td>279</td>
<td>1,424</td>
<td>8,609</td>
<td>13.40%</td>
<td>16.50%</td>
</tr>
</tbody>
</table>

Considering that the average piece of FBE coated rebar costs $17.40 per square yard and the average piece of stainless steel rebar costs $101.64 per square yard there is a significant margin for NAC-10 coated rebar to priced within. If the NAC-10 coating was five times as expensive as the FBE it would still be an incredible value of stainless steel rebar and provide comparable useful life. Thus, WinTec should fully examine the potential of this market to determine if NAC-10 has the ability to perform as it is projected to.

**Anticorrosive Bridge Coatings**

In addition to specialty rebar applications to combat corrosion internally; there are a number of contemporary coating systems to combat corrosion of steel bridge structures. A detailed

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analysis of these coatings is contained in *Exhibit Ten*. The primary traditional coating systems in today’s infrastructural arsenal include two to three coat systems applied of a clean surface. The coating systems include:

- Organic zinc primer, epoxy or polyurethane intermediate coat, and aliphatic polyurethane topcoat,
- Inorganic zinc silicate primer, chemically curing epoxy or polyurethane intermediate coat, and aliphatic polyurethane topcoat,
- High-build, high solids, good-wetting epoxy primer with aliphatic polyurethane topcoat,
- Three-coat waterborne acrylic, and
- Three-coat, lead-free alkyd.

The table below provides a snapshot of some common coating systems and analyzes them based upon a comparison of the useful life, number of maintenance cycles over a 60 cycle and total costs.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Coating System</th>
<th>Coating Life</th>
<th>Surface Prep</th>
<th>No. of Maint. Cycles</th>
<th>Cost Per Maint. Cycle</th>
<th>Total Cost in Present Day Dollars</th>
<th>Total Present Value</th>
<th>Annual Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing lead-based paint; repair and overcoat</td>
<td>3-coat alkyd</td>
<td>3</td>
<td>SP-3</td>
<td>20</td>
<td>$56.94</td>
<td>$1,138.80</td>
<td>$477.92</td>
<td>$34.01</td>
</tr>
<tr>
<td>Epoxy/mastic/polyurethane</td>
<td></td>
<td>4</td>
<td>SP-3</td>
<td>15</td>
<td>$59.42</td>
<td>$891.30</td>
<td>$458.22</td>
<td>$32.61</td>
</tr>
<tr>
<td>Existing lead-based paint; full removal by blasting</td>
<td>85% Zn / 15% Al metallizing at 6 to 8 mls</td>
<td>30</td>
<td>SP-10</td>
<td>2</td>
<td>$158.77</td>
<td>$317.54</td>
<td>$227.44</td>
<td>$16.15</td>
</tr>
<tr>
<td>JOZ epoxy/Polyurethane</td>
<td></td>
<td>15</td>
<td>SP-10</td>
<td>4</td>
<td>$123.68</td>
<td>$494.72</td>
<td>$300.64</td>
<td>$21.42</td>
</tr>
<tr>
<td>Existing lead-based paint; full removal and maintenance over approximately 20% of the surface area every 5 years after the initial 15-year service life</td>
<td>JOZ epoxy/Polyurethane</td>
<td>15</td>
<td>SP-10</td>
<td>1</td>
<td>$123.68</td>
<td>$690.41</td>
<td>$351.01</td>
<td>$24.97 $0.00</td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td>5</td>
<td>SP-3</td>
<td>9</td>
<td>$62.97</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing lead-based paint; remove and replace</td>
<td>Epoxy/mastic/Polyurethane</td>
<td>10</td>
<td>SP-10</td>
<td>6</td>
<td>$120.23</td>
<td>$721.38</td>
<td>$413.33</td>
<td>$29.49</td>
</tr>
<tr>
<td>Existing lead-based paint; repair and overcoat</td>
<td>3-coat alkyd</td>
<td>10</td>
<td>SP-3</td>
<td>6</td>
<td>$56.94</td>
<td>$341.64</td>
<td>$156.72</td>
<td>$11.19</td>
</tr>
<tr>
<td>Existing lead-based paint; full removal</td>
<td>85% Zn / 15% Al metallizing at 6 to 8 mls</td>
<td>60</td>
<td>SP-10</td>
<td>1</td>
<td>$158.77</td>
<td>$158.77</td>
<td>$158.77</td>
<td>$11.30</td>
</tr>
</tbody>
</table>
The table above provides a glimpse into the logic of engineers selecting coating systems for bridge applications. NAC-10 bench tests indicate that the coating system has the ability to provide a useful life exceeding all of the current coating systems currently employed on bridge applications. However for the purpose of discussion, this analysis elected to take a conservative approach and say that NAC-10 would only be able to duplicate the useful life of the most durable coating system in the table. That being said, with a 30 year useful life, NAC-10 will far exceed the bulk of coating systems currently utilized by most agencies. Additionally, the superior durability of NAC-10 will significantly mitigate maintenance costs and streamline the coating operation by reducing recoating frequency.

If NAC-10 coating system could be priced around $120 per square yard applied, it would far and away provide the best annualized cost over the course of a 60 year maintenance cycle for a typical bridge coating scenario. Engineers have demonstrated a willingness to accept 15 years as an average coating useful life, in order to fully capitalize on the market it is imperative the NAC-10 can show engineers unequivocal evidence to validate the coating useful life claims and justify the premium pricing.

The table below provides a detailed unit cost breakdown of some of the typical coating scenarios.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>TYPE</th>
<th>ESTIMATED COST, ($/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Preparation (labor + material)</td>
<td>SP-10 Near-White Metal Blast</td>
<td>$13.45</td>
</tr>
<tr>
<td></td>
<td>SP-3 Power-Tool Cleaning</td>
<td>$6.46</td>
</tr>
<tr>
<td>Coating Application</td>
<td>Three-Coat Full Painting</td>
<td>$13.45</td>
</tr>
<tr>
<td></td>
<td>Overcoating</td>
<td>$3.23</td>
</tr>
<tr>
<td></td>
<td>Metallizing</td>
<td>$26.91</td>
</tr>
<tr>
<td>Coating Material</td>
<td>IOZ/Epoxy/Urethane</td>
<td>$5.27</td>
</tr>
<tr>
<td></td>
<td>Epoxymastic/Urethane</td>
<td>$4.52</td>
</tr>
<tr>
<td></td>
<td>Metallizing</td>
<td>$16.15</td>
</tr>
<tr>
<td></td>
<td>Moisture-Cured Urethane</td>
<td>$2.69</td>
</tr>
<tr>
<td></td>
<td>Three-Coat Alkyd</td>
<td>$2.05</td>
</tr>
</tbody>
</table>
Conclusions

When evaluating the potential of the highway and bridge segment it quickly becomes apparent that NAC-10 has significant potential to address many of the longstanding corrosion issues plaguing this segment. Within the reinforced concrete bridges and reinforced bridge deckings segment there is significant potential for NAC-10 to usurp traditional FBE coatings. If NAC-10 can position its pricing for rebar coating applications between FBEs and the cost for stainless steel rebar while still providing similar performance numbers to the stainless steel rebar it has significant opportunity for success. The significant price difference between FBEs and stainless steel provide ample space for WinTec to price NAC-10 accordingly and gain market share. This analysis strongly recommends that WinTec dedicate resources to examining the entrance into the rebar coating market.

The evaluation of current coatings for steel bridges indicate that the vast majority of bridge coating applications have a useful life around 15 years with a coating material cost of approximately $5.50 per square meter of coated surface. If NAC-10 can exceed the useful life performance and price the product accordingly it will be able to gain significant market share as agencies look for cost effective ways to combat corrosion. It is imperative that NAC-10 will comply with all applicable regulatory standards outlined in this section.

Water & Sewer

Introduction

The water and sewer segment of infrastructure consists of some of the most promising coating application opportunities for NAC-10 of any of the infrastructure segments. According to a 2000 study by the Water Infrastructure Network, the United States government annually spends more than $38.5 billion on the water system and $27.5 billion on the sewer system for operations and maintenance. The study, detailed in Exhibit Eleven, determined that at least 50% of those annual expenditure estimates were as a result of the impact of corrosion. To aid
in providing a clear assessment of the opportunities available within both the water and sewer segments, each will initially be examined separately before more general conclusions can be drawn.

**Opportunities in Water Distribution**

According to data from *Exhibit Eleven*, the water distribution network in the United States consists of more than 870,000 miles of municipal water lines of various sizes transmitting nearly 16 billion gallons of drinking water annually. Additionally, per data from a 1992 American Water Works Association (AWWA) study, 48% of the lines in the U.S. were cast iron pipes and 19% were ductile iron pipes. Both types are highly susceptible to both internal and external corrosion and frequently require repair. One of the primary pieces to consider with water distribution systems is the amount of water lost before consumption as a result of line failures caused by corrosion. The study discussed in *Exhibit Eleven*, indicates that on average municipalities on deliver 85% of the water that goes into the system. Thus, if those numbers are applied to distribution as whole, the total cost of lost revenue with water leaking out of the system is nearly $3 billion. Additionally, 89% of water main breaks being directly attributed to corrosion of the water main.

In an effort to combat the challenges of corrosion within the water infrastructure, the industry has turned to several new pipe alternatives. Corrosion on the exterior of the distribution system can be caused by a number of factors; however, the most common cause is corrosive soil or backfill placed around the pipe. During prior construction, many lines were backfilled with a compactable fill containing corrosive soils that would breakdown and corrode the outer layers of the pipes. To combat this problem many of the new pipes installed today are protected on the exterior by coal-tar enamel coatings, polyethylene-based coatings or FBEs. Additionally, in discussion with the City of Youngstown Water Department it was learned that

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many traditional water departments simply utilize a visquine plastic wrap around the exterior of the pipe prior to installation. A brief analysis of this opportunity indicates that NAC-10 would have substantial opportunity as an exterior protective coating within this segment.

There is also a challenge with interior corrosion on the lines caused by the additives used to treat the drinking water. The most common coating used to mitigate interior corrosion is a cement mortar lining. Due to the extensive EPA regulations required to have a coating used on the interior of pipe applications, there would be substantial barriers to entry for NAC-10 to become an interior coating.

**Opportunities in Sewer & Wastewater Treatment**

According to data in *Exhibit Twelve*, the United States sewer system consists of more than 600,000 miles of sewer and 21,594 wastewater treatment plants (WWTP). Most of the contemporary treatment facilities today were constructed in the 1960s and 1970s as the federal EPA created the Clean Water Act placing increased regulations on wastewater treatment operations. As result of the boom of construction in the 1960s and 1970s many WWTPs are facing substantial capital expenditures to remain viable. A 2010 study by the University of Michigan revealed that by 2020 more than 44% of the WWTPs in the United States will be beyond their useful life and require substantial rehabilitation. Additionally, the bulk of sewer collection systems are nearing their useful life estimates, creating a confluence of consequences challenging this segment. The University of Michigan study indicated that $105.2 billion was required to rehabilitate outdated WWTPs, and $82.6 billion was required to repair damaged and failing sewer collection systems.

Additionally, a unique challenge in the sewer segment is the prevalence of combined sewer overflows (CSOs). In many Midwestern cities, CSOs were in constructed as sewer discharges

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prior to advent of modern wastewater treatment practices. As a result of the combined nature of these systems, the same sewer handling both storm water and sanitary flow, there are times where the sewers are incapable of meeting the flow demands. When a heavy rain event occurs, the water is diverted over a weir in the systems and discharges out of a CSO into a waterway. This reduces pressure in the system and averts a catastrophic failure of facilities or backups into building structures. Obviously, discharging CSOs into waterways creates a health concern and current regulations call for the removal of all CSOs. However, due to the requirements of working within the confines of the current systems and limited capital resources, municipalities are being forced to examine ways to eliminate CSOs at the lowest possible costs. The University of Michigan study estimated that the total cost to replace all CSOs in the US is $63.6 billion.

A 2007 study by the Mayor’s Water Council\textsuperscript{16} compiled the expenditure data listed below and can be found in \textit{Exhibit Twelve}. It reveals that state and local governments combined to spend more than $36 billion on wastewater applications last year, a 73\% increase from 1991. With the aging of infrastructure causing additional degradation and increased regulation requiring more contemporary facilities, these numbers can be expected to grow rapidly in the future.

<table>
<thead>
<tr>
<th>Year</th>
<th>Combined State and Local Government ($ thousands)</th>
<th>Local Government ($ thousands)</th>
<th>State Government ($ thousands)</th>
<th>Percent Local Government (%)</th>
<th>Local Government Capital Outlay for Sewer ($ thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-2005</td>
<td>$36,372,359</td>
<td>$35,254,120</td>
<td>$1,118,239</td>
<td>96.93</td>
<td>$13,616,183</td>
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<tr>
<td>2003-2004</td>
<td>$35,534,720</td>
<td>$33,966,273</td>
<td>$1,568,447</td>
<td>95.59</td>
<td>$13,186,489</td>
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<tr>
<td>2002-2003</td>
<td>$32,539,728</td>
<td>$31,536,919</td>
<td>$1,002,809</td>
<td>96.92</td>
<td>$12,062,056</td>
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<tr>
<td>2001-2002</td>
<td>$31,257,197</td>
<td>$30,207,393</td>
<td>$1,049,804</td>
<td>96.64</td>
<td>$11,169,098</td>
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<tr>
<td>2000-2001</td>
<td>$28,061,484</td>
<td>$27,074,500</td>
<td>$986,984</td>
<td>96.48</td>
<td>$8,930,797</td>
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<tr>
<td>1999-2000</td>
<td>$28,052,470</td>
<td>$27,097,840</td>
<td>$954,630</td>
<td>96.6</td>
<td>$9,689,993</td>
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<tr>
<td>1998-1999</td>
<td>$26,979,635</td>
<td>$25,851,890</td>
<td>$1,127,745</td>
<td>95.82</td>
<td>$9,091,174</td>
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<tr>
<td>1997-1998</td>
<td>$25,646,655</td>
<td>$24,514,606</td>
<td>$1,132,049</td>
<td>95.59</td>
<td>$8,422,293</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Age (years)</th>
<th>Initial Investment</th>
<th>Repairs</th>
<th>Annual Cost</th>
<th>Useful Life</th>
<th>Refurbishment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996-1997</td>
<td>25,665,908</td>
<td>$24,568,324</td>
<td>$1,097,584</td>
<td>95.72</td>
<td>N/A</td>
<td>$25,665,908</td>
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<tr>
<td>1995-1996</td>
<td>24,665,007</td>
<td>$23,137,770</td>
<td>$1,527,237</td>
<td>93.81</td>
<td>$8,412,552</td>
<td>$24,665,007</td>
</tr>
<tr>
<td>1994-1995</td>
<td>23,583,401</td>
<td>$22,121,014</td>
<td>$1,462,387</td>
<td>93.8</td>
<td>$8,040,030</td>
<td>$23,583,401</td>
</tr>
<tr>
<td>1993-1994</td>
<td>21,623,863</td>
<td>$20,305,401</td>
<td>$1,318,462</td>
<td>93.9</td>
<td>$7,214,830</td>
<td>$21,623,863</td>
</tr>
<tr>
<td>1992-1993</td>
<td>22,784,883</td>
<td>$21,687,866</td>
<td>$1,097,017</td>
<td>95.19</td>
<td>$9,577,590</td>
<td>$22,784,883</td>
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<tr>
<td>1991-1992</td>
<td>21,008,588</td>
<td>$20,100,540</td>
<td>$908,048</td>
<td>95.68</td>
<td>N/A</td>
<td>$21,008,588</td>
</tr>
</tbody>
</table>

An Analysis of Wastewater Opportunities within the City of Youngstown, Ohio

Youngstown, Ohio is one of the Midwestern cities battling the challenges of an aging sewer infrastructure and shrinking operating budget. Youngstown currently has nearly 40 remaining CSOs and is currently under a consent decree with the OhioEPA to eliminate all CSOs in the near future. Recently, the City of Youngstown has undergone several combined sewer separation projects to eliminate CSOs at an estimated cost of nearly $1.8 million per overflow. The expenditures required to eliminate these overflows, if relatively constant from one municipality to the next. EPA reports reveal that there are 772 municipalities in the United States that currently still have CSOs, expanding that number for the total outfalls for each is a staggering number. Within the CSO elimination section there is potential for NAC-10 as a protective coating on steel flapgates used to cover the sewer outfalls during non-discharge times.

Additionally, many municipalities are turning toward large holding tanks to handle the influx of combined sewer and release it into the system in a controlled manner to eliminate CSOs. The City of Youngstown is currently constructing a $4.5 million flow equalization basin for this exact purpose. Within these structures there are a significant number of opportunities for NAC-10 application. For instance, most are reinforced concrete structures that require steel rebar and other reinforcing steel. Referring to the bridges section of this analysis, NAC-10 is a strong fit for use a steel reinforcing coating. Additionally, NAC-10 could be used as a protective coating on the various steel components and pumps in the facility.

Another strong fit for NAC-10 within this segment can be found within the wastewater treatment plants themselves. According to the data in Exhibit Twelve, the average useful life for concrete structures at a WWTP is 50 years and the useful life for most other components is
15 to 25 years\textsuperscript{17}. This analysis performed a site visit to the City of Youngstown WWTP to examine potential applications for NAC-10 at this facility.

The Youngstown WWTP is one of the more modern facilities in the United States with the primary treatment facilities constructed in the 1950s and secondary and tertiary treatment constructed in the 1980s. Additionally, the facility utilizes a crew of full-time maintenance employees to maintain facility. However, with the primary treatment facility nearing the limits of its useful life the signs of corrosion can clearly be seen shining through the maintenance efforts. \textit{Exhibit Thirteen} provides photographs taken on the site visit to depict common occurrences of corrosion at the WWTPs. Corrosion can be seen at various points in the facility; including, on flow valves, steel piping, centrifugal pumps, steel structures and reinforcing steel within concrete structures. All would be great applications for NAC-10 and be a readily available market segment. While all applications would be very easily satisfied by NAC-10 one that truly stood out was the steel reinforcing within the structures.

In conversations with the plant operators, it became apparent that the failure of the aging concrete structures was causing the most difficult maintenance problems to address. While the more visible areas of surface corrosion on valves and pumps appeared more troubling, the operators said those were much easier to address with traditional sandblasting and recoating techniques. However, the corrosion on reinforcing steel within the structures was the most daunting task to overcome. There was virtually no good way to address the corrosion of the interior steel and the nature of facility meant that steel would continue to come in contact with water and thus corrode further. As previously discussed, the corrosion of interior reinforcing steel results in the cracking and spalling of concrete sections; ultimately resulting in concrete sections breaking free from the structures.

The corrosion of reinforcing steel within the structures has been aggravated by the moisture laden conditions found at treatment plants and caused many concrete sections to fail. Within one of the main pump houses, a concrete section, approximately six foot by eight foot by four inches thick, broke loose from the ceiling and dropped to the work area below. The corroded rebar can be seen in Photograph Two within Exhibit Thirteen. This type of structure failure not only poses a safety hazard to workers, but, also can significantly reduce the useful life of the structure.

Another area of significant structure degradation could be seen in the concrete settling tanks. These are large concrete tanks, approximately 100 feet by 20 feet by 20 feet deep, constructed out of reinforced concrete. These tanks act as holding tanks used to slow the flow of water through the plant and allow any solids to settle out of the treatment process. However, as would be expected in these structures they are ripe for rebar corrosion and concrete failure. As microfractures open up in the concrete water from the tanks works its way into the concrete to the steel reinforcing beginning the corrosion process. Once the reinforcing steel begins to corrode pieces of concrete begin to spall and fall into the tanks treatment water. These concrete sections are then pushed by mechanical arms with the treatment waste into intake pumps. Once the concrete pieces make it into the intakes it does not take long for it the debris then make it to the centrifugal pumps significantly damaging them. Photographs a typical damaged tank can be seen in Photographs Three and Four in Exhibit Thirteen.

With many of the concrete sections that fail being located below the water line it is impossible to know that concrete debris is in the system till it causes a pump failure. At that point, the tank must be taken offline and shutdown while pump repairs can be performed. This is a common problem that plagues many of the WWTPs throughout the U.S. and one that provides a significant opportunity for NAC-10. For instance, just in the City of Youngstown WWTP there are more than 40 similar tanks facing this common problem. Applying that multiple to the 21,564 WWTPs nationwide is a staggering number of potential tank applications.
To combat this problem many WWTPs constructing new tanks are utilizing stainless steel coated rebar in the tank construction to eliminate the potential for corrosion. If WinTec can price its coating to allow for it to be applied to traditional rebar and provide stainless steel performance levels for a lesser price it will be very successful.

Conclusions
The water and sewer segment of the U.S. infrastructure provides a plethora of opportunities for NAC-10. Current water distribution systems are woefully outdated and suffering high rates of corrosion related failures weekly. The use of cast iron and ductile iron pipes for the distribution networks further aggravate corrosion problems; causing municipalities to turn to pipes with protective anti-corrosive coatings. Currently the exterior coating market is dominated by polyethylene-based and FBE coatings. Due to extensive regulations set by the Safe Drinking Water Act of 1996 and the various EPA regulations governing interior coatings, it may be difficult for WinTec to gain entrance into that specific market segments.

Application opportunities abound for NAC-10 within the wastewater segment. According to a University of Michigan study nearly 44% of the nation’s sewer collection network is past its useful life and in need of repair. There are opportunities within the collection system for application of NAC-10 to concrete control structures, steel reinforcing bars and steel structure components.

Most obviously within this segment is NAC-10 potential as a reinforcing steel coating within water and wastewater treatment plants. According to data in Exhibit Eleven and Exhibit Twelve, there are more than 16,000 water treatment facilities and 21,564 waste water treatment plants. As discussed in this section, areas requiring corrosion protection were plentiful at the City of Youngstown Wastewater Treatment Plant.

This analysis strongly recommends that WinTec fully explore the potential of NAC-10 as a protective coating for steel reinforcing alternatives. Additionally, it offers potential as a
exterior coating on drinking water distribution lines and wastewater steel structure components.

**Airports**

**Introduction**

According to data from *Exhibit Fourteen*, there are 5,324 public use and 13,774 private use airports in the United States. While all of the airports provide some potential, the most promise for NAC-10 lies within the large public airports. These airports basically operate as standalone facilities that encompass nearly all types of infrastructure discussed in this analysis.

**Opportunities within Airports**

One aspect frequently overlooked within airports is the vast number of different infrastructure components that can be found within an airport. Typically, large airports can have full transportation networks with bridge structures and roadway, hazardous material storage tanks for jet fuel and deicing solution, water distribution systems, natural gas distribution systems, reinforced concrete structures and wastewater treatment for used deicing fluid. All of these are areas where NAC-10 can be utilized.

The airports transportation network provides a number of opportunities that have been discussed extensively in this document. Traditional steel reinforcing applications for NAC-10 could find their way into virtually all of the applications listed above; however, would be most prevalent in the transportation, reinforced concrete structures and wastewater treatment alternatives.

One of the most promising areas in the airports can be found within the hazardous material storage tanks. In the mid 1990s, the Federal EPA created a policy requiring some type of

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anticorrosion protection on all hazardous material storage tanks. Virtually all airports, publicly and private owned, have some degree of hazardous material storage tanks. At larger public airports there is potential for NAC-10 to act as an anticorrosive coating on underground storage tanks and their piping/distribution networks. These tanks are utilized to store an assortment of hazardous materials, from jet fuel to deicing solution, that are then distributed through the airport via a complex network of steel distribution lines. Both the tanks and the distribution systems require some type of corrosion protection to extend the facilities useful life and mitigate the likelihood of a catastrophic failure.

An in-depth analysis of hazardous material storage tanks is performed later in this section, however, it is important to note that hazardous material storage tanks within airports is a substantial market that must be considered for NAC-10.

**Conclusions**

Airports within the United States are complex infrastructure networks ripe for with conditions for corrosion. The impact of corrosion at airports is far reaching and effects a wide assortment of areas within the airports operations. As with many of the other segments, NAC-10 would have a future as a protective coating for reinforcing steel within airport structures. The other most promising area within airports for corrosion protection is on hazardous material storage tanks and their accompanying distribution networks used for jet fuel and deicing liquids.

**Oil & Liquid Pipelines**

*Introduction*

According to data in *Exhibit Sixteen*, the gas and liquid pipeline industry segment spends more than $6 billion annually combating the challenges of corrosion. Of those costs they can be subdivided over three different sections:

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• 10% - Cost of Failures
• 38% - Capital Improvements
• 52% - Operations and Maintenance (O&M)

The costs to for O&M required to address are the most significant in terms to total valuation, however, the costs associated with the failures can include many indirect costs that must be considered as well. As was seen in the BP failure in the Gulf of Mexico, the physical cost of repairing a failure pales in comparison to the losses in restoration costs and public image damages. Overall, the gas and oil pipeline segment is one that must be considered for NAC-10 to enter into. Due to the extensive amount of time dedicated to evaluating this market in the Phase I analysis of NAC-10 this document will only perform a brief analysis of the opportunities within this market. For a more detailed analysis, please refer to *Exhibit Sixteen* and the Phase I Analysis document.

**Opportunities in Oil and Liquid Pipelines**

The most common types of corrosion in the oil and gas pipelines occur as a result of several different types of corrosion. Stray current corrosion occurs when ground currents from various electrical systems ground through the earth and metal structures, like pipelines, become an indirect grounding conduit. The current running through the structure has a tendency to accelerate corrosion. Microbiologically-Induced Corrosion (MIC) occurs when bacteria or fungi accelerate corrosion; MIC is estimated to account for 20 to 30 percent of pipeline corrosion. Stress cracking corrosion (SCC) occurs when the coating material cracks as a ductile substrate moves and settles over time, allowing the substrate to become exposed to environmental factors that can create corrosion.

The most common type of coating used in this segment is the FBE coating, due in large part to its familiarity in the North American marketplace. However; FBE coatings are very brittle and susceptible to failure over the years as a result of SCC.
Conclusions
The North American oil and liquid pipeline segment offers significant potential for NAC-10, however, as was discussed in the Phase I analysis this is a highly regulated segment that will likely generate substantial barriers to entry. That being said, if WinTec elects to pursue this market it will have to dedicate substantial time to developing a full understanding of the regulatory hierarchy within this segment.

Electricity
Introduction
According to data in Exhibit Seventeen, the total cost of corrosion within the electricity segment is estimated at nearly $7 billion annually\(^\text{20}\). That cost includes, corrosion expenses at all types of power generating facilities (nuclear, hydraulic and fossil fuel) as well as the full cost of corrosion through out the electricity distribution grid.

Opportunities in Electricity
Similarly to the pipeline industry segment, the electricity industry is very highly regulated, especially regarding the power generating facilities. However, there are opportunities for applications at the power generating facilities. Additionally, the electrical power grid is requires an assortment of anticorrosive protection on everything from overhead cable towers to buried conduits housing electrical lines. The challenge within this segment lies in the unique properties of electrical operations. As with the pipeline industry segment, this is a highly regulated segment that creates barriers to entry for new anticorrosive coating applications.

Conclusions
The electrical infrastructure component of infrastructure does yield some promising opportunities for NAC-10 act as an anticorrosive coating. However, the regulatory landscape

and unique challenges of operating within an electrically charged environment requires NAC-10 to be closely developed to fit the specific need of each application with the electrical component. A detailed breakdown of possible NAC-10 applications with this infrastructure segment is included within Exhibit Seventeen.

**Railroads**

**Overview**

The railroad infrastructure suffers relatively little direct damage as a result of corrosion. Most of the components are fairly robust with little impact being caused by corrosion. According to data in Exhibit Eighteen, the railroad industry only replaces an average of $110,000 worth or rail due to the effects of corrosion. Despite the negligible impact on railroad infrastructure itself, the railroad industry does play a fairly important role when it comes to facilitating corrosion in other industry segments.

As a result of the direct current systems that many transit rail systems operate with, there are substantial stray current corrosion costs for neighboring infrastructure components. The stray current corrosion causes debilitating corrosion on neighboring buried conduits that are frequently buried adjacent to existing rail lines. Additionally, the stray current corrosion caused by the railroads can help to cause corrosion on the very bridges that the railroads travel.

Considering the data and information contained within Exhibit Eighteen, this analysis recommends that WinTec only utilize the railroad industry as a way to target potential

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applications for NAC-10. Due to the robust construction of railroad construction, the industry itself has relatively little need for NAC-10. However, the stray current corrosion caused by direct current transit systems will allow WinTec to target of more susceptible forms of infrastructure located within the vicinity of these systems.

**Hazardous Material Storage**

*Introduction*

According to data from *Exhibit Nineteen*, there are more than 8.5 million hazardous material storage tanks in the United States. The tanks are either classified as above ground storage tanks (ASTs) or underground storage tanks (USTs). A 2007 study, estimated the total cost of corrosion for hazardous material storage tanks at $7 billion annually. The varying types of tanks can be protected with an assortment of methods described below.

*Opportunities in Hazardous Material Storage*

ASTs are virtually all protected from external corrosion through some type of protective painted coating, while one-third utilized cathodic protection and one-tenth have an anticorrosive coatings on the inside of the tanks. Annually this market expends $2.8 billion for external coatings, $1.2 billion for cathodic protection and $500 million for internal anticorrosive coatings. ASTs suffer many of the same types of corrosive forces previously discussed in this document. NAC-10 offers promising protection as both and internal and external anticorrosive coating within this segment.

The bulk of hazardous material storage tanks are USTs and suffer very high rates of external corrosion with minimal internal corrosion. Regulations on USTs have increasingly been implemented by the EPA, requiring all tanks to have external corrosion protection of some type

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by 1998. Despite the new regulations, exterior corrosion accounts for more than 65% of all UST failures in the United States. Exterior corrosion is exacerbated by corrosive soils and stray current corrosion within the area of the tanks. Additionally, these USTs are primarily hazardous material storage tanks at airports.

The ensuing table\textsuperscript{25} provides a breakdown of hazardous material storage tanks by each respective industry segment.

<table>
<thead>
<tr>
<th>INDUSTRY</th>
<th>FACILITIES PERCENTAGE</th>
<th>COMMON PRODUCT</th>
<th>AVERAGE NUMBER OF TANKS PER FACILITY</th>
<th>TOTAL ESTIMATED NUMBER OF TANKS</th>
<th>PER FACILITY AVERAGE</th>
<th>PER TANK AVERAGE</th>
<th>TOTAL CAPACITY</th>
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</thead>
<tbody>
<tr>
<td>Farms</td>
<td>42.2</td>
<td>Diesel</td>
<td>3.5</td>
<td>571,050</td>
<td>171.7</td>
<td>49.1</td>
<td>98.1</td>
</tr>
<tr>
<td>Coal Mining / Nonmetallic Mining</td>
<td>9.5</td>
<td>Diesel</td>
<td>4.9</td>
<td>9,060</td>
<td>8.8</td>
<td>1.8</td>
<td>0.1</td>
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<tr>
<td>Oil Production</td>
<td>37.5</td>
<td>Crude Oil</td>
<td>8.5</td>
<td>1,226,967</td>
<td>44.3</td>
<td>53</td>
<td>54.4</td>
</tr>
<tr>
<td>Contract Construction</td>
<td>1.9</td>
<td>Diesel</td>
<td>5.9</td>
<td>42,285</td>
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<td>17.7</td>
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<tr>
<td>Food and Kindred Products</td>
<td>1.1</td>
<td>Other</td>
<td>12.7</td>
<td>54,788</td>
<td>162.3</td>
<td>12.8</td>
<td>8.9</td>
</tr>
<tr>
<td>Chemical and Allied Products</td>
<td>0.8</td>
<td>Other</td>
<td>8.5</td>
<td>27,889</td>
<td>492.4</td>
<td>57.9</td>
<td>13.7</td>
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<td>Petroleum Refining and Related Industries</td>
<td>0.2</td>
<td>Other</td>
<td>65.0</td>
<td>53,755</td>
<td>536.1</td>
<td>82.5</td>
<td>288.3</td>
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<tr>
<td>Primary Metals Industries</td>
<td>0.2</td>
<td>Lube Oil</td>
<td>18.5</td>
<td>12,284</td>
<td>38.2</td>
<td>2.1</td>
<td>0.5</td>
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<td>Other Manufacturing</td>
<td>4.0</td>
<td>Lube Oil</td>
<td>6.6</td>
<td>102,472</td>
<td>64.4</td>
<td>9.8</td>
<td>6.6</td>
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<td>Railroad Fueling</td>
<td>4.5</td>
<td>Diesel</td>
<td>6.3</td>
<td>176.5</td>
<td>28.0</td>
<td></td>
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<tr>
<td>Bus Transportation</td>
<td>0.0</td>
<td>Lube Oil</td>
<td>2.0</td>
<td>1,5</td>
<td>0.8</td>
<td></td>
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</tr>
<tr>
<td>Trucking &amp; Warehouse / Water Transp. Services</td>
<td>0.0</td>
<td>Lube Oil</td>
<td>5.1</td>
<td></td>
<td>109.2</td>
<td></td>
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<tr>
<td>Air Transportation</td>
<td>0.0</td>
<td>Gasoline</td>
<td>6.8</td>
<td>128.4</td>
<td>18.9</td>
<td></td>
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<tr>
<td>Electric Utility Plants</td>
<td>0.7</td>
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<td>23,214</td>
<td>1,792.7</td>
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<td>Petroleum Bulk Stations &amp; Terminals</td>
<td>1.8</td>
<td>Gasoline</td>
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<td>71,188</td>
<td>618.1</td>
<td>59.4</td>
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<td>Gasoline Service Stations</td>
<td>3.4</td>
<td>Gasoline</td>
<td>6.5</td>
<td>84,474</td>
<td>427.3</td>
<td>65.7</td>
<td>36.1</td>
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<td>Vehicle Rental</td>
<td>0.0</td>
<td>Diesel</td>
<td>2.5</td>
<td>11.0</td>
<td>4.4</td>
<td></td>
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<tr>
<td>Fuel Oil Dealers</td>
<td>0.6</td>
<td>Fuel Oil</td>
<td>5.9</td>
<td>12,744</td>
<td>73.2</td>
<td>12.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Hospitals</td>
<td>0.9</td>
<td>Fuel Oil</td>
<td>7.0</td>
<td>23,856</td>
<td>41.2</td>
<td>5.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Education</td>
<td>0.0</td>
<td>Fuel Oil</td>
<td>4.9</td>
<td>16.0</td>
<td>4.0</td>
<td></td>
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<tr>
<td>Colleges</td>
<td>0.0</td>
<td>Fuel Oil</td>
<td>28.4</td>
<td>29.6</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Military Installations</td>
<td>0.3</td>
<td>Fuel Oil</td>
<td>48.9</td>
<td>48,313</td>
<td>90.6</td>
<td>1.9</td>
<td>4.4</td>
</tr>
</tbody>
</table>

The vast bulk of tanks can be found in farming operations and oil production facilities with an estimated 571,050 and 1,226,967 respectively. The next largest segment is the transportation segment, including airports and bus transportation stations, at 103,900 tanks.

**Conclusions**

The hazardous material storage tanks segment of the infrastructure market offers some promise for NAC-10 as well. Specifically, NAC-10 would fit well as a external coating on both

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\textsuperscript{25} Results of 1995 Survey of Oil Storage Facilities, U.S. Environmental Protection Agency (EPA), July 1996.
ASTs and USTs, pending the ability to meet environmental regulations. This analysis recommends that WinTec explore ASTs and USTs further in additional analysis to determine the applicability of NAC-10 to these applications.

**Waterways & Ports**

*Introduction*

According to data contained within *Exhibit Twenty*, the United States has more than 25,000 miles of navigable waterways, 600 ports and locks and more than 10,000 waterfront facilities. Corrosion cost estimates on all pieces of infrastructure associated with this segment place an estimate at nearly $300 million annually.\(^{26}\)

*Opportunities in Waterways & Ports*

Waterways and ports have a number of potential applications for NAC-10; including, piers, docks, bulkheads, retaining walls, mooring structures and navigational aides. More and more this segment is turning to protective anticorrosive coatings to mitigate the effects of corrosion on the various infrastructure components. However, coatings used within this segments must meet strict regulations regarding volatile organic compounds and various other chemical restrictions.

The most common types of coating utilized in this segment include epoxy coatings that contain no volatile solvents with anti-foulants being applied to submerged section of infrastructure to prevent microbiologically induced corrosion. Epoxy coatings that are commonly used in this segment typically cost $18 to $20 per gallon while anti-foulants being far more expensive at

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$45 to $80 per gallon\textsuperscript{27}. Additionally, to mitigate the amount of steel structures being corroded, and thus requiring anticorrosive coatings, many new structures are being constructed out of reinforced concrete utilizing FBE coated rebar.

**Conclusions**

The use of NAC-10 as an exterior coating in most waterways and ports will likely be met with a plethora of regulation complicating entrance into this market segment. Currently the extensive environmental regulations are requiring protective coatings costing up to $80 per gallon. NAC-10 will have great difficulty achieving the environmental clearance required to be readily applied within this segment. However, with many agencies now dedicating their efforts to developing structures that are naturally corrosive resistant there are additional opportunities for NAC-10. As discussed, many steel structures are being replaced with reinforced concrete structures utilizing FBE coated rebar for reinforcing. This is another example of the potential that the rebar coating segment provides for NAC-10.

**Key Stakeholders**

An evaluation of the material examining the specific infrastructure markets examined in the previous infrastructure sections of this analysis revealed a plethora of information regarding the key stakeholders within each segment. Regarding the highway and bridges section of the analysis it was very apparent that the vast bulk of the infrastructure belonged to either local municipalities or state agencies. Typically projects within this segment will either fall under the local municipality or the state Department of Transportation for project oversight. The oversight would occur at the local level if the local participating agency has a charter establishing it a home-rule municipality.

\textsuperscript{27} (2011) EPA Self-Audit and Inspection Guide. Paint and Coatings Resource Center Organization. Retrieved From: \url{http://www.paintcenter.org/ctc/Pcoat2.cfm}
Regarding the sewer and water infrastructure, virtually the entire infrastructure belonged to local municipalities or counties. The vast bulk of the oversight within this segment lies with the EPA at the state level. Airports and their accompanying infrastructure typically are owned and operated by port authorities or local municipalities. Additionally, many of the components of the airport maybe operated and maintained by contracted service providers. Oversight for the airport operations will largely rest with the FAA with the EPA having purview over the environmental components of the airport operations.

The oil and gas segment is typically owned and operated by private firms like BP Plc. and Shell Oil. Similarly, the oil and liquid pipeline segments are commonly maintained by private firms. Electricity components within the infrastructure are typically owned by public electricity utilities that that are governed by Public Utility Commissions on a state-by-state basis.

Most railroads are commonly owned and operated by private firms although they fall under the auspices of Rail Development Commissions on a state-by-state basis. Hazardous material storage tanks can be found in more than 20 different industry segments. However, the primary agency monitoring their use is the EPA. Finally, waterways and ports typically fall under the maintenance of either port authorities of the U.S. Army Corps of Engineers with the EPA playing a critical role in the oversight of their operations.

It is imperative for WinTec to determine the relative stakeholders in whatever section it elects to pursue for market development. Once a landscape of stakeholders can be determined, it will allow WinTec to more accurately target agencies for conversion to NAC-10 for anticorrosive coating needs.

**Barriers to Entry**

There are substantial barriers to entry within all of the market segments previously described. The four of the most significant barriers to entry include:

- Lack of Brand Awareness & Reputation
• Perceived Risk of New Coating within the Segment
• Environmental Regulations Governing Coating Applications
• Lack of Stakeholder Education Regarding Anticorrosive Coatings

The lack of brand awareness and reputation of WinTec and NAC-10 instantly creates challenges for WinTec’s success. In the infrastructure market for anticorrosive coatings a firm’s reputation is critical for the firm to be readily accepted. Firms like PPG and 3M have reputations that instantly validate them in the eyes of consumers. However, it is quite likely that most end-users would have never even heard of WinTec. This makes it very difficult for WinTec to gain market share with NAC-10. The best way to achieve the need reputation will be to reach out to universities and state agencies to validate the quality of the coating. For instance, the Turner Fairbanks Institute of the Federal Highway Administration (FHWA) can test and certify the quality of NAC-10. Despite the plethora of bench test performed by WinTec and their hired services; the only way to truly prove the coating in the eyes of end-users will be through the testing and approval of third party agencies, like the Turner Fairbanks Institute.

The lack of brand reputation also creates a situation where NAC-10 will have a significant amount of risk in the eyes of prospective end-users. The severe costs of anticorrosive coatings within the infrastructure segment make the coating selection a high-involvement purchase. Anytime a decision is being made that has the potential significantly impact the long-term viability of project, a purchaser will have inherent concerns regarding the coating selection. The person making the purchasing decision will have inherent concerns for their own wellbeing if they select a coating that fails prematurely. This coupled with the North American market’s hesitancy to select modern coating types creates a situation where NAC-10 may have challenges. The North American propensity toward FBE coatings over other alternative coating types is explored in the following section of this analysis.

As would be expected within a segment that has so much exposure to environment, there are a plethora of regulations governing the coating requirements. There are some specific
regulations for each coating segment governing the technical specifications of the coating performance. However, most of these technical specifications relatively vague and will easily be met by NAC-10. The most stringent of the regulations lie within the environmental policies governing anticorrosive coatings. These regulations will likely cause challenges for NAC-10 when it comes time to enter the respective market segments. The previous analysis sections touch on some of the more specific environmental challenges of each market. Because of the difficulties of the markets, NAC-10 will have the greatest likelihood of success if it targets markets where the coating will not be applied in the open environment and exposed in the environment. Factory applied applications, like rebar, would eliminate any concern with NAC-10 phosphoric acid etching bath due to the controlled factory application of the coating.

Probably the greatest challenge facing not just NAC-10, but all anticorrosive coatings, is a lack of education amongst the end-users making the coating selection. Frequently at the local level most agencies lack the experience to know of all anticorrosive coating alternatives. The common consensus is that many local agencies making coating selection automatically assume that anticorrosive coatings are exceedingly expensive and will not perform as their promotional material promises. It is imperative that NAC-10 is able to reach out to these areas and develop a knowledge base about the NAC-10 coating system.

**Market Entrance Strategies**

For WinTec to successfully enter the infrastructure market with NAC-10 it must first determine which areas offer the greatest potential for success. This analysis recommends utilizing resources to focus the analysis initially on reinforcing steel applications for NAC-10. This is a massive opportunity that exists across nearly all segments of infrastructure. Additionally, reinforcing steel is currently primarily coated with FBE coatings that NAC-10 has proven superior to in WinTec’s bench tests. Furthermore, the reinforcing steel, in particularly rebar, is coated in factory applications that make NAC-10 phosphoric pre-wash a non-factor in regards to coating selection. The factory application allows applicators to apply NAC-10 to avoid many of the environmental regulations governing coating application.
Additionally, it is imperative that WinTec look to partner with an independent testing agency, rather than a university or something similar to the Turner Fairbanks Institute. This independent validation of NAC-10 quality will go a long way towards assuaging some of the concerns of various end-users. While WinTec has hired various independent testing contractors to validate the performance of WinTec’s own bench tests, those are minimally effective at convincing end-users.

Finally, it is imperative that WinTec reach out to end-users directly to inform them of the anticorrosive coatings currently available to them. Considering the sheer number of agencies it would be virtually impossible to reach them all directly. However, the vast bulk of end-users utilize engineering consultants to design their projects due to inadequate in-house staffing. Thus, it may be easier for WinTec to reach out to prominent civil engineering firms nationwide and use them as conduit to reach all of the end-users they serve.

**Infrastructure Conclusions**

The various sections of infrastructure discussed in this analysis pose a significant opportunity for NAC-10. Considering the crumbling of America’s infrastructure and the significant investment necessary to bring it to adequate standards, there is considerable promise for NAC-10. This area is also uniquely situated as a result of its potential to provide a relatively recession proof market. Due to deplorable infrastructure condition in the U.S.\(^{28}\), detailed in *Exhibit Twenty One*, this area will see substantial continued investment heading into the future. Additionally, as long-term funding for operation and maintenance, agencies are searching for ways to increase the useful life of facilities and stave off the effects of corrosion.

In 2009, the American Society of Civil Engineers forecasted that five year spending on infrastructure will be more than $903 billion with $2.122 trillion needed for to fully address the issues. The five year spending forecast is available in *Exhibit Twenty Two*. NAC-10 and WinTec are uniquely situated to capitalize on this incredible expenditure of funds to address the long-term viability of the United States infrastructure. NAC-10 has the ability to significantly increase the useful life of improved repaired or replaced infrastructure and reduce long-term operation and maintenance costs.

This analysis strongly recommends that WinTec dedicate resources to explore the sections of infrastructure that best suit the application of NAC-10. This analysis indicated that NAC-10 on reinforcing steel was the most desirable infrastructure segment to address. Reinforcing steel applications will be mostly performed in factory OEM situations that will virtually eliminate the role that environmental regulation plays in the application process. The phosphoric acid pre-wash of the NAC-10 coating system would be a non-factor in rebar applications due to the nature of plant application. Additionally, reinforcing steel finds its way into all of the infrastructure segments discussed in this analysis; meaning that over the course of the next five years NAC-10 could play a role in at least $903 billion of infrastructure improvements.

**North American Adoption of Three Layer Polypropylene and Three Layer Polyethylenes**

*Introduction*

During Phase I of the NAC-10 market analysis, it was revealed that technically superior three layer polyethylene (3LPE) or three layer polypropylene (3LPP) coatings were still trailing fusion bonded epoxy (FBE) coatings in the North American marketplace. This point was an anomaly warranting additional analysis during the second phase of NAC-10 project. Despite out performing FBE coatings and being readily adopted in overseas markets; 3LPE and 3LPP coatings were hardly a blip on radar of most end-users in North America.
According to data in *Exhibit Twenty Three*, 3LPE coatings are the world wide market leader with nearly a 50% market share for onshore pipeline applications. Additionally, 3LPE coatings have continued to show greater adoption numbers in developing markets like China, India and Middle East countries. However, within the North American market adoption has been slow at best with traditional FBEs still holding strong. The increased acceptance of 3LPE can mostly be linked to its broad operating temperature range (-45°C to +85°C) and ability to withstand very rough handling and installation practices without damage to the coating. 3LPE systems consist of an epoxy primer, a grafted copolymer medium density (MDPE) adhesive to bond the epoxy primer with a high density (HDPE) topcoat.

Additionally per data in *Exhibit Twenty Three*, 3LPP coatings demonstrate superior durability in comparison to FBE coatings and similarly have shown slow North American adoption. For instance, 3LPP systems are recognized as excellent systems for offshore projects with elevated operating temperature (0°C to +140°C) and extreme mechanical stress on the pipes. Recent projects in the North Sea, Africa, Gulf of Mexico and Arabian regions have set new standards for 3LPP coatings, which provide access to deeper gas and oil fields. 3LPP system consists of an epoxy primer, a grafted copolymer PP adhesive to bond the epoxy primer with a PP topcoat (*Exhibit Twenty Three*).

Considering their superior performance, it is difficult to fully assess why North American firms have been slow to adopt these new innovative coating technologies. The following analysis will yield some analysis of various factors influencing coating selection habits and possible explanations for the slow adoption of 3LPE and 3LPP in the North American marketplace.

**Analysis of Overseas Adoption**

With all new coating technology developments there are a number of factors that must be closely considered during development and during the coating selection process. Considerations will include the durability of the coating, the long-term performance
characteristics, the operating temperature ranges and the short-term and long-term costs analysis. However, some of the various factors influencing the coating selection process are not identical from market segment to market segment. This section of the analysis will examine the overseas market to yield some reasons for quick adoption in those markets.

**Environmental Factors**

Increased acceptance and adoption of 3LPE in developing markets may be greatly influenced by the environmental factors at play within those markets. A detailed overview of these factors can be found in *Exhibit Twenty Four*. For instance, the increased acceptance of 3LPE in China, India and Middle East is due to its broad operating temperature range and ability to withstand very rough handling and installation practices without damage to the coating.

Additionally, the Persian Gulf region presents many environmental challenges; like a high water table, aggressive Sabkha soil, high ambient temperature and UV radiation, pipeline often getting direct exposure to sunlight due to shifting of sand cover etc.

India and many Asian countries pose the challenge of poor road condition, rough transportation and insufficient handling infrastructure, high ambient temperature and humidity, high rainfall in many areas and difficult terrain in many parts.

Such environmental considerations are not as prevalent in the North American market and may be one of the reasons the North American market has been slow to adopt the new technologies. In essence, many of the overseas markets present extreme conditions that require a superior coating technology in order to simply be viable; meanwhile the North American market may be able to suffice with inferior FBE coating technology with the infrastructure and environmental considerations in the North American market.

**Overseas Coating Development**
According to data in *Exhibit Twenty Four*, over the course of the past several decade the major developments in 3LPE have largely been made by European leaders within the industry\textsuperscript{29}. Firms like Neste Chemicals (currently Borealis), BASF (currently Lyondell Basell) and other European firms were innovative leaders in the 3LPE coating research and development. Throughout the 3LPE and 3LPP development process the European firms partnered with overseas end-users to develop a network of firms familiar with the product. By doing this the coating developers were able to instill a sense of ownership in the end-users and convey the value that 3LPE and 3LPP can offer their firms.

Additionally, these actions can go a long way to reduce the perceived risk of a new coating technology. If a firm has had the opportunity to be a partner in the coating development and testing phases they will have a considerable amount of trust in the new technology. This type of direct interaction can be invaluable when it come to convincing and end-user to select an innovative new coating technology.

**North American FBE Dominance**

For more than 35 years, fusion bonded epoxies have been the premium choice for plant applied pipe coating technology in North America. A detailed review of this data can be found in *Exhibit Twenty Four* of this document. Additional information on the background of FBE coatings in North America can be found in *Exhibit Twenty Five*.

Current Trends in the North American FBE Market

Over the past few years many world manufacturers of FBEs have established a North American presence in order to compete in lucrative domestic markets\(^{30}\). To gain market share against 3M and Du Pont, offshore competitors have been reducing prices since 2000 by more than 30% of what they were. Prices have dropped and so have the profits and this is likely to cause possibly detrimental long term strategies amongst FBE powder manufacturers.

The markets are competing now based on better formulations, enhanced applicator or technical support and manufacturing excellence. Future is headed towards higher standards and quality products. The business model has been changing as powder source decisions are increasingly being based on price of user approved material. Pipeline owner companies have even asked applicators to share any financial benefit based on powder selection. Manufacturers are questioning their product development direction and cost of advancing the FBE pipe coating technologies.

The FBE market in North America is undergoing changes because of the following trends:

1. *Cheaper Formulations* – The current trend looking at diminishing profits is to consider cheaper raw materials, organizing ingredients by cost, assessing risk of product failure and financial fears.

2. *Loss of Human Expertise* – The manufacturers are trying to recover from low prices by staff reductions which have led to loss of key relationships and personal energy invested by people in support activities to their industry.

3. *Loss of Support for Associations* – Industry associations have been mutually benefitting manufacturers by sharing common goals but now dues as well as event sponsorships are being carefully scrutinized for expenses.

4. **Loss of Major FBE Manufacturers** – The historical decision by FBE applicators to share volumes between suppliers to ensure healthy competition is almost impossible now.

Looking at the above scenario, NAC-10 has an opportunity to enter the market as a substitute product that could suit the requirements of long-term cost, high profitability and long term benefits. While there is potential for new adoption in the North American marketplace to replace FBE coatings, the inability of 3LPE and 3LPP fill the needs of the North American market calls this situation into question. Clearly the FBE market is under intense pressure as the strong industry bonds are breaking as prices are continuously being driven down. The above mentioned FBE industry trends have continued to emerge slowly and yet 3LPE and 3LPP have not made significant strides in North American market share.

**FBE Performance in North America**

Augmenting the FBE coating stronghold in the North American market place have been recent studies extolling the durability of FBE coatings. Additionally, the studies have delved into the cost and long-term durability of FBE coatings. For instance, an October 2006 study in *Pipeline and Gas Journal* explored sections of 30 plus year old FBE coated pipelines and revealed surprisingly good coating performance and condition given the age of the coating. A detailed summary of the analysis is included in *Exhibit Twenty Four*.

This rigorous case study makes a strong case for FBES from Nap-Gard which is a functional coating line of DuPont Powder coatings, USA. The relative point to take from this case is that North American FBE coatings have achieved greater useful life than the original design life of 25 years. Additionally, the familiarity with FBE coatings helps to assuage any concerns that managers may have with relatively untested new coating technologies. FBES are tried and

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proven within the North American marketplace and capable of providing levels of performance that will exceed the careers of the managers making the purchase decisions.

**Challenges in 3LPE & 3LPP Standardization**

FBE coatings were the first and so far the only coating system to complete the entire ISO process for the preparation and publication of a standard in the years 2007-08\(^{32}\). A complete overview of this section can be found in *Exhibit Twenty Four*. ISO external coating standards have been driven by two factors:

1. Time and finances in developing and publishing standards for a relevant coating.
2. Expedited publication of the standards if they are to meet the industry needs and ISO publication schedules.

In 2008, a need was identified to publish standards on 2 and 3 layer PE and PP coatings, FBE, girth-weld coatings and concrete coatings. The new family of international standards (2010) is intended to create minimum standard requirements for coating raw materials, application processes, testing and inspection methods as well as handling and storage of coated pipes. The ISO draft goes through 4 main stages (1) the committee draft (CD), (2) draft international standard (DIS), (3) Final Draft International Standard (FDIS) and (4) published international standard.

In 2008, the developing of a single standard for 2 and 3 layer coatings became impractical and as a result was split into 2 separate standards. The structure of the development of ISO coating standards was:

1. WGI4-1 Three-Layer PE/PP Coatings; Josef Gronsfeld (Germany). (ISO/DIS 21809-1 Petroleum and natural gas industries – External Coatings for Buried or Submerged

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Pipeline Used in Pipeline Transportation Systems – Part 1; Polyolefin Coatings ((three-layer PE and three-layer PP)).

2. WG14-2 Fusion-Bond Epoxy Coatings; Keith Coulson (Canada).

3. WGI4-3 Field Girth Weld Coatings; Marcel Roche (France). (ISO/DIS 21809-3 Petroleum and natural gas industries - External Coatings for Buried or Submerged Pipeline Used in Pipeline Transportation Systems - Part 3: Field Joint Coatings.)

4. WG14-4 Two Layer PE Coatings; Dennis Wong (Canada). (ISO/DIS 21809-4 Petroleum and natural gas industries - External Coatings for Buried or Submerged Pipeline Used in Pipeline Transportation Systems - Part 4: Polyethylene Coatings ((2-layer PE)).

5. WG 14-5 Concrete Coatings; Betty Friedman (USA). (ISO/DIS 21809-5 Petroleum and natural gas industries - External Coatings for Buried or Submerged Pipeline used in Pipeline Transportation Systems - Part 5: External Concrete Coatings.)

In the case of FBE coatings (Work Group WG14-2), there was extremely wide interest in participating on the preparation of the standard. With 23 P voting countries, the 21809-2 standard for external FBE coatings was accepted by a vote of 19. All this was in 2008; the standards for each of the different categories of coatings are in a different stage of development as of 2010.

The FBE coatings standard — ISO 21809-2:2007 — Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 2: Fusion-bonded epoxy coatings — was published in 2007, but ISO decided in April 2010 to change the title of the standard to single layer fusion-bonded epoxy coatings and to revise the standard to include single-layer high temperature FBE coatings in its scope.

The field joint coatings standard — ISO 21809-3:2008 — Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems

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Part 3: Field joint coatings — was published by ISO in December 2008 and has already been re-opened for an amendment that is in the committee draft stage. The 2LPE coating standard — ISO 21809-4:2009 — Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 4: Polyethylene coatings (2-layer PE) coating was published in November 2009.

The 3LPE and 3LPP coating standard (ISO/DIS 21809-1) has faced challenges in its development as the different involved stakeholders — raw material producers, coating applicators, and pipeline operators could not agree on some high profile topics, such as type of coatings covered by the standard. After several rounds of negative votes from the ISO countries, the standard is still in DIS stage. On the other hand, FBE standard has already been published and there is an ongoing development effort to create more standardized regulations of FBE coatings.

FBE coatings standard will be revised before the end of 2012. Although amendments are being continued on 3LPE and 3LPP standard draft, the FBE standards have come a long way. This has been identified as a strong reason for the stakeholders to be choosing FBEs instead of 3LPE and 3LPP coatings as the ISO standards on one exist and continue to improve while the other remains debatable. All major competitors; 3M, PPG, Bredaro Shaw, and others are ISO certified as can be seen on their websites. The discussion here shows that the stakeholders clearly agree on major aspects of FBE coatings while they have failed to do so in case of 3LPE and 3LPP coatings. Based on the previous discussion and the detailed analysis in this paper, quite a few potential reasons for the slow adoption of 3LPE and 3LPP in North America can be enumerated.

The difficulty in reaching ISO standardization for 3LPE and 3LPP coatings may be one of the major contributors to the slow adoption in the North American marketplace. It is imperative to note that most North American firms will not even consider working with an alternative that is not an ISO standard.
Conclusions on 3LPE & 3LPP Adoption

There are a number of lessons NAC-10 can learn from the slow adoption of 3LPE and 3LPP coatings in the North American marketplace. First and foremost, it is not merely enough for a firm to have a technically superior coating and expect end-users to flock to the offering. Despite the superior performance of 3LPE and 3LPP coatings in comparison to FBEs the North American marketplace has been hesitant to fully embrace the new technology.

Instead of simply relying on the technical merits NAC-10 must speak to the end-users and instill trust in them. One of the lessons learned from 3LPE and 3LPP research and development was the heavy involvement of end-users in the process. This type of involvement is critical to conveying a sense of quality and trust to the end-users. Additionally, it helps to mitigate perceived risk by making end-users feel like they were key stakeholders in the research and development phase of product.

It is also critical that NAC-10 focus on meeting the specific needs of the end-user markets it is planning to target. As previously discussed, one of the primary reasons 3LPE and 3LPP have been more readily adopted overseas is the more aggressive environmental conditions faced in the markets. The FBE coatings may be sufficient in some North American applications that offer ideal conditions; however, they would be inadequate in most overseas operations. Thus, it is imperative that NAC-10 is marketed to the areas and segments that truly require the superior durability and performance the coating has to offer.

Many North American managers may find the 30+ year performance of FBEs more than sufficient given the reliability of that coating alternative. FBEs are tried and true and virtually guaranteed to last the length of the managers’ careers; this may be enough to convince managers to forego some long-term savings in order to go with a short-term alternative that will nearly prohibit the chance of a catastrophic failure during the career of the manager.
NAC-10 must also strive to reach ISO standardization for its coating type. As previously outlined, the ISO process is convoluted and time consuming, however, it can significantly reduce the perceived risk and open up opportunities for NAC-10.

**Anticorrosive Coatings for Petrochemical Industry**

**Oil & Gas**

**Introduction**

Domestic oil and gas production can be considered a “dinosaur industry” in the United States because most of the significant onshore oil and gas reserves have been exploited. The significant recoverable reserves left to be discovered and produced in the United States are probably limited to less convenient locations, such as deep water offshore, remote arctic locations, and difficult-to-manage reservoirs with unconsolidated sands. Materials and corrosion control technologies used in traditional onshore production facilities have not significantly changed since the 1970s. The materials and corrosion control technologies required for the more difficult production areas must be more reliable due to the excessive cost of replacement or failure in these locations. An overview of this section, along with the sources used to compile it can be found in *Exhibit Fifteen*.

Downhole tubing, surface pipelines, pressure vessels, and storage tanks in oil and gas production are subject to internal corrosion by water, which is enhanced by the presence of CO2 and H2S in the gas phase. Internal corrosion control is the major cost item. The high “lifting” costs associated with oil and gas production in the United States put the industry at a distinct disadvantage compared to the Middle East and the former Soviet Union, where the only barriers to increased production are investment capital and political complications. To remain competitive with the world market, maintenance costs must be kept to a minimum. Also, the conservative culture in the oil patch seldom allows for a new, unproven technology to be embraced.
**Opportunities in Oil & Gas**

External corrosion problems in oil and gas production normally are similar to those found in the pipeline industry, but since the lines are shorter and smaller in diameter, their economic impact on the total cost of production is limited. Atmospheric corrosion of structures and vessels is a problem for offshore fields and those operating near marine environments. Improvements in the quality of protective coatings for offshore environments have dramatically reduced the frequency of repainting platforms and tanks.

Corrosivity is increased for the following reasons:

- Oil, water, and gas are produced in every oil field. Water is re-injected downhole to maintain reservoir pressure and stability, and often water flooding (using seawater or fresh water sources) is used to drive oil out of the formation. As a field ages, the water cut, or the ratio of water to oil in the fluids produced, increases to levels of 95 percent or higher depending on the economics of production. As the oil industry matures and the number of old oil fields relative to new fields increases, the amount of water produced increases and the internal corrosion increases.
- Water injection from seawater or fresh water sources contributes to “souring” of oil fields with H2S, usually resulting in an increase in the corrosion rate, which sometimes requires a complete change in the corrosion strategy. These water sources may necessitate biocide injection and will require de-aeration to avoid introducing new corrosion mechanisms into the existing system.
- Tertiary recovery techniques are often based on miscible and immiscible gas floods. These gas floods invariably contain a high percentage (often 100 percent) of CO2, which dramatically increases the corrosivity of the produced fluids.
- Due to the high cost of failure and the inability to rehabilitate facilities in deep water, offshore production in deep water necessitates the use of high-alloy steels and other more exotic corrosion control measures. A similar need for advanced measures exists in the production of high-pressure, high-temperature offshore oil and gas fields where conventional corrosion mitigation is not possible.
Corrosion in oil and gas production varies from location to location. Corrosion can be classified into one of three general categories of internal corrosion caused by the produced fluids and gases, external corrosion caused by exposure to groundwater or seawater, and atmospheric corrosion caused by salt spray and weathering offshore. Of these, internal corrosion is the most costly since internal mitigation methods cannot be easily maintained and inspected. According to 1999 data, the operational costs are summarized below –

<table>
<thead>
<tr>
<th>CORROSION EXPENSE</th>
<th>COST ($ x thousand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection, monitoring, and staff costs</td>
<td>$9,625</td>
</tr>
<tr>
<td>Repairs</td>
<td>$1,350</td>
</tr>
<tr>
<td>Corrosion inhibitor (chemical alone)</td>
<td>$7,200</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$18.175 million</strong></td>
</tr>
</tbody>
</table>

Cost of corrosion in oil production field by activity.
Based on the above discussion it is clear that Oil and Gas production industry is also equally affected by corrosion and provides a huge opportunity for WinTec to dig in to this market. As a bulk of money is spent on corrosion repairs and maintenance, the ultimate equipment and the machinery needs even more careful anti-corrosion layers to protect them from the constant wrath of the external environment at these locations as well as to maintain the internal portions intact. As discussed internal corrosion costs more, WinTec should be able to tap this area by participating in the installing process of the facility or by integrating itself into the supply chain of the already existing facilities.

For the offshore operations, it becomes more imperative to adopt anti-corrosion practices as the sea water particularly affects the equipment such as the oil rig. According to the October ReedHycalog rig census, the total number of US rigs increased by 259 in 2008, boosting the total fleet by another 9% to 3,076 rigs. Although after 2008, there was an expected stagnation in the industry and the utilization rates were expected to decline, according to ODS-Petrodata,
floating rig utilization in the Gulf of Mexico held steady at about 98%, with about 34 rigs running.

The worldwide fleet is aging according to Arthur Berman in his article Lifecycle Rig design. New builds are helping overcome this aging process, but there are a number of rigs out there that are now past their design lives. Good maintenance, upgrades and overhauls have kept many of them viable. Second, we are advancing into increasingly difficult-to-reach hydrocarbon accumulations. These reservoirs are deeper, hotter, and farther away from decent drill sites and may contain fluids and gases that would have precluded them from being producible in the past, with high concentrations of corrosives and inerts. Under these circumstances, we cannot expect our aging drilling fleets to continue working safely at the remote edges of their operating envelopes indefinitely.

Sadly, during this downturn in drilling, there are a good number of drilling contractors who are taking the opportunity to refurbish their old rigs with new or like-new components. Some of these are from other rigs that are stacked or decommissioned with their component parts sold on eBay. In the past, components such as engines, drawworks, derricks, substructures and whole mud plants from one rig were simply pulled off and mounted on an old, worn-out rig to "bring it up to speed." Then, the newly cobbled-together rig was painted, given a new name or number, and its depth rating revised. Some of these are the rigs of today-collections of parts re-assembled into "new" rigs. Problem is: If all the parts are from 30- to 40-year-old rigs, it's not really a new rig. But if this is the current industry trend, WinTec sure can sell NAC-10 as part of the newly cobbled-together rig.
The World Offshore Rig Market

Introduction

According to the most recent data from *Offshore*\(^3\), the worldwide rig deliveries have outpaced the demand and as a result the new orders have fallen. Increasing supply has put a downward pressure on the day rates. New mobile offshore drilling rigs are being delivered into a market ill-suited at present to absorb new capacity, and some rigs are being delivered with no work prospects in hand. In conjunction, new rig orders have fallen dramatically over the past year, according to data compiled by ODS-Petrodata.

The increase in fleet size will continue, as 126 new offshore rigs are still under construction, most for delivery by the end of 2012. The boom seems to have ended. As had been expected,

the number and value of new rig orders fell dramatically in 2009 compared to the four preceding years when the new rig construction boom was in full swing. New offshore rig orders to date in 2010 are running at a slower pace than 2009, with only two ordered as of May at an estimated cost of $837 million.

With supply continuing to grow and uncertainty still dogging the global financial and oil markets, downward pressure on day rates is another challenge for rig owners. The tragic explosion on the semisubmersible Deepwater Horizon that killed 11 people and subsequently saw the rig lost at sea and oil washing ashore uncontrolled has coat heavily to the Gulf of Mexico rig market. The deepwater component of the US Gulf rig market at the time of the April 20 explosion represented a significant portion of the worldwide deepwater rig market. Of the
93 existing rigs in the world rated for 6,000-ft (1,829-m) water depths or greater, 29 were deployed in the US Gulf, the most of any single market. Despite the strained market, the US Gulf can maintain its status as one of the world’s most active deepwater oil and gas provinces, and a destination for some of the new deepwater drilling units scheduled to enter service over the next few years.

Based on this discussion, two major areas of opportunity for NAC-10 can be observed:

1. There still are a lot of projects under construction that WinTec can exploit while the final constructions are due in the next few years.
2. Due to the outpaced demand and the strain on the companies to increase their utilization rates, WinTec can help realize better performance and cost savings from the expensive anti-corrosion and maintenance activities for the rigs.

The number of mobile offshore drilling units under contract worldwide is currently 572, almost identical to the number of rigs under contract at this time last year. However, there are now 790 rigs in the worldwide drilling fleet, compared to the 749 in existence in January 2010. With the increase in fleet size, worldwide offshore rig utilization is now 72.4%, down from 76.5% a year ago. According to ODS-Petrodata’s RigBase market intelligence tool, 104 mobile offshore drilling rigs are under construction or on order around the world, with 57 of these rigs scheduled for delivery this year. Only 30 of the rigs set for delivery this year have contracts lined up\textsuperscript{35}.

U.S. Gulf of Mexico - The Macondo disaster and its aftereffects proved horrible for the U.S. Gulf of Mexico. From the perspective of the offshore industry, a federally imposed delay on deepwater drilling halted the issuing of new deepwater permits. Even with the delay now officially over, the Bureau of Ocean Energy Management, Regulation, and Enforcement has not been forthcoming with new deepwater permits, and regulatory changes have resulted in a sharp reduction in the number of shallow water permits issued. Offshore rig fleet utilization in the U.S. Gulf is now 47.6%, down from an already-anemic 55.9% utilization rate in January 2010. Of the 126 rigs in the region, 60 are under contract. Jackup utilization is only 37.3%. Drillship utilization has remained 100%, and, although only three rigs are actually working, all of the 11 units that remain in the area still have contracts and/or contract commitments. Despite the grim situation, drilling in the U.S. Gulf is expected to resume in some fashion over the next 12 months, and demand is expected to rise for some rigs, according to ODS-Petrodata’s World Rig Forecast Short Term Trends.
**Latin America** - Latin America, Brazil, Mexico and Venezuela continue to be the major hubs for offshore drilling in the south region. Current offshore rig fleet utilization in Mexico, Central, and South America combined is at 76.43%. Of the 31 offshore rigs in Mexican waters, 22 are under contract to state oil company Petroleos Mexicanos (PEMEX) for a fleet utilization rate of 70.97%. Demand for jackups in Mexico is expected to rise in 2011, assuming PEMEX can deal with certain budget and political woes. An increase in demand for semisubmersibles is also possible, with the number of semisubmersibles under contract to PEMEX potentially increasing by as many as three by mid-year.

**Europe, Mediterranean and Black Sea** - The European rig fleet has increased since January 2010, going from 104 units to a current level of 116. The contracted rig count also increased, from 90 to 93, but utilization dropped from 86.5% to 80.2%. Even with this decline, Europe still has the highest fleet utilization of any major rig market. Overall the number of floating rigs working in European waters will rise only modestly in 2011. However, number of jackups under contract in the area could rise by 10% or more. A modest net increase in the number of jackups and floating rigs working in the Mediterranean and Black Seas is also forecast.

**West Africa** - Fleet utilization is now 71.9%. When broken down by rig type, 11 of 13 drillships, 15 out of 19 semi-submersibles and 20 out of 30 jackups are under contract. Demand for all three rig types is predicted to rise modestly in West Africa. New drilling programs offshore Nigeria, Ghana, Angola, and Cote d’Ivoire will drive the majority of the increases.
Middle East - The Middle East is a jackup market. Boosted by Saudi Aramco’s activities offshore Saudi Arabia and the Iranian Offshore Oil Co. in Iran, Middle Eastern jackup demand is likely to rise during 2011.

Caspian Sea - Six rigs are working in the Caspian Sea, with another, Maersk Drilling semisubmersible Maersk Explorer, under contract and expected to begin work in the very near future. Current drilling is taking place in Iran, Kazakhstan, Turkmenistan, and Azerbaijan. Demand is expected to be almost flat throughout 2011 for the Caspian Sea.

Asia/Australia - In the Asia/Australia region, offshore rig fleet utilization is at 76.1%, with 108 out of 142 mobile offshore rigs under contract. Jackup utilization is at 77.4%, semisubmersible utilization is 72.2%, and drillship utilization is 75.0%. In Southeast Asia, slight increases in semisubmersible and drillship demand will be countered by a drop in demand for jackups. In Australia and New Zealand, jackup demand is expected to go up by one or two rigs this year, and the floating rig market could see a similar net increase in the number of rigs under contract.
Changes in the Rig Industry

The field of engineering, technology and innovation has taken a giant leap in providing sophisticated undersea equipments and maintenance strategies like CBM (Condition Based Maintenance) for the rigs. WinTec has a huge opportunity to collaborate with the oil rig operators who are now adopting technologies like CBM to keep profits flowing from their facilities. It cannot be stressed upon more that maintaining safety is paramount for offshore operators, a focus harshly re-sharpened in the wake of the recent catastrophic disaster in the Mexican Gulf. Downtime is expensive and key spares are becoming less readily available, with some parts now having to be specially made. Improved drilling and extraction technologies, together with increased oil prices, have allowed companies to extend the life of the oilfields and with it the planned operational life of their rigs. An increase in reliability of just one percent can represent huge eight or nine figure annual savings for operators: if an oil rig produces 20,000 barrels a day at a margin of $70 per barrel, lost profits are $1.4 million for every day the rig is shut down for unscheduled repairs.\(^\text{36}\)

Condition based maintenance or CBM is employed in capital intensive industries such as the nuclear or aircraft industries where the repercussions of a failure can be catastrophic. Using CBM, or simply a real time maintenance system, can help detect problems or upcoming issues and enable to be rectified before any huge failures. In the oil rig industry, asset management has become more relevant based on the critical assets which are expensive and need monitoring from the both the standpoints of safety and finance, especially after episodes like the gulf spill.\(^\text{37}\)

CBM allows a firm to perform information audit of critical assets according to criticality and failure history. It requires incorporating an enterprise wide asset management program. Most


drilling contractors use CBM to rectify specific components or problems by using infrared, thermal, UV guns; oil analysis; common instrumentation on equipment (oil pressure, engine temperature, etc). The paradigm has shifted from reactive to proactive maintenance and hence the future demands a holistic integration of CBM at the enterprise level into the maintenance strategies.

WinTec can explore the opportunity to use CBM based on it nanotechnology oriented polymeric structure in future. Nanotechnology reaches down to the macromolecular structure at the interface and allows the control of matter to such a minute extent that the possibility of a spill can be theoretically abolished. In civil engineering the practical applications of nanotechnology have been seen in creating ultra high strength and ductility of steel, polymers composites and concrete and multifunctional materials. The newest development of course has been the use of this technology in corrosion protection coatings, self healing and self cleaning coatings. Intelligent aggregates and coatings act as wireless sensors and actuators which can act as feeds to CBM or other real time maintenance systems. With such systems in place even for infrastructure segments, one can think of cracked bridges and pot holes repairing on their own, guardrails aligning automatically or bridges adjusting shapes based on movements of wind.

After putting sensors in place, the system would require a real time IT system to monitor everything but think about the increase in durability and safety with these mechanisms especially for bridges and rigs. Ultimately, if NAC-10 is used in such an asset management application involving critical assets, it will not only lead to longer life expectancy but also a well-monitored self correcting system which may prove invaluable to a firm.

**Types of Rig Structures**

*Jackups* – usually towed to a location after which the legs are lowered to the seabed and the hull is jacked above the sea surface.

*Drill Ships* – look like ordinary ships with a derrick on top which drills through a hole in the hull. They can be anchored or positioned with computer-controlled propulsion systems.

*Submersibles* – can be floated to shallow water locations and ballasted to sit on the seabed.

*Semi-submersibles* – have the superstructure supported on a hull or pontoons which are ballasted below the water surface.

Once the drilling rigs have completed their work, they are generally replaced by production platforms.

*Fixed production platforms* – typically constructed of steel and attached to the seabed with piles.

*Floating Production Storage Offloading (FPSO)* and Floating Storage and Offloading (FSO) vessel – either anchored or tethered.

*Tension Leg Platform (TLP)* – typically used in deepwater applications, these platforms are built from steel or concrete and anchored to the sea floor with vertical “tendons.”

Other supporting infrastructure for the offshore oil and gas industry includes the ships and aircraft which transport people and supplies to the platforms and pipelines which transfer the product back to refineries and other users on shore.

**Considerations for Corrosion**

The most obvious consideration for corrosion control of offshore structures is the marine environment in which they operate. An offshore platform has significant exposure in seawater immersion, splash zone, and salt air. Corrosion of steel in these environments can be greater than 100 mils per year. Corrosion rates are highest in the splash zone as illustrated in the figure below. In addition to the marine environment, offshore platforms have areas subjected to

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severe abrasion and highly corrosive water chemistries. For floating structures, ballast tank interiors comprise a significance portion of the coated surface.

**Steel Corrosion Rate Relative to Sea Level**

**Atmospheric Zone:** Steel structures situated above the water in the so-called atmospheric zone are in a high corrosivity category - classified as C5-M according to ISO 12944-2. In this zone the corrosion rate of unprotected steel is typically in range of 80 - 200 μm (3 - 8 mils) per year - for comparison most steel structures placed inland are situated in zones classified as C3 where the corrosion rate is only 25 - 50 μm (1 - 2 mils) per year. The very high corrosion rates are caused by extended periods of wetness and high concentrations of chlorides that accelerate corrosion. Another factor that needs to be considered in the atmospheric zone is UV - light from the sun as this may have a degrading effect on some types of corrosion protection.

**Splash zone:** The part of the construction that is alternately above and below the water line due to tide and waves is called the splash zone, and here the corrosion stresses are even higher - corrosion rates of 200 - 500 μm (8 - 20 mils) per year have been measured in this area. Other
factors in this area that need consideration include UV-light from the sun, but also erosion from the water, possible debris and in some places of the world even ice.

**Immersion:** This concerns the part of the construction that is below the water line - at lowest tide. In this zone the corrosion rate of unprotected steel is typically in range of 100 - 200 μm (4 - 8 mils). Another factor that needs to be considered is fouling. A special case of immersion is related to the part of the steel structure that is situated below the seabed - typically rammed into the bottom. Corrosion rates are here typically much lower due to lower concentrations of oxygen. The above listed corrosion rates do not take into account pit corrosion, where the rate may be significantly higher.

<table>
<thead>
<tr>
<th>Area</th>
<th>Corrosion rate (steel loss per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric zone (C5-M)</td>
<td>80 - 200 μm (3 - 8 mils)</td>
</tr>
<tr>
<td>Splash zone</td>
<td>200 - 500 μm (8 - 20 mils)</td>
</tr>
<tr>
<td>Immersion (1m 2)</td>
<td>100 - 200 μm (4 - 8 mils)</td>
</tr>
</tbody>
</table>

Since offshore platforms appear similar in many respects to ships, it might be anticipated that much of the corrosion control design would be similar. Indeed, most coating systems are heavy duty epoxies which are also common on ships. Inorganic zinc pre-construction primers are used in new construction, and may be repaid and kept depending on the design philosophy of the owner. Cathodic protection is typically used below the waterline. However there are some substantial differences between the operating environments for ships versus offshore platforms. For example, once located at sea, offshore platforms rarely come back to port for maintenance whereas a ship is frequently dry-docked. Offshore platforms do not usually have the same weight consideration as ships, allowing the use of sacrificial cathodic protection as the sole method of corrosion control for the underwater portions in some instances. Even among offshore platforms, different design considerations exist. Weight reduction is a more important issue for FPSO’s than fixed structures.
Coating Selection Parameters

- Size of the rig
- Coatings specifications
- External weather data
- Power location and availability
- Tank openings
- Site logistics
- Type and condition of the substrate
- Environment and possible additional stresses
- Surface preparation
- Quality of the coatings
- Selection of the coating systems (Generic types, thickness etc.)
- Application
- Quality control

Substrate - The substrate is steel - new building and new steel. But even with new steel, there are different grades of qualities or the steel may have been stored under unfavorable conditions resulting in pit corrosion. Too many laminations in the steel and/or too much corrosion of the new steel (grade D according to ISO 8501-1) will make the surface preparation process more difficult and not even the best coating or the highest quality of workmanship can make up for this in the later coating process.

Environment - The offshore environment is, one of the most corrosive natural occurring environments that can be found - this factor must be considered throughout the project both in terms of general exposure such as time of wetness/immersion, UV exposure, corrosion rates etc. but also the special stresses on the construction e.g. impact and abrasion in the splash-zone or in working areas must be taken into account. Other special stresses encountered on

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40 Ault, J.P. The Use of Coatings for Corrosion Control on Offshore Oil Structures.
offshore structures may be of thermal or chemical nature - e.g. from equipments working at high temperatures or areas subject to spillage of chemicals.

**Surface Preparation** - The surface preparation is the single most important parameter in relation to the performance of any coating system. It is the degree of cleaning (removal of rust, mill scale, oil/grease, soluble salts etc.) and the roughness (anchor pattern) as well as preparation (rounding and grinding) of sharp edges, welding seams and other imperfections in the steel work, that are critical in this phase. Paint adheres better to a clean and rough surface and will therefore also last longer.

**Coatings** - The coatings selected for the job should be of a good quality (based on quality raw materials), and produced according to strict guidelines, ensuring a uniform high quality in each delivery. To document the quality of the coatings and the production procedures, the coating manufacturers should normally be able to present references, third party test results as well as ISO 9000 certification of production facilities.

**Coating systems** - The Coating systems should be selected with due consideration to the environment as well as the special stresses. For the atmospheric zone, this will typically mean a zinc-rich primer followed by epoxy intermediate coats and a UV durable topcoat (e.g. Polyurethane). Minimum 320 μm/13 mils dry film thickness in no less than 3 coats. The Splash-zone will often be protected with epoxy or polyester coatings - in a thickness that take into account also the special stresses - normally more than 600 μm/24 mils total dry film thickness. For optimum impact resistance zinc-rich primers are normally avoided in such areas. Finally the part that is immersed will be coated with epoxy barrier coatings in a film thickness of no less than 450 μm/ 18 mils in minimum 2 coats.

It is important that the epoxy coating system is compatible with the cathodic protection system used. In the immersed zone fouling will occur. On ships fouling is prevented by anti-fouling or fouling release coatings, these methods will however on static offshore structures only delay
fouling and make the removal easier. High strength epoxy coatings will not be damaged by marine fouling and when such products are used, the corrosion protection is therefore not intimidated. The coating systems must be selected in accordance with the working schedules as well as available application equipment and anticipated micro climatic conditions during the application.

### Table 2: Typical coating systems used for offshore

<table>
<thead>
<tr>
<th>Area</th>
<th>Coating types</th>
<th>Coating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric zone</td>
<td>Zinc-rich primer, Epoxies and UV durable topcoat</td>
<td>Minimum 320 μm/13 mils in minimum 3 coats.</td>
</tr>
<tr>
<td>Splash zone</td>
<td>Epoxy or Polyester</td>
<td>Minimum 600 μm/24 mils in minimum 2 coats.</td>
</tr>
<tr>
<td>Immersion</td>
<td>Epoxy</td>
<td>Minimum 450 μm/ 18 mils in minimum 2 coats.</td>
</tr>
</tbody>
</table>

### Coating Systems for Oil & Gas Platforms

Coatings systems for offshore structures such as the oil rigs must be designed to protect hyper-expensive assets from the effect of the most corrosive and hostile environments known. Huge investments are made in the exploration and production of offshore oil & gas fields in remote areas that will provide energy products for a great many years and the costs of protecting capital infrastructure cannot be compromised by poorly designed, selected or applied protective coatings systems.

Offshore oil & gas fields provide a challenge to not only the engineers who must design structures that will operate in and withstand these hostile environments but, also the coatings manufacturers to assist in protecting those structures from the ambient conditions that are most destructive to coatings systems;

- Continuous exposure to salt spray in atmospheric zones
- Continuous wet/dry conditions from wave action
- Severe exposure to ultra violet sunlight
- Constant movement and flexing of substrates
• Severe abrasion from drill pipe and casings, boat landings, etc.
• Chemical spills

The lack of availability for routine maintenance also mandates that the coatings systems be engineered for a very high level of performance and maximum service life. Coatings designed to enhance personnel safety, such as non-skid deck coatings, high visibility color markings, fire and high heat resistant and other specialty coatings are necessary to further protect personnel as well as capital assets.

Coating Systems for offshore oil and gas platforms-
Individual coatings are formulated to perform specific functions and must be selected to become components of a total system designed for optimum results considering the environment and service expectations. In the case of offshore environments, and considering all of the factors previously mentioned, the best that technology has to offer that can be applied in a practical and cost effective manner is warranted.

Additional coats and higher cost materials are used in many cases as the system must outlast those used for other types of marine vessels, such as workboats, that receive scheduled routine maintenance. The higher cost of some of these materials becomes a secondary concern when the purpose that they serve is considered. The following analysis provides an overview of the common coatings.

Inorganic Zinc Silicate Primers - Various anticorrosive pigmented primers are available, some that passivate the steel but the most effective are inorganic zinc silicate primers which essentially become anodic to the steel in a corrosion cycle. The primary advantage of this type of coating is that it arrests rust creep, or undercutting of the coatings surrounding the damaged

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area, and confines corrosion to the point of the damage. These coatings also provide a high degree of resistance to heat and chemical spills.

**High Build Epoxy Coatings** - Epoxies are generally more abrasion and chemical resistant than primers and topcoats and protect not only the substrate itself, but the zinc primer as well from all of the detrimental factors. Although epoxies are widely used in direct-to-metal applications, combined with a zinc-rich primer they will provide the best possible long life anticorrosive protection available from atmospheric exposure. However, one drawback with epoxy coatings is very poor resistance to ultra violet from sunlight and most chalk and fade rapidly. This leads to an erosion of the coatings’ film thickness, reducing the barrier protection of the system.

**Aliphatic Polyurethane Topcoats** - Polyurethane finish coats are generally acknowledged as providing optimum resistance to UV and high degrees of flexibility and chemical resistance. They also help to maintain a very high level of cosmetic gloss and color retention and can be cleaned very easily, generally with low pH detergents and fresh water pressure washing.

**Epoxy/Polysiloxane Finish Coats** - Polysiloxane coatings technology permits the availability of ultra-high performance by the combination of the barrier protection and durability properties of high build epoxy with UV resistance, color and gloss retention greater than that achieved with a polyurethane topcoat, and without the use of isocyanate. This unique technology not only provides superior performance but eliminates the need for polyurethane topcoats that may raise health and safety concerns, as well as reducing application costs at new construction. A three coat system consisting of zinc/epoxy/epoxy-polysiloxane rivals the performance achieved with a typical four coat zinc/epoxy/epoxy/polyurethane system.

**Zinc Rich Epoxy Primers** - Zinc modified epoxy anti-corrosives provide a high level of service and are more tolerant to compromised surface preparation and ambient weather conditions provided the zinc loading of the formula is sufficient. Zinc rich epoxy is also most effective in maintaining damaged areas and breakdown of the coatings systems applied at new
construction as it is compatible with alternate methods of surface preparation such as power tool cleaning and UHP Hydro Blasting.

Splash Zone and Boat Landing Barrier Coatings - These areas of offshore structures are subjected to an extreme corrosive environment due to constant wet/dry conditions, being an area most difficult to maintain and high abrasion from service craft unloading crews and supplies. Special coatings are designed to form a highly abrasive resistant barrier, or cladding, and in many cases incorporate the use of glass beads, quartz, aluminum flake and other inert pigmentation that enhance impermeability and abrasion resistance.

These barrier coatings are applied in ultra-high film thicknesses, direct-to-metal, without any topcoats and require specialized application equipment in many cases. They are also formulated to cure very quickly, be compatible with damp or wet conditions and in some cases cure underwater.

Non-Skid Deck Coatings - Maintaining safe working conditions is of paramount importance at offshore work areas due not only to the harsh environment but the dangerous nature of the work and specialized coatings assist in reducing risk to personnel. Anti-slip deck coatings are essential in walkways, exterior work areas, helidecks and boat landing platforms and must be highly durable. Coatings specifically designed with anti-slip properties normally incorporate very course aggregates for an exaggerated profile. They are applied in very high film builds and normally without a zinc rich primer. When primers are required they are usually epoxy types.

Protective coatings systems are somewhat dependent on the performance of its counterparts. In simplistic terms, the zinc provides galvanic protection for the steel, the epoxy protects the zinc, the topcoat protects the epoxy and the whole system’s overall performance is the sum of the proper selection of the components.
Looking through the websites of marine coating providers like Sherwin Williams and Akzo Nobel, a clear dominance of the epoxy based coatings can be observed. Epoxy coatings, as explained above have proven to be sufficiently successful in surviving under harsh marine environments for longer periods of time and with minimum maintenance. As discussed the epoxy itself is protected by a topcoat to enhance its durability. NAC-10 could look at the specific requirements of a marine structure and use the context of the specific structure requirement to become a part of the protective coating system (like the coat on zinc that provides galvanic protection).

Application Process

Corrosion control on offshore structures commonly includes the following five approaches –

- No Protection (wastage allowance)
- Protective Coatings
- Cathodic Protection of Bare Steel
- Cathodic Protection of Coated Steel
- Corrosion Resistant Metallic or Plastic

Current technologies include the use of organic zinc-rich primers, higher build epoxies, and polysiloxane coatings. The transition to organic zinc-rich primers (predominately epoxies but also moisture cure urethanes) has been driven by cost and schedule considerations. Organic zinc primers are less expensive than zinc silicates and can be applied under a broader range of environmental conditions. Higher build epoxy intermediate coats have a number of environmental, production and performance benefits. The higher build formulation typically had lower VOC and HAPS than more solvent laden counterparts. The high build requires fewer coats to achieve the required thickness and retains film build around sharp edges. Polysiloxane coatings are formulated to provide a durable surface that is resistant to abrasion, wear, and weathering.
Recently there has been some use of thermal spray aluminum (TSA) coatings on offshore structures. TSA can be a high performance coating system but does not appear suitable for all areas of the structure. Specifically, in immersion areas the TSA will act as an anode and sacrifice itself to protect exposed steel. Even at thick builds of 10-15 mils, the sacrificial action will quickly consume the TSA coatings, leaving bare steel. The bare steel left behind increases the galvanic reaction on the remaining TSA.

The key parameters in the application process are the equipment (type and condition), microclimate during the application and curing of the coatings and most importantly - workmanship. It is important that the correct film thickness is applied (within the normal tolerances of a quality paint application) - not too thin as this will result in premature corrosion either because of pinholes in the film or just because of insufficient thickness, but not too thick either as this also can result in adverse effects such as solvent retention – reduced adhesion, cracking etc. Due to the variations in film thickness during the application, which cannot be avoided as long as the paint is being applied manually, then more coats will generally give better protection than only few coats in the same total film thickness. The variations in the application of each single coat are leveled out with the application of the additional coats. Stripe coating on welding seams, edges, corners and areas that are difficult to reach by the airless spray is mandatory for a later high durability of the coating system.

**Surface Blasting of Oil Rigs**

As for coating oil and gas pipelines or infrastructure steel, the initial process of preparing the surface is very important here as well to ensure long lasting results. Millions of dollars are being allocated toward the maintenance of offshore platforms with the goal to maximize oil

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production operations. The opportunity costs during equipment failure or production shutdowns are large.

An increasing emphasis on offshore preventative maintenance has led to scheduled coating maintenance long before total coating failure. Many offshore coating maintenance professionals start coating maintenance when only 3% to 6% of the coating is failing. This practice minimizes corrosion and minimizes the scale of operations required to restore the coating’s effectiveness – ultimately lowering the total life-cycle cost and the potential for future interruption to oil producing operations.

Historically, painting contractors and offshore maintenance consultants have considered media cost and cut rates as key cost determinants. Conventional abrasives all offer similar cut rates and profiles with similar characteristics regarding freight, dust, rebound and waste. Except for price per pound and cut rate, no conventional abrasive material offered any exceptional benefit versus another that could be calculated into a given project. Therefore, cut rate and price per pound drove the choice to use one conventional abrasive over another, and project estimate calculations tended to overemphasize these elements.

With the development of innovative abrasive blasting technologies, a variety of new, meaningful, value oriented choices have become available. Considerations like media handling, freight costs, process cleanliness, personnel safety, containment costs, consumption rates and disposal costs are increasingly driving the decision to utilize one technology instead of another.

Abrasives like sodium bicarbonate (soda) have, for nearly a decade, enjoyed a leading role on offshore platforms among the new abrasive blasting technologies. In recent years, pliant media has been found to match soda as a useful tool as well. Pliant media can be defined as dual component granules containing a pliant, sponge-like material and an abrasive, cutting particle. As dual component granules, pliant media offer certain benefits commonly associated with conventional abrasives as well as those associated with high-tech, low dust abrasive
technologies. It is one of the few technologies that combine the best attributes of each category.

**The Rig Coating Process**

As discussed before the offshore oil and gas platforms operate under extreme weather conditions be it the salt content around, the violent storms or just the high humidity in the surrounding air. The wear in such conditions requires regular maintenance on site because the platforms cannot be moved out to dry-dock easily. Due to the location of many of these platforms, the thick walls of the support columns may react very slowly to changes in the ambient temperature and humidity, making condensation a persistent problem. In order to prevent rust growth, the relative humidity within the central support is required to be maintained at all times below 50%.

**The Basic Administrative Framework**

Approximately 30% of the US domestic oil production and 20% of the domestic gas production is generated from the outer continental shelf (OCS). By far the majority of that production is in the Gulf of Mexico. The remainder of US domestic production is in the Pacific and Alaska regions (which have similar production levels) and the Atlantic region (which is a distant fourth in terms of production). Beyond the current production, OCS resources are projected to contain the majority of undiscovered gas and oil in the United States.

The OCS Lands Act (Title 43, Chapter 29 of the US Administrative Code) requires the Department of the Interior to manage Federal offshore lands used for oil and gas production. The DOI determines the size, timing and location of areas to be used and ensures that the US Governments is fairly compensated for acreage made available through leases. Importantly, the DOI is also charged with responsibility to protect the environment and ensure that the offshore activities operate safely. The DOI carries out these operations through the Mineral Management Service (MMS). The MMS Offshore program coordinates the extensive offshore
production activities. The key mechanism includes frequent Notices to Lessees and Operators (NTL) as well as the Federal Administrative Record (FAR).

**Coating Evaluation, Maintenance and Quality Control**

Corrosion of offshore structures results in a significant operational cost to the operators and/or owners of the structures, especially as the structures age. An assessment of the relative effectiveness as well as costs is central to investment decisions concerning life extension and integrity management for older structures. MMS recognizes the importance of corrosion and corrosion control as part of the overall maintenance effort.

While MMS does not evaluate structures to the level of detail required for effective maintenance management, they regulate inspection through the requirements outlined in API RP-2A, Recommended Practice for Planning, Design, and Constructing Fixed Offshore Platforms. API RP 2A requires annual inspection of protective coatings, cathodic protection, and other corrosion control systems. There are various interpretations of the requirements, but they typically contain the following characteristics:

- Multiple levels of inspection including basic visual inspections with more sophisticated testing (UT, Radiographic) as required.
- An inspection effort sufficient to identify imminent safety hazards, critical areas of concern, and prioritize needs on the remainder of the structure.
- Use of a relatively simple grading system with extensive visual and written documentation to support and archive the findings.

The final parameter and again one of the most important ones is Quality Control - throughout the process. Here of course with focus on the surface preparation and coating application process - where several check points need to be confirmed to ensure the proper result. Coating inspection is a craft in itself, and a certified inspector (NACE or FROSIO) should be preferred as the foundation for professional supervision.
Standards for the Specifiers

The most important standards that apply within the field of offshore coatings are the following:
- NORSOK M501-revision 5
- ISO 12944-1998
- ISO 20340-2003

In addition a number of NACE publications, recommended practices etc. are also available.

**NORSOK M501-rev 5. (First version issued in 1994)** - Surface preparation and protective coatings. This is a Norwegian standard for the corrosion protection of offshore structures with protective coatings. The aim of the NORSOK M501 standard is to obtain optimal protection of the installations - with a later minimum need for maintenance. The standard basically deals with all of the previously listed different steps in the coating process - and list minimum requirements in each step; including qualification requirements to painters, inspectors and the coating systems. Even though it is a national standard the NORSOK standard is today probably the most recognized standard within the field of offshore coatings. (The NORSOK standards can be downloaded free of charge from the Internet: www.standard.no - look under petroleum).

**ISO 12944 (first version issued in 1998)** - Corrosion protection of steel structures by protective paint systems, Is the international standard in this field - it recognize that the satisfactory performance of paint coatings for protection of steel structures against corrosion is determined by - the choice and formulation of the products used in differently classified environments; and - the standard of workmanship and execution of the contract Agreement between the client and the contractor as to the specifications to be applied is essential to the satisfactory execution of the work. The standard consists of 8 parts. ISO 12944 deals with most of the different types of environments found on land and offshore.

**ISO 20340 (first edition issued in 2003)** - Performance requirements for protective paint systems for offshore and related structures. Is a complementary standard to ISO 12944 part 6. Due to
the special conditions in the offshore environment, significantly tougher testing of the coating systems is specified in this standard.

**NACE** - A number of NACE publications also exist on the subject of offshore coatings and presently a number of standards prescribing test methods and recommended qualification criteria are being developed for the different areas that are relevant on offshore structures. Examples are a number of Standard Test Methods:

- TM 0404: Offshore Platform Atmospheric and Splash Zone New Construction Coating System Evaluation

**Life Expectancy of Oil Rigs**

For offshore oil and gas platforms, life expectancy of more than 20 years for offshore installations requires that corrosion protection plays an important role. Apart from the durability of the corrosion protection, maintenance should also be as little as possible during the planned operating period, since any type of repair offshore is very expensive as discussed before.

Cathodic protection is very effective in zones of structures that are permanently immersed in water but is largely ineffective in transition and splash zones because the metal is not continuously in contact with seawater (the electrolyte). Normally, the steel components here are protected with polyurethane or epoxy resin-based coating systems that have a life of roughly 15 years.

One thing that these systems have in common is that they have to be repaired and partially renewed regularly to achieve their designed life time. The transition zone, in particular, causes
considerable expense. It is also very important to listen to the needs of the customer and in doing so meet the requirements and expectations they have established. What may be good for one operator or owner is not acceptable to another. Normally this is a function of effective antifouling performance.

**Wear Resistance of Polymeric Coatings – A Case Analysis**

After analyzing the types of external coatings that have dominated the rig markets, a deeper look at the performance of thermoplastic and thermosetting polymeric coatings used to prevent injector tubulars from corroding reveals that they can be easily damaged by tools used during work-over and/or inspection of the oil well. As discussed before the internal coating costs are much higher, a case study presented in this section reinforces the need for NAC-10 to focus on the internal coating requirements as well.

Sea water is often re-injected into oil wells through injector tubulars in order to stabilize the reservoir pressure. Injector tubulars are made from expensive chromium alloys due to the corrosiveness of sea water. However, to minimize cost, the tubulars can be made from inexpensive carbon steel and protected internally with cheap polymeric coatings to prevent the tubulars from corroding. A case study performed in U.K.\(^{43}\), presents the results of the wireline wear study performed on various thermoplastic and thermosetting polymeric coatings, undertaken to understand the effect of wireline asperities on the tribological performance of filled and unfilled coatings.

The results show that the unfilled thermoplastic coating can have the highest wear resistance while the filled thermoplastics have the worst wear resistance. The performance of coatings was found to be linked to the chemical and physical nature of the matrix material (either thermoplastic or thermosetting). The results show that filler shape, size and type have a significant effect on wear resistance of the coatings.

Factors such as filler pull-out, filler fracture and poor abrasion resistance of the filler were found to be responsible for the poor wear resistance of some of the filled coatings because of the inadequacy of fillers to act as load bearing elements. Scanning electron microscopy (SEM) micrographs of the worn sample surfaces show either plastic deformation/cutting or formation of short fragile tendrils.
The above case study reveals the deficiencies in the current epoxy coatings as not being thoroughly efficient as a part of the internal coating system. Based on other parameters such as
the filler type, shape and size, NAC-10 can act as a better compliment to the coating component system. It will help in avoiding the above mentioned issues as well as drive the costs of maintenance down.

**Pipe Supply Chains in Petrochemical Firms**

*Overview*

During Phase I of the project a cursory review of the pipe supply chain and process flow within the petrochemical industry was performed. To gain a more comprehensive understanding of the true nature and cost of the supply chain inefficiencies at play within this industry segment, Phase II set out to perform an in-depth evaluation of the supply chain inefficiencies.

Through the Phase I analysis, it was revealed that the current process flow employed by end-users was riddled with inefficiencies; largely as a result of the shortcomings of the protective coatings currently used by the end-users. These inefficiencies result in a substantial amount of direct and indirect costs and are shown in the blue process flow on the following page. This process flow depicts a substantial amount of short circuiting that result in the end-user having a redundant and unnecessarily lengthy process flow. Through the superior durability of NAC-10 many of the inefficiencies currently at play within the end-users process flow will be removed and a more streamlined and efficient process flow can be realized.

To best analyze those costs, Phase II intended will utilize contacts within the end-users to develop a detailed process flow of the pipe/tubing distribution though the end-users process. Once that detailed process flows were to have been mapped out; costs would have been assigned and a total cost of the current system can be calculated. The cost of the current process flow was then to be compared to that of the proposed process flow with NAC-10 and a cost comparison could have been calculated to justify the superiority of NAC-10 to traditional FBEs.
However, as analysis was beginning to be performed, the Tagos Group directed the Youngstown State University research team to shift efforts and evaluate the coating alternatives within the oil drilling rig industry segment. Thus, the progress on the section was largely stopped. If WinTec plans on exploring opportunities within the oil and gas pipe industry
in future projects, this analysis strongly recommends that a full analysis of the supply chain inefficiencies is performed. Current FBE coatings that dominate the market segment are woefully inadequate and create a situation where there are substantial amounts of short-circuiting within the operations. With the superior durability of NAC-10, WinTec would be able to provide a coating that would eliminate those inefficiencies and provide substantial savings in both direct and indirect costs to the end-user.
Exhibits
Exhibit One

Phase I Project Charter

1. General Project Information

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<tr>
<th>Project Title:</th>
<th>WinTecGroup, NAC-10 Strategic Analysis</th>
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<th>NAC-10 Strategic Analysis</th>
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<td>Sponsor Representative:</td>
<td>Patrick Gonzales</td>
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<td>Prepared by:</td>
<td>Kolt Codner</td>
<td>Version:</td>
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<tr>
<td>Project Manager</td>
<td>Kolt Codner</td>
<td>330.261.3331</td>
<td><a href="mailto:krcodner@gmail.com">krcodner@gmail.com</a></td>
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<tr>
<td>Customer/User Representative(s)</td>
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3. Executive Summary

This project is designed to perform a product and market analysis of WinTec Group’s NAC-10 nano-based anti-corrosive coating and formulate a strategic marketing plan for future use by WinTec. Due to the vast amount of time required to perform a proper analysis, the project will be split into three separate phases that will build upon the foundation built by the previous stage. This analysis will provide a far-reaching overview of critical factors that will be analyzed and used to develop a foundation for future market development initiatives and plans.

4. Business Need

Anti-corrosive coatings provide a means to increase the useful life of metal surfaces by mitigating and decelerating section loss as a result of corrosion. The impact of corrosion can be realized in a wide array of industry segments; however, the need is most dramatic within the
infrastructure and utility segments. Within the infrastructure segment, the need for corrosion protection can be found in a number of areas; including, structural steel bridge superstructures, concrete rebar reinforcing, hazardous materials storage and water and wastewater treatment plant facility equipment and conduit. Additionally, the needs for corrosion protection within the utility segment can be found in oil and natural gas pipelines, utility distribution lines and utility poles.

5. Business Case

According to data compiled by CorrosionCost.com, a website sponsored by the Federal Highway Administration, the annual cost of corrosion in the United States is $270 billion. Furthermore, with over 500,000 bridges, 328,000 miles of natural gas transmission and gathering lines and 8.5 million hazardous materials storage tanks within the United States there are a plethora of domestic opportunities for anti-corrosive coatings. Additionally, with the recent substantial investment in public infrastructure through the American Recovery and Reinvestment Act (ARRA), an increasing number of facilities are being rehabilitated and offer prime opportunities for innovative anti-corrosive coatings. Within the natural gas distribution segment, gas distributors are continuing with a systematic replacement of bare metal and cast iron distribution lines that were susceptible to corrosion. Additionally, in the light of the recent natural gas transmission line explosion in San Bruno, California; there is increasing public pressure on utilities to utilize fail-safe anti-corrosive coatings for their lines. Through technical analysis provided by WinTec, the NAC-10 coating will provide an impenetrable and self-healing Polymeric coating that appears to provide corrosion protection for (use 5x; studies indicate 10-15 fold) years. The NAC-10 coating could provide a significant long-term cost savings by increasing the useful life of a wide assortment of metal substrates and realizing labor savings by significantly reducing operation and maintenance costs over the life of the coated materials.

6. Project Scope

In order to fully assess the true market potential for the NAC-10 coating there are a number of critical areas which must be addressed. Considering the substantial time requirements to perform a detailed analysis of NAC-10 and develop a strategic market engagement plan; the greater project will be split into multiple sequential phases to ensure the accuracy and integrity of the plan development. Project phase one will focus specifically on determining the attractiveness of the marketplace within which the NAC-10 coating competes. Additionally, phase one will also incorporate an analysis of existing oil pipeline supply currently utilized by potential NAC-10 users. Phase one of the project will be completed by December, 2010; a detailed review of the phase one action is included later in the project charter. Phase two of the project will entail a detailed technical review of the NAC-10 coating by Youngstown State University’s STEM Material Laboratories to ensure all previous testing results are accurate and provide third party validation of WinTec’s findings for potential customers. Phase three of the project will focus on building upon the information gathered in phases one and two of the project to develop a strategic marketing plan. Phase three will include product pricing information, specific market outreach initiatives and direct out-reach to potential distributors and customers. However, without a complete analysis being performed in phases one and two
of the project it is virtually impossible to accurately develop the initiatives in stage three.

![Project Timeline](image)

**Project Phase One**
The focal point in phase one will be developing a comprehensive analysis of the market the NAC-10 coating competes in and converting it into strategic implementation recommendations. The market analysis will require specific quantitative research to determine that opportunities available within the marketplace. The requisite data will partially be compiled through an in-depth review of trade journals and peer-reviewed scholarly journals and an analysis of data available within the North American Industry Classification System (NAICS). Additionally, research will be conducted by reaching out to the Association of Oil Pipe Lines (AOPL) to form a collaborative relationship and fully utilize the information currently available within its resources. The analysis will also fully leverage data compiled by the United States Department of Energy and the Federal Highway Administration’s Turner-Fairbank Highway Research Center. The fundamental pieces of the market analysis will include the components depicted below.

- Simple Technical Analysis of NAC-10
- Market Analysis
- Competitive Analysis
- NAC-10 SWOT Analysis
- Porter’s Five Forces Analysis of NAC-10

Additionally, phase one will include a review and analysis of supply chains currently utilized by potential customers within the oil pipeline industry. This will allow the latter phases in the project to have a holistic view of the potential cost savings realized by NAC-10. For instance, preliminary research indicates that potential customers currently utilize a laborious and costly supply chain that results in wasted effort that could be averted by the employing the NAC-10 coating in the early stages of production. Thus, the potential cost savings of NAC-10 reach beyond the simple added life and also impact potential cost savings through leaning out and streamlining the supply chain.

**Project – Phase One Schedule**
Phase one of the project will commence with a project kick-off meeting on October 1, 2010. From that point out the consultant will continue to compile information and submit draft one of the document to WinTec management on October 22, 2010 for comment and review. From that point out WinTec will submit comments to the consultant by October 29, 2010 and the consultant will incorporate the comments and additional information into the draft document. From that point out the schedule below will be utilized for draft document submissions and
requisite revisions until the final document is presented to WinTec management on December 3, 2010.

### Project Phase One Timeline

<table>
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<th>Date</th>
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<td>Project Kick-Off</td>
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<tr>
<td>Submit Phase One Progress Document to WinTec for Comments</td>
<td>10/22/2010</td>
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<tr>
<td>Receive Comments from WinTec On R1 Submission</td>
<td>10/29/2010</td>
</tr>
<tr>
<td>Submit R2 to WinTec for Comment</td>
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<td>Submit R3 to WinTec for Comment</td>
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<tr>
<td>Receive Comments from WinTec On R3 Submission</td>
<td>11/26/2010</td>
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<tr>
<td>Present Final Document and Findings to WinTec</td>
<td>12/3/2010</td>
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7. **Critical Success Factors**
The critical success factors of this project will be acquiring adequate technical analysis and comparison of the NAC-10 coating with competitors within the relatively short project time frame. Additionally, for the successful development of a strategic implementation plan, it will be essential for NAC-10 coating to be found a significant improvement over rival coatings currently within the marketplace. If the analysis can successfully demonstrate the superiority of the NAC-10 coating, a market positioning plan and strategic market development plan can be formulated.

8. **Project Assumptions / Constraints**
Obviously with a relatively short project schedule and limited financial resources and in-depth analysis cannot be performed. Rather, this project will look to develop a foundation of analysis upon which future initiatives can be developed and implemented. The project will also assume that the preponderance of technical analysis will derived from testing already performed by WinTec.

9. **Project Deliverables**
At the conclusion of the phase one of the project the consultant will present to WinTec, a comprehensive report of initial findings. This will be accomplished through the presentation the written market analysis and supply chain analysis coupled with all of the supporting documents and sources necessary to develop the analysis. Throughout the development of phase one, three versions of the draft document will be submitted to WinTec for comment and revisions. Additionally, the findings will be presented to WinTec in a final presentation in December, 2010.
Exhibit Two

**Market Analysis Project Approach**

The full market analysis for WinTec’s NAC-10 coating will include a multi-faceted approach to provide a holistic analysis of the environment within which NAC-10 will be competing; the project approach is outlined below. This analysis will follow the order progression outlined below.

1. **Evaluation of current issues facing the oil pipeline industry**
   a. In order to fully discern the environment within which NAC-10 is competing it is imperative to perform a comprehensive evaluation of the various elements currently at play within the industry. This analysis will develop a context within which further analysis will be performed and evaluated.
   b. Key areas of review will include:
      i. Evaluation of current regulatory developments
      ii. Analysis of recent coating developments
      iii. Review of public pressures influencing oil company decisions

2. **Determine the current technical requirements for NAC-10**
   a. Before being able to adequately meet the needs of end users within the marketplace it is essential to determine what the technical requirements of various coatings within the industry actually are.
   b. Key areas of review will include:
      i. Evaluation of regulating agency requirements to determine the minimum standards for anti-corrosive coatings. Additionally, the review will focus on determining what agencies supersede other agencies. Thus, the review will provide a hierarchy of oversight for WinTec.
         1. Agencies to be reviewed will include:
            a. NACE
            b. ASTM
            c. EPA
            d. TCEQ
            e. DEQ
            f. Coast Guard/Navy Requirements

3. **Evaluation of the needs of the end users of NAC-10**
   a. This section of the analysis will focus on determining what the requirements of NAC-10 end users are. This analysis will focus on determining what the minimum technical specifications of a coating are in order to meet the firm’s requirements. Additionally this analysis will also aim to determine the testing process that would have to be undertaken in order to receive buy-in from end users.

4. **Determination of corrosion inhibitor competitors to NAC-10**
   a. Obviously, without performing a review of various competitors within the coatings industry it will be impossible to develop specific points of differentiation that can be used to develop NAC-10 as a unique alternative attractive to end users. Additionally, this section of the review will allow for the development of a market penetration strategy for WinTec to employ as the project moves forward.

5. **Evaluate and compare the complexity of NAC-10 coating system with competing alternatives**
a. One point that will be under close consideration by manufacturers who would eventually apply the NAC-10 coating will be the complexity of the coating process. The analysis will aim to determine the current application processes and determine how they differentiate from the NAC-10 application. This step in the analysis expose the unique differences between NAC-10 and current coating application processes. It is imperative to understand the differences between the types of coating application processes because a significant differentiation from the status quo may generate substantial hesitation on the application process.
b. Additionally, the analysis will also have to determine what the pre-qualification process for application contractors of NAC-10 will be. Operating within such a high-risk industry it is critical to ensure that applicators follow the proper processes in the application of NAC-10. Even the best coatings can be undone if they are applied improperly and these consequences of such misapplication are so extreme development of an applicator pre-qualification is essential.
   i. Key areas of review will include
      1. Evaluation of other coating applicators
      2. Determination of the differences in the application process
      3. Evaluation of the tolerances in the application process

6. Evaluation of worst case scenarios in the event of a coating or system failure
   a. The most important components of any coating is its ability to reduce the likelihood of a catastrophic failure of the surface it is protecting. Obviously, within the oil and gas pipeline industry there are significant ramifications if a pipeline failure were to occur. In order to fully develop the value of a coating, it is critical to determine what the consequences are of a catastrophic failure as a result of corrosion.
b. Key areas of review will include
   i. Evaluation and calculation of environmental clean up costs
      1. Including any fines that would be associated with the failure
   ii. Evaluation of the potential damage to public opinion of the company in the event of a failure
      1. This cost will look into the full cost of the impact; including, loss of goodwill and lost revenues

7. Examine the supply chains of end users to quantify and potential savings from NAC-10
   a. As previously discussed, it is believed that NAC-10 could provide significant savings through streamlining the supply chains of end users and simplifying the coating processes.
b. Key areas of review will include:
   i. Analysis of current supply chains within the oil pipeline industry
   ii. Evaluation of potential cost savings realized by streamlining the coating supply chain process

8. Determine and calculate the benefits NAC-10 provides to the client
   a. This section will build on the information compiled in the previous seven phases of the market analysis to determine both financial and intangible benefits provided by NAC-10. This step will look to provide a holistic review of potential savings NAC-10 provides over various competing coatings.
Exhibit Three

NAC-10 Phase II Analysis – Proposed Project Scope

Introduction
Phase II of the NAC-10 analysis will build upon the information gathered through Phase I during fall 2010. Working with WinTec and the Tago Group, the Phase I project performed a wide-ranging analysis, including:

- Situational Analysis of NAC-10 within the Petrochemical Industry
- Detailed Competitive Analysis of Competing Firms
- Overview of the Competitor Coating Types
- Analysis of End-Users within the Petrochemical Segment
- Overview of Regulatory Agency Oversight within the Industry Segment

While Phase I answered many of the questions initially posed it also generated several points for further analysis during Phase II of the analysis project. Key points for further analysis in Phase II include:

- Examining Supply Chain Inefficiencies within Petrochemical End-Users
- Establishing Product Pricing Recommendations
- Map Regulatory Agency Oversight Process
- Examine the Slow Adoption of 3LPE & 3LPP Coatings in North American Market
- In-Depth Analysis of Opportunities within the Infrastructure Segment

A detailed description of the work proposed for the Phase II section of this analysis is included in the Proposed Phase II Project Scope section below.

Proposed Phase II Project Scope

Petrochemical Pipe Supply Chain Analysis
During Phase I of the project a cursory review of the pipe supply chain and process flow within the petrochemical industry was performed. To gain a more comprehensive understanding of the true nature and cost of the supply chain inefficiencies at play within this industry segment, this project will perform a comprehensive analysis of the processes of the targeted end-users.

Through the Phase I analysis, it was revealed that the current process flow employed by end-users was riddled with inefficiencies; largely as a result of the shortcomings of the protective coatings currently used by the end-users. These inefficiencies result in a substantial amount of direct and indirect costs and are shown in the blue process flow shown below. This process flow depicts a substantial amount of short circuiting that result in the end-user having a redundant and unnecessarily lengthy process flow. Through the superior durability of NAC-10 many of the inefficiencies currently at play within the end-users process flow will be removed and a more streamlined and efficient process flow can be realized.

To best analyze those costs, this project will utilize contacts within the end-users to develop a detailed process flow of the pipe/tubing distribution though the end-users process. Once that detailed process flow is mapped out costs will be assigned and a total cost of the current system can be calculated. The
cost of the current process flow will then be compared to that of the proposed process flow with NAC-10 and a cost comparison will be calculated to justify the superiority of NAC-10 to traditional FBEs.

**Current End-User Process Flow of Pipe**

1. Pipe Delivered from Intermediary
2. Temporary Zinc Coating Stripped
3. Traditional FBE Coating Placed on Pipe
4. Pipe Shipped to End-User Storage Yard
5. Pipe Shipped from Storage Yard to Work Site
6. Unused & Damaged Pipe Returned from Work Site to Storage Yard
7. Unused Pipe Damaged During Transportation & in Storage Yard Activities
8. Damaged Pipe Stripped and Re-Coated with FBE Coating
9. Re-Coated Pipe Sent Back to End-User’s Storage Yard
10. Re-Coated Pipe and New Pipe Sent to Work Site
11. Unused & Damaged Pipe Returned to Storage Yard

**Proposed Process Flow with NAC-10 Coating Applied to Pipe**

1. Pipe Delivered from Intermediary
2. Temporary Zinc Coating Stripped
3. NAC-10 Applied to Pipe
4. Pipe Shipped to End-User Storage Yard
5. Pipe Shipped from Storage Yard to Work Site
6. Unused Pipe Returned from Work Site to Storage Yard
7. Pipe Sent to New Work Site

**Product Pricing Information**

Through Phase I of this analysis a detailed review of the competing firms was performed with a review of their strategic positions. Due to time and resource constraints during Phase I a detailed analysis of pricing information for each respective competitor was unable to be performed. During Phase II a comprehensive analysis of the pricing information will be performed. This will aid in giving a complete
view of the current market structure and assist in providing comparison points for NAC-10 pricing recommendations and strategies.

Additionally, the product pricing recommendations will build upon the information gathered in the supply chain section of the Phase II analysis and utilize it to reveal a full picture of the financial benefits of the using NAC-10. The financial benefits taken into consideration with NAC-10 will also include a review and cost assessment of the increased useful life gained by utilizing NAC-10 as opposed to a traditional FBE coating. The combination of these relevant data points will allow for a complete pricing strategy for NAC-10 to be developed and reviewed.

**Petrochemical Industry Regulatory Agency Oversight**
During Phase I of this analysis an overview of the regulatory agency oversight within the petrochemical industry was performed. However, it was found that the amount of information that was truly available regarding the specific agencies was vague and provided no hierarchy. Through Phase II of the analysis, a detailed agency oversight map will be compiled. That mapping process will provide a clear agency oversight hierarchy allowing a simple analysis and review of the regulatory agency oversight process.

**Examination of 3LPE and 3LPP Slow Adoption in North America**

**Research Done**
**Place into Final Format**
Information gathered during Phase I of the analysis revealed that despite being technically superior to FBE coatings three layer polyethylene (3LPE) and three layer polypropylene (3LPP) coatings have not been readily adopted in the North American market. According to the data gathered in Phase I, 3LPE and 3LPP coatings have largely replaced FBE coatings in international markets because of the superior capabilities. However within the North American marketplace end-users have been slow to adopt 3LPE and 3LPP coatings; with FBE coatings still being the dominant coating choice.

This is a trend that should be significantly troubling for NAC-10 if the North American marketplace is unwilling to adopt new technologies. This analysis will focus on getting to the root of this trend. It is imperative reason the 3LPE and 3LPP coatings are not being readily adopted in the North American marketplace. The analysis will review the regulatory climate to determine if the reason for the slow adoption is a result of some regulatory issues.

Additionally, the situation will be reviewed to determine if the reason for the slow adoption is as a result of the North American end-users preferring FBE coatings. If it is revealed that the North American end-users prefer FBE coatings the reasoning for that preference will then be delved into. Initial reasons for a potential preference to FBEs could include:

- End-user managers preferring and FBE coating they have worked with previously
- A short-sighted view from managers preferring to stick with traditional technologies that will work for the life of the employment rather than looking a long-term fix with a higher degree of perceived risk.
- A lack of applicators capable of properly applying 3LPE and 3LPP coatings
- A limited supply of 3LPE and 3LPP coating material

**Analysis of Infrastructure Opportunities**
**Research Largely Finished**
**First Person Interviews In Process**
**Place into Finish Format**

Phase I of the analysis revealed that coating companies were dedicating more and more resources to infrastructure segment. In the Phase I document it became apparent that firms were committed to gaining additional market share within the infrastructure segment of the marketplace. The Phase II analysis will provide a detailed overview of the infrastructure opportunities currently available. This profile will include a review of the overall market size, a summary of the regulatory oversight, an analysis of the barriers to entry within the segment, an examination of the growth potential and a summary of key stakeholders.

Additionally, the infrastructure section of the analysis will look to provide a detailed strategy for entering the infrastructure segment and a reputation for quality within it. Beyond that, this analysis will review the infrastructure segment in its entirety and make recommendations on what pieces of the segment that would be most desirable for NAC-10 to target. Upon initial review, some of the more desirable segments include; re-bar coatings, wastewater and water applications and structural steel members.

**Project Plan**

Currently, Youngstown State University has a team of three MBA students assigned to this project. Phase II of the analysis will be led by Kolt Codner, the project manager from Phase I of the project completed last fall. The students assigned to the project bring a unique combination of project management, engineering and financial auditing experience to this section of the analysis. Included below is a proposed project schedule based upon a series of the project assumptions at this early formative stage in the project.

---

**Proposed Phase II Project Schedule**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/4/2011</td>
<td>YSU Team Meeting Youngstown, OH</td>
</tr>
<tr>
<td>2/18/2011</td>
<td>WinTec Kickoff Meeting Houston, TX</td>
</tr>
<tr>
<td>2/25/2011</td>
<td>Finalize Project Plan</td>
</tr>
<tr>
<td>3/1/2011</td>
<td>Continue Research Initiatives</td>
</tr>
<tr>
<td>3/28/2011</td>
<td>Findings Draft to WinTec</td>
</tr>
<tr>
<td>4/1/2011</td>
<td>Receive WinTec/Tagos Comments</td>
</tr>
<tr>
<td>5/13/2011</td>
<td>Deliver Final Findings to WinTec Houston, TX</td>
</tr>
</tbody>
</table>

---
Introductions & Overview

Review of Actions to Date

- Examination of 3LPE and 3LPP Slow Adoption in US
  - Scope of Work
    - Explore Indications for NAC-10
    - 100% Complete
- In-Depth Analysis of Infrastructure Opportunities
  - Scope of Work
    - Market Size
    - Barriers to Entry
    - Growth Potential
    - Key Stakeholders
    - Regulatory Oversight
    - Market Entrance Strategies
  - Research 100% Complete
  - Rough Composition 100% Complete
  - Final Completion 85%
  - Estimated Completion Date: Friday April 15, 2011
- Analysis of Oil Rig Coating Opportunities
  - Scope of Work
    - No. of Rigs in Operation
    - Geographic Characteristics of Marketplace
    - Operation Trends
    - Current Coating Systems
      - Inorganic Zinc Silicate Primers
      - High Build Epoxy Coatings
      - Aliphatic Polyurethane Topcoats
      - Epoxy/Polysiloxane Finish Coats
      - Zinc Rich Epoxy Primers
      - Polymeric Coatings
    - Oil Rigs by Firm*
    - Current Coating Costs*
    - Current Coating Life Expectancy*
    - Current Coating Process*
  - Research 85% Complete
- **Rough Composition 80% Complete**
- **Final Completion 60%**
- **Estimated Completion Date: Friday April 24, 2011**

- **Regulatory Agency Oversight**
  - **Scope of Work**
    - Hierarchy of Oversight
    - Minimum Specifications for Agencies
  - **Research 90% Complete**
  - **Rough Composition 80% Complete**
  - **Final Completion 55%**
  - **Estimated Completion Date: Friday April 24, 2011**

- **Comprehensive Analysis of Petrochemical Industry Supply Chains**
  - **Scope of Work**
    - Process Mapping
    - Estimate Direct and Indirect Costs of Supply Chain
  - **Secondary Objective at this Point**
  - Some analysis performed, will be included for reference in final document
  - Data will be Relevant for Future Projects
  - **Research 40% Complete**
  - **Rough Composition 30% Complete**
  - **Final Completion 25%**
  - **Estimated Completion Date: Friday May 1, 2011**

- **Product Pricing Information**
  - **Establish Pricing Recommendations**
  - **Need Direct Contact within Industry for Competitor Pricing**
  - Can Provide a Estimated Improvement over Current Standards to Justify Pricing
    - For instance, if current coating costs X, NAC-10 can warrant 2.5X
  - **Research 30% Complete**
  - **Rough Composition 15% Complete**
  - **Final Completion 10%**
  - **Estimated Completion Date: Friday May 1, 2011**

The project timeline and milestones are as follows:

- **Today**
- **4/11/2011** Complete Infrastructure
- **4/15/2011** Complete Oil Rig
- **4/24/2011** Complete Regulatory
- **5/1/2011** Complete Supply Chain
- **5/1/2011** Complete Pricing
- **5/23/2011** Create Final Document
- **5/16/2011** Final Presentation
- **5/23/2011** Contingency Final Date

*WinTec NAC-10 - Phase II Analysis*
Exhibit Five

3M COMPANY

| Company Headquarters: | 3M Center, Bldg. 220-11W-02, St. Paul, MN 55144-1000, US |
| Phone: | (651)-733-1110 |
| Website: | www.3m.com |
| NAICS/ Industry Codes: | 33911 |

Company Profile:

3M Company (3M), incorporated in 1929, is a diversified technology company with a global presence in industrial and transportation; health care; consumer and office; safety, security and protection services; display and graphics, and electro and communications. The Company is a primary manufacturer of products for many of the markets it serves. The Company’s products are sold through numerous distribution channels, including directly to users and through numerous wholesalers, retailers, jobbers, distributors and dealers in a variety of trades in many countries worldwide. In January 2009, 3M (Safety, Security and Protection Services Business) purchased 100% of Alltech Solutions, a provider of water pipe rehabilitation services based in Moncton, New Brunswick, Canada. In April 2010, the Company completed its acquisition of a majority stake in the A-One branded consumer and office label business, and related operations. In May 2010, the Company acquired J.R. Phoenix Ltd. In June 2010, MTI Global Inc. sold its MTI PolyFab subsidiary to the Company. In October 2010, the Company acquired Arizant Inc. In October 2010, the Company acquired Attenti Holdings S.A., a supplier of remote people monitoring technologies.

Industrial and Transportation Business

The Industrial and Transportation segment serves a range of markets, such as appliance, paper and packaging, food and beverage, electronics, automotive original equipment manufacturer (OEM) and automotive aftermarket (auto body shops and retail). Industrial and Transportation products include tapes, a variety of coated and non-woven abrasives, adhesives, specialty materials, filtration products, energy control products, closure systems for personal hygiene products, and components and products that are used in the manufacture, repair and maintenance of automotive, marine, aircraft and specialty vehicles. Major industrial products include vinyl, polyester, foil and specialty industrial tapes and adhesives; scotch masking tape, scotch filament tape and scotch packaging tape; packaging equipment; 3M VHB bonding tapes; conductive, low surface energy, hot melt, spray and structural adhesives; reclosable fasteners; label materials for durable goods, and coated, nonwoven and microstructured surface finishing and grinding abrasives for the industrial market.

Source: Reuters, 3M Reuters Description

Product Portfolio:

3M’s major products include tapes, coated and nonwoven abrasives, adhesives, specialty materials, filtration products, closures for disposable diapers, automotive components, abrasion-resistant films, structural adhesives and paint finishing and detailing products, energy control products.

Since 1960, major oil and gas companies around the world have been using 3M Scotchkote coatings as their primary corrosion protection system for protecting their pipelines. Scotchkote fusion bonded
epoxy coating is reliable, tough, durable and field-proven – it’s a vital element in the gas and oil pipeline network. Scotchkote liquid epoxy internal pipe coating is also a preferred material of international applicators and pipeline operators.

3M offers a variety of corrosion protection products targeting the following industries:

1. Oil and Gas
2. Water Infrastructure
3. Building and Construction
4. Utilities and Power
5. Transportation Infrastructure
6. Production and Manufacturing

Source: Company website, Corrosion Protection Products

Annual Revenues:

The company posted full-year 2009 sales of $23.1 billion. The industrial and transportation division includes anti-corrosion chemicals is $7.1 billion.

<table>
<thead>
<tr>
<th></th>
<th>2009 (Millions)</th>
<th>2008 (Millions)</th>
<th>2007 (Millions)</th>
<th>Operating Income (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial and Transportation</td>
<td>$7,116</td>
<td>$8,173</td>
<td>$7,639</td>
<td>$1,238</td>
</tr>
<tr>
<td>Health Care</td>
<td>4,294</td>
<td>4,303</td>
<td>3,980</td>
<td>1,350</td>
</tr>
<tr>
<td>Consumer and Office</td>
<td>3,471</td>
<td>3,578</td>
<td>3,494</td>
<td>748</td>
</tr>
<tr>
<td>Safety, Security and</td>
<td>3,180</td>
<td>3,450</td>
<td>2,944</td>
<td>745</td>
</tr>
<tr>
<td>Protection Services</td>
<td>3,132</td>
<td>3,268</td>
<td>3,168</td>
<td>590</td>
</tr>
<tr>
<td>Display and Graphics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electro and Communications</td>
<td>2,276</td>
<td>2,835</td>
<td>2,805</td>
<td>322</td>
</tr>
<tr>
<td>Corporate and Unallocated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elimination of Dual Credit</td>
<td></td>
<td>(358)</td>
<td>(361)</td>
<td>(87)</td>
</tr>
<tr>
<td>Total Company</td>
<td>$23,123</td>
<td>$25,269</td>
<td>$24,462</td>
<td>$4,814</td>
</tr>
</tbody>
</table>

Source: Company Filings, 3M 2009 Annual Report, p. FC 151

R & D Efforts:

Research, development and related expenses (R&D) were 5.6 percent of net sales in 2009, 2008 and 2007. R&D expenses in dollars declined approximately 8 percent in 2009 compared to 2008, following an increase of 2.6 percent when comparing 2008 to 2007. 3M has continued to support its key larger programs, but overall dollar spending has been impacted by company-wide cost-cutting initiatives such as reductions in indirect spending and the banked vacation policy change.
Evaluation of Strategic Initiatives:

A distinguishing factor of 2009 was this resolve to maintain investments in the future. We maintained investments of more than a billion dollars in R&D at a time when many companies were forced to dramatically cut back. And we still managed to achieve an impressive free cash flow conversion, about 126%, even with $900 million capital investment last year and nearly $1.4 billion put into our pension and postretirement plans, the majority of which was cash. These investments are a clear and present signal of our confidence in the future of 3M and will only serve to make us stronger yet.

Source: Company Filings, 3M 2009 Annual Report, p. FC 2
Exhibit Six

PPG Industries

| Company Headquarters: | 1 PPG Pl., Pittsburgh, PA 15272, US |
| Phone: | (412) 434-3131 |
| Website: | www.ppg.com |
| NAICS/ Industry Code: | 325510 |

Company Profile:

PPG Industries, Inc. (PPG), incorporated in 1883, is a global supplier of protective and decorative coatings. The Company operates in six segments: Performance Coatings, Industrial Coatings, Architectural Coatings, Optical and Specialty Materials, Commodity Chemicals and Glass. The Performance Coatings, Industrial Coatings and Architectural Coatings segments supply protective and decorative finishes for customers in a range of end use markets, including industrial equipment, appliances and packaging; factory-finished aluminum extrusions and steel and aluminum coils; marine and aircraft equipment; automotive original equipment, and other industrial and consumer products. In addition to supplying finishes to the automotive original equipment market, PPG supplies refinishes to the automotive aftermarket.

Performance Coatings, Industrial Coatings and Architectural Coatings

The Performance Coatings consists of the refinish, aerospace, protective and marine and architectural coatings businesses. The refinish coatings business supplies coatings products for automotive and commercial transport/fleet repair and refurbishing, light industrial coatings for an array of markets and specialty coatings for signs. These products are sold primarily through distributors. The aerospace coatings business supplies coatings products for automotive and commercial transport/fleet repair and refurbishing, light industrial coatings for a range of markets and specialty coatings for signs.

The protective and marine coatings business supplies coatings and finishes for the protection of metals and structures to metal fabricators, heavy-duty maintenance contractors and manufacturers of ships, bridges, rail cars and shipping containers. These products are sold through the architectural coatings Company-owned architectural coatings stores, independent distributors and directly to customers. The architectural coatings business primarily produces coatings used by painting and maintenance contractors and by consumers for decoration and maintenance. Architectural coatings products are sold through a combination of Company-owned stores, home centers, paint dealers, independent distributors and directly to customers. The architectural coatings business operates approximately 400 Company-owned stores in North America and approximately 50 Company-owned stores in Australia.

The Company’s Industrial Coatings segment consists of the automotive, industrial and packaging coatings businesses. The industrial and automotive coatings businesses sell directly to a variety of manufacturing companies. PPG also supplies adhesives and sealants for the automotive industry and metal pretreatments and related chemicals for industrial and automotive applications. The packaging coatings business supplies coatings and inks to the manufacturers of aerosol, food and beverage containers. The Architectural Coatings business supplies a variety of coatings under a number of brands and purchased sundries to painting contractors and consumers in Europe, the Middle East and Africa.
The products are sold through a combination of about 560 company-owned stores, home centers, paint dealers, independent distributors and directly to customers.

Performance Coatings, Industrial Coatings and Architectural Coatings

PPG is a major global supplier of protective and decorative coatings. The Performance Coatings, Industrial Coatings and Architectural Coatings – EMEA reportable segments supply protective and decorative finishes for customers in a wide array of end use markets, including industrial equipment, appliances and packaging; factory- finished aluminum extrusions and steel and aluminum coils; marine and aircraft equipment; automotive original equipment; and other industrial and consumer products. In addition to supplying finishes to the automotive original equipment market, PPG supplies refinishes to the automotive aftermarket. PPG also supplies coatings to painting and maintenance contractors and directly to consumers for decoration and maintenance. The coatings industry is highly competitive and consists of a few large firms with global presence and many smaller firms serving local or regional markets. PPG competes in its primary markets with the world’s largest coatings companies, most of which have global operations, and many smaller regional coatings companies. Product development, innovation, quality and technical and customer service have been stressed by PPG and have been significant factors in developing an important supplier position by PPG’s coatings businesses comprising the Performance Coatings, Industrial Coatings and Architectural Coatings – EMEA reportable segments.


Source: Reuters, PPG Reuter's Description and Annual Report p. 2, Annual Report

Product Portfolio:

PPG protective and marine coatings offer a variety of protection-based products.

Protective Coatings

1. Civil Infrastructure

PPG Protective & Marine Coatings delivers proven performance for the severe conditions found in the Civil Infrastructure segment. These markets cover a wide variety of structures, many of which involve huge investment and exposure to corrosive environments.

Constant innovation and investment has given PPG proven, durable products for a range of Civil Infrastructure applications: Airport, Bridges, Pipelines, Stadiums, Water and wastewater treatment plants, Water transmission and storage.

2. Offshore

Using state-of-the-art technology, PPG’s segment-leading coatings requirements offer the best protection against steel corrosion in the most extreme environmental conditions. Combined with hydrocarbon Passive Fire Protection offerings, PPG offshore systems provide exceptional protective coatings solutions feature our high performance tank lining range, general purpose epoxy primers and durable finishes.
Their coatings have been tested by third party laboratories and certificates are available on request.

Constant innovation and investment has given PPG proven, durable products for a range of Offshore applications: Topsides, Decks, Tanks, Passive Fire Protection (PITT-CHAR® XP), Splash zone, Subsea.

3. Petrochemical
The environmental conditions found within the Petrochemical industry are some of the most extreme in the protective coatings industry. PPG Protective & Marine Coatings has a wealth of experience in this field to meet and service the requirements of our global customers.

PPG offers an excellent range of protective coatings featuring our unique tank linings, general purpose epoxy primers and durable finishes. Our advanced coating systems, combined with our hydrocarbon Passive Fire Protection offer, give PPG the capability of providing a complete solution – whatever your need.

Continuous innovation and investment has given PPG proven, durable products for a range of Petrochemical applications: Jetty protection, Structural steel, Storage facilities, Process equipment, Pipes, Passive Fire Protection (PITT-CHAR® XP).

4. Power
PPG helps energy producers meet this challenge with proven products by making plants and equipment last longer, work better, and lower on-going maintenance costs – even in some of the world’s harshest environments.

Decades of innovation and investment have given PPG proven, durable products for a range of Power sectors: Fossil fuel, Nuclear, Hydroelectric, Wind, Transmission towers.

Marine Coatings
PPG continually strives to develop and market products that meet the current requirements of both operators and yards. Consequently, they have launched coatings that allow for extended laid-up periods, meet latest IMO PSPC regulations for water ballast tanks, and reduce the cost of onboard maintenance.

In addition, they have coatings solutions that reduce fuel consumption and carbon dioxide emissions as a result of improved hydrodynamics of the ship’s hull.

Constant innovation and investment has given PPG proven, durable products for a range of Marine applications: Marine new-build, Marine dry dock, Marine sea stock.

Source: Company website, Product Divisions

Market Share:

n/a

Annual Revenues:

The Industrial Coatings reportable segment is comprised of the automotive, industrial and packaging coatings operating segments. This reportable segment primarily supplies a variety of protective and
decorative coatings and finishes along with adhesives, sealants, inks and metal pretreatment products. Industrial coatings are the company’s second largest business area.

PPG Industries, Inc. generated net sales of $3,068 million in the financial year ended December 2009. The company’s net income totaled $538 million in fiscal 2008, a decrease of 35.5% compared with 2007. The performance coatings segment generated revenues of $4,716 million, which made up 30% of PPG Industries total revenues at the end of the fiscal year December 2008.

<table>
<thead>
<tr>
<th>Reportable Business Segments</th>
<th>Performance Coatings</th>
<th>Industrial Coatings</th>
<th>Architectural Coatings – EMEA</th>
<th>Optical and Specialty Materials</th>
<th>Commodity Chemicals</th>
<th>Class(1)</th>
<th>Corporate / Eliminations / Non-Segment Items(2)</th>
<th>Consolidated Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net sales to external customers</td>
<td>$4,095</td>
<td>$3,068</td>
<td>$1,952</td>
<td>$1,002</td>
<td>$1,273</td>
<td>$849</td>
<td>$—</td>
<td>$12,239</td>
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<tr>
<td>Intersegment net sales</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>9</td>
<td>(12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total net sales</strong></td>
<td><strong>$4,095</strong></td>
<td><strong>$3,068</strong></td>
<td><strong>$1,952</strong></td>
<td><strong>$1,002</strong></td>
<td><strong>$1,282</strong></td>
<td><strong>$849</strong></td>
<td><strong>($12)</strong></td>
<td><strong>$12,239</strong></td>
</tr>
<tr>
<td><strong>Segment income</strong></td>
<td><strong>$551</strong></td>
<td><strong>$159</strong></td>
<td><strong>$128</strong></td>
<td><strong>$235</strong></td>
<td><strong>$132</strong></td>
<td><strong>($39)</strong></td>
<td><strong>$—</strong></td>
<td><strong>$1,186</strong></td>
</tr>
</tbody>
</table>

Source: Annual Report p. 70, Annual Report

Performance coatings and industrial coatings accrue 34 percent and 25%, respectively, of segment net sales.

Source: Corporate Brochure p. 4, Corporate Brochure

R&D Efforts:

Technology innovation has been a hallmark of PPG’s success throughout its history. Research and development costs, including depreciation of research facilities, were $403 million, $468 million and $363 million during 2009, 2008 and 2007, respectively. These costs totaled approximately 3% of sales in each of these years, representing a level of expenditure that is expected to continue in 2010. PPG owns and operates several facilities to conduct research and development relating to new and improved products and processes. Additional process and product research and development work is also undertaken at many of the Company’s manufacturing plants. As part of our ongoing efforts to manage our costs effectively, we operate a global competitive sourcing laboratory in China, have outsourcing arrangements with several laboratories and have been actively pursuing government funding of a small, but growing portion of the Company’s research efforts. Because of the Company’s broad array of products and customers, PPG is not materially dependent upon any single technology platform.

Patents

PPG considers patent protection to be important. The Company’s reportable business segments are not materially dependent upon any single patent or group of related patents. PPG earned $45 million in 2009, $52 million in 2008 and $48 million in 2007 from royalties and the sale of technical know-how.
**Backlog**
In general, PPG does not manufacture its products against a backlog of orders. Production and inventory levels are geared primarily to projections of future demand and the level of incoming orders.

*Source: Annual Report, p. 10, Annual Report*

**Evaluation of Strategic Initiatives:**

PPG is currently in a restructuring phase to cut costs. During the first quarter of 2009, the Company finalized a restructuring plan that is focused on further reducing PPG’s global cost structure. The Company recorded a charge of $186 million for the cost of this restructuring. During the third quarter of 2008, the Company finalized a restructuring plan that is part of implementing PPG’s global transformation strategy and the integration of its acquisition of Sigma Coatings. The Company recorded a charge of $163 million for the cost of this restructuring.

Other earnings increased by $13 million in 2009 due primarily to the impact of gains on non-operating asset sales.

*Source: Annual Report, p. 17, Annual Report*
Exhibit Seven

COST OF CORROSION CONTROL METHODS

One of the two methods described in this report to estimate the total cost of corrosion is based on a method where the total cost of corrosion control methods and services is estimated. This method was used by Uhlig(1) in one of the first studies that examined the cost of corrosion in the United States, and was later adapted to estimate the cost of corrosion to the Japanese economy.(2-3) These studies are described in more detail in the section titled “Review of Previous National Cost of Corrosion Studies.” The corrosion control methods that were considered include protective coatings, corrosion-resistant metals and alloys, corrosion inhibitors, polymers, anodic and cathodic protection, corrosion control services, corrosion research and development, and education and training. The total annual cost of corrosion estimated with this method for the average year of 1998 was $121.41 billion or 1.381 percent of the $8.79 trillion Gross Domestic Product (GDP). Table 1 shows the distribution of the corrosion control methods and services costs.

Table 1. Costs of corrosion control methods and services.

<table>
<thead>
<tr>
<th>MATERIAL AND SERVICES</th>
<th>RANGE</th>
<th>AVERAGE COST</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($ x billion)</td>
<td>($ x billion)</td>
<td>(%)</td>
</tr>
<tr>
<td>Protective Coatings</td>
<td>($ x billion)</td>
<td>($ x billion)</td>
<td>(%)</td>
</tr>
<tr>
<td>Organic Coatings</td>
<td>40.2 – 174.2</td>
<td>107.2</td>
<td>88.3</td>
</tr>
<tr>
<td>Metallic Coatings</td>
<td>1.4</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Metals and Alloys</td>
<td>7.7</td>
<td>7.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Corrosion Inhibitors</td>
<td>1.1</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Polymers</td>
<td>1.8</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Anodic and Cathodic Protection</td>
<td>0.73 – 1.22</td>
<td>0.98</td>
<td>0.8</td>
</tr>
<tr>
<td>Services</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Research and Development</td>
<td>0.020</td>
<td>0.02</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Education and Training</td>
<td>0.01</td>
<td>0.01</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$54.16 – $188.65</td>
<td>$121.41</td>
<td>100%</td>
</tr>
</tbody>
</table>

Protective Coatings

Both organic and metallic coatings are used to provide protection against corrosion of metallic substrates. These metallic substrates, particularly carbon steel, will corrode in the absence of the coating, resulting in a reduction of the service life of the steel part or component. Both types of coating are reviewed in the following sections.

Organic Coatings

The major organic coatings are often classified by a curing mechanism, with the two basic types of cured coatings being nonconvertible and convertible.(4) The nonconvertible coatings cure solely by evaporation of the solvent with no chemical change in the resin matrix. They can be re-dissolved in the solvent originally used to dissolve the resin. Convertible coatings, on the other hand, cure primarily by a polymerization process in which the resins undergo an irreversible chemical change.

The common types of nonconvertible coatings include the following:
Chlorinated rubbers – elastomers formed when natural rubber or a polyolefin is reacted with chlorine. These materials are usually modified by other resins to obtain high solid contents and to decrease brittleness.

Vinyls – made by dissolving polyvinyl chloride (PVC) polymers in a suitable solvent. They are generally low solid coatings applied in very thin coats. Vinyl coatings are used for their weathering ability.

Acrylics – made by dissolving polymers made from acrylic acid and methacrylic acid or acrylonitrile. Water-based acrylics are widely used due to their weathering properties and ease of application.

Bitumen – generally based on residues from petroleum or coal mining processes. Bitumen coatings can also come from naturally occurring sources such as gilsonite. The presence of aromatic hydrocarbons (such as benzene) in some of these coatings has limited their acceptability in recent years due to health and environmental concerns.

Flame-spray polymers – these are not evaporative cure coatings; rather, they cure by cooling from a molten state. The most common flame-spray polymer is polyethylene, which is ground into a powder state and flocced through a flame, which converts the polyethylene into a molten state. The molten polymer hits the substrate and cools, solidifying into a protective film. This type of coating can be re-melted or dissolved by an appropriate solvent, although there are very few solvents for polyethylene.

Coalescence coatings – in this type of coating, tiny particles of resin are encapsulated in a soaplike material and then dispersed in water, which acts as a diluent rather than a true solvent. This type of blend is known as an emulsion. When the water evaporates, the resin particles fuse (coalesce) to form a stable, cured coating film. These coatings, once cured, cannot be re-dissolved in water, although stronger solvents may dissolve them. Examples of these include acrylic latex suspensions and epoxy emulsions.

Most convertible coatings cure by polymerization. Polymerization occurs when two or more resin molecules combine to form a single, more complex molecule. The resin molecules may be monomers (single units) or they may be shorter chain polymers, which react to form longer chain polymers. There are four main types of polymerization used in coating technology (oxygen-induced, chemically-induced, heat-induced, and hydrolysis). Other types of polymerization, such as radiation-induced polymerization, are possible; however, the vast majority of convertible coatings use one of the following four mechanisms.

**Oxygen-induced polymerized coatings:**

Alkyds – referred to as oil-based primers and topcoats, alkyds are based on vegetable or fish oils blended with pigments and catalysts in a solvent. The film forms when the oil reacts with oxygen assisted by the catalyst, and the solvent evaporates. Most paints that are sold in spray cans are alkyds.

Drying oils – penetrating oils and lacquers that form a thin protective film. Chemically-induced polymerized coatings:

Epoxies – the preferred corrosion control coating for severe environments. Epoxies are a generic class of materials based on the presence of an epoxide polymer side group. They exhibit superior adhesion and
chemical resistance properties, yet are susceptible to weathering degradation (by chalking) and are
often topcoated to shield them from ultraviolet (UV) light.

Polyurethanes – these set the standard for color retention and weathering, and are widely used over
steel for long-term decorative corrosion protection. Polyurethanes also vary widely in chemistry and can
be formulated to be very flexible elastomers, rigid foams, or dense brittle films.

**Heat-induced polymerized coatings:**

Polyesters and vinyl esters – these materials are based on styrene monomers with a very reactive
catalyst. They could be classified as chemically-induced curing polymers; however, the actual reaction is
heat-induced. The catalytic reaction generates a great deal of heat, which polymerizes the styrene
monomer and the ester groups. They are used as tank linings and form the basis for many freestanding
fiberglass structures.

Phenolics – these are thin films, which form by evaporation of solvent followed by baking at high
temperatures [204 °C (400 °F) or greater]. Phenolics form a very strong, hard chemical- and
temperature-resistant film used for storage of strong acids and solvents.

Silicones – chemically, silicones vary greatly; however, the corrosion-resistant coatings based on silicone
are baked to create an inorganic silicone backbone that withstands very high temperatures. In
applications such as furnaces and boilers, silicone-based coatings are often the only option.

Fusion-bonded epoxies – powder-based epoxies that are applied to hot substrates. When the powder
hits the hot substrate, it melts and the chemical reaction occurs. Upon cooling, the film solidifies. Fusion
bonded epoxies are widely used for pipelines and concrete rebar applications.

**Hydrolysis-induced polymerized coatings:**

Inorganic zinc – usually zinc metal powder is dispersed in a zinc silicate binder, and the zinc silicate uses
moisture from the air to form a cured matrix. The zinc particles behave as individual anodes to
sacrificially protect the steel from corrosion. Many steel bridges and freestanding structural steel
members are coated with inorganic zinc, which has a characteristic gray-green color. For other
applications, the zinc is topcoated with an epoxy and/or polyurethane to provide an excellent system for
corrosion control. There are also water-based inorganic zinc coatings, which react with CO2 to cure.

Moisture-cured polyurethanes – some polyurethane coatings form their protective cured film by
reaction with moisture from the air. Their properties are usually quite different from two-component
polyurethanes, but contain a basic urethane side group, which classifies them as polyurethanes.

The selection of coating chemistry for the different industrial applications is based on intended service,
application, intended service life, and cost. According to the U.S. Department of Commerce, Census
Bureau, the total amount of organic coating material sold in the United States in 1997 was 5.56 billion L
(1.47 billion gal), at a value of $16.56 billion.(5) Table 2 summarizes the total volume and value of paint
sold in the United States for the years 1990 to 1999. The total sales can be broken down into four
categories: architectural coatings, Original Equipment Manufacturers (OEM) coatings, special-purpose
coatings, and miscellaneous allied paint products.
Table 2. Summary of estimated U.S. total quantity and value of shipments of paint and allied products: 1990 to 1999 "As Revised," as reported by the U.S. Census Bureau.(5)

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<th>OEM COATINGS</th>
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<td>Value</td>
<td>Quantity</td>
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Architectural coatings are applied on-site to new and existing residential, commercial, institutional, and industrial buildings. Small percentages of these are used as primers and undercoats, and may be classified as corrosion control coatings. Water-based and water-thinned coatings dominate the architectural market. In fact, more than 75 percent of all architectural coatings are now water-based.(6) Table 3 shows the markets for corrosionrelated architectural coatings according to the 1997 Census Bureau data.

Source:
HIGHWAYS & BRIDGES

Cost of Corrosion
The dollar impact of corrosion on highway bridges is considerable. The annual direct cost of corrosion for highway bridges is estimated to be $6.43 billion to $10.15 billion, consisting of $3.79 billion to replace structurally deficient bridges over the next 10 years, $1.07 billion to $2.93 billion for maintenance and cost of capital for concrete bridge decks, $1.07 billion to $2.93 billion for maintenance and cost of capital for concrete substructures and superstructures (minus decks), and $0.50 billion for the maintenance painting cost for steel bridges. This gives an average annual cost of corrosion of $8.29 billion. Life-cycle analysis estimates indirect costs to the user due to traffic delays and lost productivity at more than 10 times the direct cost of corrosion. In addition, it was estimated that employing “best maintenance practices” versus “average practices” can save 46 percent of the annual corrosion cost of a black steel rebar bridge deck, or $2,000 per bridge per year.

While there is a downward trend in the percentage of structurally deficient bridges (a decrease from 18 percent to 15 percent between 1995 to 1999), the costs to replace aging bridges increased by 12 percent during the same period. In addition, there has been a significant increase in the required maintenance of the aging bridges. Although the vast majority of the approximately 108,000 prestressed concrete bridges have been built since 1960, many of these bridges will require maintenance in the next 10 to 30 years. Therefore, significant maintenance, repair, rehabilitation, and replacement activities for the nation’s highway bridge infrastructure are foreseen over the next few decades before current construction practices begin to reverse the trend.

Conventional Reinforced-Concrete Bridges
The primary cause of reinforced-concrete bridge deterioration is chloride-induced corrosion of the black steel reinforcement, resulting in expansion forces in the concrete that produce cracking and spalling of the concrete. The chloride comes from either marine exposure or the use of deicing salts for snow and ice removal. Because the use of deicing salts is likely to continue, if not increase, little can be done to prevent bridge structures from being exposed to corrosive chloride salts. Therefore, bridge designs and concrete mixes must be resistant to chloride-induced corrosion. This can be accomplished by: (1) preventing chlorides from getting to the steel surface (physical barriers at the concrete surface, coating the rebar, or low chloride-permeable concrete), (2) making the concrete less corrosive at specific chloride levels (inhibitors or admixtures), or (3) making the rebar resistant to corrosion (corrosion-resistant alloys, composites, or clad materials).

Over the past 20 years, there has been a trend in new construction toward utilizing higher quality concrete and more corrosion-resistant rebars. Longer bridge service life is currently achieved by using epoxy-coated rebars in the majority of new bridge construction, with the limited use of stainless steel-clad or solid rebars in more severe environments. The expected service life of a newly constructed bridge is typically 75 years and up to 120 years for stainless steel rebar construction. Admixtures to the concrete for the purpose of increased corrosion resistance have included corrosion-inhibiting admixtures and mineral admixtures such as silica fume. High-range water reducers permit the use of low water-cement ratio concretes that have lower permeability to corrosive agents and, thus, result in longer times to corrosion initiation of the rebar. Many of these methods are used in combination with each other to obtain a longer service life.

Many rehabilitation methodologies designed to extend the service life of bridges that have deteriorated due to corrosion of the reinforcing steel have been developed and put into practice within the past 25 years. These include cathodic protection, electrochemical chloride removal, overlays, and sealers. Although each of these methods have been shown to be successful, continuing developments are necessary to improve effectiveness and increase the life extension provided by these methods.

Prestressed Concrete Bridges
Whereas some of the methods discussed for conventional reinforced-concrete bridges are applicable to prestressed concrete components (e.g., high-performance concrete and corrosion inhibiting admixtures), special consideration for corrosion prevention of prestressed reinforced-concrete bridges is required.
Most of these bridges are relatively new and their numbers are relatively low; therefore, the overall economic impact is not as significant as for conventional reinforced-concrete bridges. However, failure of the high-strength prestressing steel can compromise the integrity of the prestressed concrete bridge (corrosion-related deterioration compromising the structural integrity of a conventional concrete structure is highly unlikely). This makes close attention to construction details and subsequent monitoring and inspection of the prestressed concrete bridges critical.

Corrosion prevention of pretensioned structures is primarily accomplished through the use of high-performance concretes or the addition of corrosion-inhibiting admixtures. Remedial measures such as cathodic protection are possible as long as care is taken to prevent overprotection that can lead to hydrogen-induced cracking of the high-strength steel. Other measures such as electrochemical chloride removal cannot be used for prestressed concrete structures because of the relatively large amounts of hydrogen produced at the steel surface during the removal process.

Recent failures of post-tensioned structures have underscored the importance of maintaining void-free grouting of the tendons, especially near the anchorage. Maintaining the integrity of the post-tensioned tendon starts with ensuring the integrity of the duct (typically polyethylene), followed by the application of a good-quality grout that is continuous around the strands. Placement of the grout is often more difficult when low water-cement ratio mixes and/or mineral admixtures are employed. Improved grouting practices are continuing to be developed. In addition, the use of corrosion-inhibiting admixtures can provide added protection against corrosion of the prestressing steel strands. Note that in August 2001, the American Segmental Bridge Institute conducted a 3-day training school for certifying grouting specialists. This training school will be held in the future once or twice a year.

Steel Bridges
The primary cause of corrosion of steel bridges is the exposure of the steel to atmospheric conditions. This corrosion is greatly enhanced due to marine (salt spray) exposures and industrial environments. The only corrosion prevention method for these structures is to provide a barrier coating (paint).

Changes in environmental protection regulations have brought about transformation of the approach to corrosion protection for steel bridges. Until the mid- to late-1970s, virtually all steel bridges were protected from corrosion by multiple thin coats of lead- and chromate-containing alkyd paints applied directly over mill scale on the formed steel. Maintenance painting for prevention of corrosion was rare and primarily was practiced on larger bridge structures. Since the majority of the steel bridges in the interstate highway system were constructed between 1950 and 1980, most of these structures were originally painted in this manner; therefore, a large percentage of the steel bridges in the interstate system are protected from corrosion by a coating system that is now beyond its useful service life.

Moreover, the paint system commonly used for steel bridge members contains chromium and lead and can no longer be used because of the effects it has on humans and the environment. The bridge engineers have a choice of either replacing the lead-based paints with a different coating or painting over the deteriorating areas. Removal of lead-based paint incurs high costs associated with the requirements to contain all the hazardous waste and debris.

Developments include: (1) improved and environmentally safe coating systems and (2) methodologies to optimize the use of these systems, such as “zone” painting (adjusting coating types and maintenance schedules based on the aggressiveness of the environment within different zones on the bridge). Overpainting techniques to eliminate the cost of expensive paint removal also have been developed.

Opportunities for Improvement and Barriers to Progress
A typical dilemma of bridge management is how to allocate the often insufficient funds for construction, rehabilitation, and maintenance. Compounding the problem is that funding typically comes from city, state, and federal sources with spending restrictions based on the funding source. This makes allocating the funds in order to optimize construction, rehabilitation, and maintenance decisions difficult. The cooperation of these different funding agencies is required to permit allocation of resources to achieve the best cost benefit.

An increased need for bridge inspection has placed additional drains on maintenance funds. In the case of prestressed concrete bridges, the issue of careful inspection becomes particularly acute because an individual failure of a tendon may have a significant impact on the structural integrity of the bridge. The importance of inspection was recently illustrated when tendon failures in two Florida bridges were identified through routine inspections before
the safety of the bridges was compromised. The economic analysis performed in this study showed that monitoring of bridge condition and subsequent maintenance based on that information (information-based maintenance) was the most cost-effective maintenance strategy.

The economic analysis further indicated that capital funding for the higher quality materials of construction (e.g., epoxy-coated rebars) results in lower annualized costs due to postponement of repair/rehabilitation expenses incurred by the owner agency. The analysis further indicated that user costs (traffic delays during maintenance) are significant and can be 10 times greater than the direct costs to the owner/operator. This places a premium on the selection of materials of construction that minimize maintenance over the bridge service life. It also highlights the importance of careful planning for traffic control and alternative routes during bridge maintenance and rehabilitation activities.

The significant rise in costs for maintenance of steel bridges (environmental issues dealing with lead paint removal and handling of volatile organic compounds) has placed a significant strain on maintenance budgets. In fact, over the past few years, environmental regulations have become the single most influential force in the bridge painting industry. The focus for expenditures must shift to long-term effectiveness of dollars spent. This is a significant change in philosophy for a majority of the bridge painting industry. To date, bridge maintenance painting has been accomplished based on incremental budgets, rather than life-cycle considerations.

Additionally, the use of technological advances among bridge owners has not been uniform. This can, in part, be explained by the difference in funding and technical staffing between the agencies. Because of the perceived high costs of certain corrosion control methods, these methods go unused. With the general tendency to reduce the maintenance departments’ size and budget, corrosion control becomes one of the many responsibilities of personnel without the experience to understand the problems and without the knowledge of available solutions. There remains a significant need for life-cycle cost analysis to aid in the selection of repair-rehabilitation-replacement decisions.

**Recommendations and Implementation Strategy**

The technological advances, both in concrete (conventional and prestressed) and steel bridge corrosion control methodologies and construction materials, provide the opportunity that the newly constructed bridges will last considerably longer than the bridges that were constructed 20 to 30 years ago. However, newly developed materials of construction and corrosion control methodologies must be implemented properly over the entire bridge project (both design and construction phases).

These improvements, however, do not signify that the problems with corrosion on highway bridges will disappear soon. The percentage of deficient bridges, while declining, still remains high. At the same time, the costs of bridge repair and rehabilitation are steadily increasing, thereby offsetting any potential savings. Some of the bridges owned by state and city agencies simply cannot be replaced due to their historic value and/or the enormous strain on the traffic resulting from a bridge closure (e.g., the New York City East River bridges and the Oregon coastal U.S. Highway 101 bridges). These bridges are maintained and rehabilitated even at high costs.

There is an urgent need for allocation of greater monetary resources, so that the bridge engineers can properly maintain the structures based on timely inspections, thereby optimizing maintenance practices. At present, maintenance personnel are forced to make the choices based on inadequate funds, which will ultimately lead to a less-than-optimal cost benefit.

Despite appreciation of the corrosion-related issues in the bridge community, there is still a need for raising awareness and the transfer of the advanced methodologies for efficient corrosion protection to the end-users. The Federal Highway Administration (FHWA), which has amassed considerable research and field application data on corrosion protection methods for concrete and steel bridges, has served as an effective conduit for dissemination of such information through periodic demonstration programs and educational seminars. These demonstration programs have been successful and should be continued with increased staffing and funding levels.

There remains a considerable need for additional research in innovative construction materials such as corrosion-resistant alloy/clad rebars (metallic and non-metallic) and more durable concrete with inherent corrosion-resistant properties. In addition, research and development is needed in rehabilitation technologies that
can mitigate corrosion with minimal maintenance requirements, such as sacrificial cathodic protection systems.

CORROSION CONTROL METHODS
Methods utilized for corrosion control on bridges are specific to the type of bridge construction and whether its intended use is for new construction or maintenance/rehabilitation of existing structures. In this section of the report, corrosion control practices are reviewed for the three types of bridge structures focused on in this sector (conventional reinforced concrete, prestressed concrete, and steel). For the purposes of discussion, conventional reinforced concrete and prestressed concrete corrosion control methods are combined. Although prestressed concrete bridges have very special concerns (e.g., anchorage in both post-tensioned and pretensioned structures and ducts for post-tensioned structures), the general corrosion control methods are applicable to both prestressed and conventional reinforced bridges.

Reinforced-Concrete Bridges
Conventional reinforced-concrete bridges refer to those with superstructure constructed with conventional reinforced concrete. Often, prestressed concrete and steel bridges will have conventional reinforced-concrete decks or substructures. Therefore, corrosion control practices for conventional reinforced concrete are applicable to components of many other bridge structures. Therefore, a significant amount of detail is provided for conventional reinforced-concrete corrosion control practices.

New Construction
Corrosion protection can be incorporated into new bridge structures by proper design and construction practices, including the use of high-performance concrete (e.g., silica fume additions), low-slump concrete, and an increase in concrete cover thickness. Each of these attempts to impede migration of chlorides and oxygen (or other corrosive agents) through the concrete to the steel rebar surface. However, eventually, these corrosive agents will penetrate through the concrete cover and cracks, making other corrosion control practices necessary. A widely used method of corrosion prevention is the use of coated carbon steel rebar and, to some degree, corrosion-resistant alloy/clad rebars. The typical organic rebar coating is fusion-bonded epoxy, while the metallic rebar coating is galvanizing (very limited use in bridge structures). Rebar cladding with a corrosion-resistant alloy (e.g., stainless steel) is relatively new. Solid rebars constructed of stainless steel alloys have been used on a limited basis. In addition, non-metallic composite materials have been used. Another corrosion control practice available to new construction is the addition of corrosion-inhibiting admixtures to the concrete.

Epoxy-Coated Rebars
A Technical Note prepared by the FHWA and summarized here reviews the use of epoxy-coated rebar in bridge decks. (14) Epoxy coatings (often referred to as powders or fusion-bonded coatings) are 100 percent solid, dry powders. These dry epoxy powders are electrostatically sprayed over cleaned, preheated rebar to provide a tough impermeable coating. The coatings achieve their toughness and adhesion to the substrate as a result of a chemical reaction initiated by heat. Since these epoxy powders are thermosetting materials, their physical properties, performance, and appearance do not change readily with changes in temperature. The epoxy coating becomes a physical barrier between aggressive chloride ions (permeating the concrete cover) and the steel rebar.

For many years, bridge deck deterioration, stemming from corrosion of reinforcing bars, has been the number one problem for bridges. Prior to 1970, it was thought that portland cement itself provided sufficient protection to the reinforcing steel against corrosion. In the early 1970s, it became evident that corrosion of the reinforcing steel was related to the increasing application of deicing salts. Unfortunately, this was not learned until after thousands of bridge decks containing black reinforcing steel showed signs of spalling about 7 to 10 years after construction. It was also observed that substructure members were also deteriorating because of the leakage of the deicing salts through joints or exposure to seawater. Although the deterioration of substructure components is less obvious than the deterioration of bridge decks, it is much more serious and costly to repair or rehabilitate substructures.

Epoxy-coated rebar was introduced in the mid-1970s as a means of extending the useful life of reinforced-concrete bridge components by minimizing concrete deterioration caused by corrosion of the reinforcing steel. The epoxy coatings are intended to prevent moisture and chlorides from reaching the surface of the reinforcing steel and reacting with the steel. Since the late 1970s, the highway industry has widely used epoxy coatings as the preferred protective system for bridge decks due to its excellent performance in resisting corrosion and significantly delaying subsequent deterioration of the concrete. As for all coating systems, the coating will degrade over time and corrosion of the rebar will proceed in the presence of sufficient chlorides in the concrete.
When used in substructures and exposed to a severely corrosive marine environment, the epoxy-coated rebars did not perform as well as in bridge deck applications. Such was the case with a number of concrete bridges located in the Florida Keys. Significant premature corrosion of the epoxy-coated rebar was observed in substructure members of these bridges after only 6 to 9 years. These members are subjected to salt spray in the splash zone where the usual wetting/drying cycles, and high water and air temperatures produce a very corrosive environment.

The deterioration observed on the Florida Keys bridges and on some other bridges located in harsh environments raised questions concerning epoxy-coated rebar as a durable corrosion protection system. After an evaluation of the performance of epoxy-coated rebar decks by several state departments of transportation agencies, the overall condition of the bridge decks was considered to be good. Deck cracking did not appear to be corrosion-related. Very few of the decks had any delamination or spalling associated with the epoxy-coated rebar. Any delamination or spalling associated with corrosion of epoxy-coated rebar was small and generally isolated. The epoxy-coated rebar did not appear to perform as well in cracked concrete as it did in uncracked concrete. Corrosion was observed on epoxy-coated rebar segments extracted from locations having heavy cracking, shallow concrete cover, high concrete permeability, and high chloride concentrations. Reduced adhesion and softening of the coating also occurred as a result of prolonged exposure to a moist environment. The number of defects in the epoxy coating had a strong influence on the adhesion and performance of epoxy-coated rebar. There was no evidence of significant premature concrete deterioration that could be attributed to corrosion of the epoxy-coated rebar. It was concluded that the use of sufficient good-quality concrete cover, adequate inspection, finishing, and curing of the concrete, and the use of epoxy-coated rebar has provided effective corrosion protection for bridge decks since 1975.

At present, epoxy-coated rebar is the most common corrosion protection system and is used by 48 state highway agencies. To date, there are approximately 20,000 bridge decks using fusion-bonded epoxy-coated rebar as the preferred protection system. This represents roughly 95 percent of new deck construction since the early 1980s. The data from the Concrete Reinforcing Steel Institute (CRSI) shows that more than 3.6 billion kg (4 million tons) of epoxy-coated rebar (approximately 158 million m2 of reinforced concrete) were used worldwide as of 1998, with 79 percent installed in the last 10 years. (15) A significant portion of this epoxy-coated rebar was used in bridge decks. Over the past 20 years, the formulation of the epoxy has been modified to achieve increased performance of the epoxy coating. (15)

To estimate the cost of different construction options, the cost of the baseline case for black steel rebar is first calculated. The following cost analysis is provided to compare epoxy-coated rebar to black steel rebar. The amount of rebar contained in a bridge deck depends on the design. A typical “traditional” bridge deck (e.g., with two mats – each mat contains one longitudinal and one transverse rebar at 15-cm (6-in) centers – one mat of No. 5 rebar and one mat of No. 4 rebar) contains 33.2 kg of steel per square meter of deck (6.8 lb per ft2). Other designs (e.g., two mats – each mat contains one longitudinal and one transverse rebar at 20-cm (8-in) centers – both mats of No. 4 rebar) contain 19.6 kg of steel per square meter of deck (4 lb per ft2). An average of these two scenarios gives 26.4 kg of steel per square meter of deck (5.4 lb per ft2). The cost of black steel rebar is estimated at $0.44 per kg ($0.20 per lb). (16) Using 26.4 kg per m2 (5.4 lb per ft2) as the weight of rebar in a square meter of deck, the cost of rebar in a black steel deck is $11.60 per m2 ($1.08 per ft2). The cost of a deck installed using black steel rebar is assumed to be $484 per m2 ($45 per ft2). (6,16) It is estimated that black steel rebar provides an expected life of 10 years prior to required maintenance resulting from concrete deterioration due to corrosion of the rebar. (14)

Typically, the cost of epoxy-coated rebar adds $0.22 per kg ($0.10 per lb) to the cost of rebar, which is an increase in the cost of rebar of 50 percent. (16-17) This gives a cost of rebar for an epoxy-coated rebar deck of $17.40 per m2 ($1.62 per ft2) of deck or an increase in the cost of epoxy-coated rebar as compared to black steel of $5.80 per m2 ($0.54 per ft2) of deck. However, the rebar is a relatively small portion of the total deck construction costs. The added cost of epoxy-coated rebar depends on whether both mats of rebar are coated (many bridges have been constructed with only the top mat of rebar epoxy coated, although current practice typically uses both mats epoxy coated) and on the overall construction costs. Assuming the cost of new construction for a bridge deck is $484 per m2 ($45 per ft2) and both mats are epoxy coated, the increase to the total deck cost is 1.2 percent ($5.80 / $484 x 100). This value is consistent with other references discussed below. It is estimated that epoxy-coated
rebar provides an expected bridge deck life of 20 to 40 years.\textsuperscript{(14,18)} The service life depends, in part, on whether a single top mat of epoxy-coated rebar is used in conjunction with a bottom mat of black steel rebar versus both mats constructed of epoxy-coated rebar. With the current practice of coating both rebar mats and current coating formulations, a 40-year life is typically assumed. The costs for using only a single mat of epoxy-coated rebar would be estimated at 50 percent of that for both mats coated.

The Concrete Reinforcing Steel Institute (CRSI) estimates that the increase in the total cost of the structure due to coating both mats of rebar is typically between 1 and 3 percent.\textsuperscript{(17)} An FHWA study provided data for three Illinois bridge decks (1994 construction data) and showed that the increase in the cost of the deck due to using epoxy-coated rebar on both mats was between 0.5 and 2.2 percent, with an average increase of 1.4 percent.\textsuperscript{(16)}

The New York State Department of Transportation (DOT)\textsuperscript{(19)} has been using epoxy-coated rebars in the top mat reinforcements for the past 20 years. A summary of the data is presented in table 6. For deck replacement, the increase in the cost of coating the top mat was approximately 0.1 percent and, for rehabilitation, the cost increase was approximately 0.25 percent. The New York State DOT estimates that this small increase in costs for epoxy-coated rebars gives at least a 10-year life extension for the bridge structures. One factor that explains the lower percent increase in the structure cost due to using epoxy-coated rebar is that, in New York, only the top mat of rebar was coated. In addition, the bridge construction costs are higher in New York, making the average percent increase due to using epoxy-coated rebar lower.

\textbf{Source:}
Exhibit Nine
Metal-Coated/Clad Rebars and Solid Corrosion-Resistant Alloy Rebars
To provide a more corrosion-resistant rebar, a number of metallic coatings, metallic claddings, and rebar alloys have been tested. The most promising are galvanized (zinc-coated) rebars, stainless steel-clad rebars, and solid stainless steel rebars.(6) Titanium has also been discussed as a clad or solid rebar material, but its cost is significantly greater than that of stainless steel, and the increased corrosion resistance (relative to stainless steel) may not be required.

Epoxy-Coated Rebars
A Technical Note prepared by the FHWA and summarized here reviews the use of epoxy-coated rebar in bridge decks.(14) Epoxy coatings (often referred to as powders or fusion-bonded coatings) are 100 percent solid, dry powders. These dry epoxy powders are electrostatically sprayed over cleaned, preheated rebar to provide a tough impermeable coating. The coatings achieve their toughness and adhesion to the substrate as a result of a chemical reaction initiated by heat. Since these epoxy powders are thermosetting materials, their physical properties, performance, and appearance do not change readily with changes in temperature. The epoxy coating becomes a physical barrier between aggressive chloride ions (permeating the concrete cover) and the steel rebar.

For many years, bridge deck deterioration, stemming from corrosion of reinforcing bars, has been the number one problem for bridges. Prior to 1970, it was thought that portland cement itself provided sufficient protection to the reinforcing steel against corrosion. In the early 1970s, it became evident that corrosion of the reinforcing steel was related to the increasing application of deicing salts. Unfortunately, this was not learned until after thousands of bridge decks containing black reinforcing steel showed signs of spalling about 7 to 10 years after construction. It was also observed that substructure members were also deteriorating because of the leakage of the deicing salts through joints or exposure to seawater. Although the deterioration of substructure components is less obvious than the deterioration of bridge decks, it is much more serious and costly to repair or rehabilitate substructures.

Epoxy-coated rebar was introduced in the mid-1970s as a means of extending the useful life of reinforced-concrete bridge components by minimizing concrete deterioration caused by corrosion of the reinforcing steel. The epoxy coatings are intended to prevent moisture and chlorides from reaching the surface of the reinforcing steel and reacting with the steel. Since the late 1970s, the highway industry has widely used epoxy coatings as the preferred protective system for bridge decks due to its excellent performance in resisting corrosion and significantly delaying subsequent deterioration of the concrete. As for all coating systems, the coating will degrade over time and corrosion of the rebar will proceed in the presence of sufficient chlorides in the concrete.

When used in substructures and exposed to a severely corrosive marine environment, the epoxy-coated rebars did not perform as well as in bridge deck applications. Such was the case with a number of concrete bridges located in the Florida Keys. Significant premature corrosion of the epoxy-coated rebar was observed in substructure members of these bridges after only 6 to 9 years. These members are subjected to salt spray in the splash zone where the usual wetting/drying cycles, and high water and air temperatures produce a very corrosive environment.

The deterioration observed on the Florida Keys bridges and on some other bridges located in harsh environments raised questions concerning epoxy-coated rebar as a durable corrosion protection system.
After an evaluation of the performance of epoxy-coated rebar decks by several state departments of transportation agencies, the overall condition of the bridge decks was considered to be good. Deck cracking did not appear to be corrosion-related. Very few of the decks had any delamination or spalling associated with the epoxycoated rebar. Any delamination or spalling associated with corrosion of epoxy-coated rebar was small and generally isolated. The epoxy-coated rebar did not appear to perform as well in cracked concrete as it did in uncracked concrete. Corrosion was observed on epoxy-coated rebar segments extracted from locations having heavy cracking, shallow concrete cover, high concrete permeability, and high chloride concentrations. Reduced adhesion and softening of the coating also occurred as a result of prolonged exposure to a moist environment. The number of defects in the epoxy coating had a strong influence on the adhesion and performance of epoxy-coated rebar. There was no evidence of significant premature concrete deterioration that could be attributed to corrosion of the epoxy-coated rebar. It was concluded that the use of sufficient good-quality concrete cover, adequate inspection,
finishing, and curing of the concrete, and the use of epoxy-coated rebar has provided effective corrosion protection for bridge decks since 1975.

At present, epoxy-coated rebar is the most common corrosion protection system and is used by 48 state highway agencies. To date, there are approximately 20,000 bridge decks using fusion-bonded epoxy-coated rebar as the preferred protection system. This represents roughly 95 percent of new deck construction since the early 1980s. The data from the Concrete Reinforcing Steel Institute (CRSI) shows that more than 3.6 billion kg (4 million tons) of epoxy-coated rebar (approximately 158 million m2 of reinforced concrete) were used worldwide as of 1998, with 79 percent installed in the last 10 years.(15) A significant portion of this epoxy-coated rebar was used in bridge decks. Over the past 20 years, the formulation of the epoxy has been modified to achieve increased performance of the epoxy coating.(15)

To estimate the cost of different construction options, the cost of the baseline case for black steel rebar is first calculated. The following cost analysis is provided to compare epoxy-coated rebar to black steel rebar. The amount of rebar contained in a bridge deck depends on the design. A typical “traditional” bridge deck (e.g., with two mats – each mat contains one longitudinal and one transverse rebar at 15-cm (6-in) centers – one mat of No. 5 rebar and one mat of No. 4 rebar) contains 33.2 kg of steel per square meter of deck (6.8 lb per ft2). Other designs (e.g., two mats – each mat contains one longitudinal and one transverse rebar at 20-cm (8-in) centers – both mats of No. 4 rebar) contain 19.6 kg of steel per square meter of deck (4 lb per ft2). An average of these two scenarios gives 26.4 kg of steel per square meter of deck (5.4 lb per ft2). The cost of black steel rebar is estimated at $0.44 per kg ($0.20 per lb). (16) Using 26.4 kg per m2 (5.4 lb per ft2) as the weight of rebar in a square meter of deck, the cost of rebar in a black steel deck is $11.60 per m2 ($1.08 per ft2). The cost of a deck installed using black steel rebar is assumed to be $484 per m2 ($45 per ft2). (6,16) It is estimated that black steel rebar provides an expected life of 10 years prior to required maintenance resulting from concrete deterioration due to corrosion of the rebar. (14)

Typically, the cost of epoxy-coated rebar adds $0.22 per kg ($0.10 per lb) to the cost of rebar, which is an increase in the cost of rebar of 50 percent.(16-17) This gives a cost of rebar for an epoxy-coated rebar deck of $17.40 per m2 ($1.62 per ft2) of deck or an increase in the cost of epoxy-coated rebar as compared to black steel of $5.80 per m2 ($0.54 per ft2) of deck. However, the rebar is a relatively small portion of the total deck construction costs. The added cost of epoxy-coated rebar depends on whether both mats of rebar are coated (many bridges have been constructed with only the top mat of rebar epoxy coated, although current practice typically uses both mats epoxy coated) and on the overall construction costs. Assuming the cost of new construction for a bridge deck is $484 per m2 ($45 per ft2) and both mats are epoxy coated, the increase to the total deck cost is 1.2 percent ($5.80 / $484 x 100). This value is consistent with other references discussed below. It is estimated that epoxy-coated rebar provides an expected bridge deck life of 20 to 40 years.(14,18) The service life depends, in part, on whether a single top mat of epoxy-coated rebar is used in conjunction with a bottom mat of black steel rebar versus both mats constructed of epoxy-coated rebar. With the current practice of coating both rebar mats and current coating formulations, a 40-year life is typically assumed. The costs for using only a single mat of epoxy-coated rebar would be estimated at 50 percent of that for both mats coated.

The Concrete Reinforcing Steel Institute (CRSI) estimates that the increase in the total cost of the structure due to coating both mats of rebar is typically between 1 and 3 percent.(17) An FHWA study provided data for three Illinois bridge decks (1994 construction data) and showed that the increase in the cost of the deck due to using epoxy-coated rebar on both mats was between 0.5 and 2.2 percent, with an average increase of 1.4 percent.(16)

The New York State Department of Transportation (DOT)(19) has been using epoxy-coated rebars in the top mat reinforcements for the past 20 years. A summary of the data is presented in table 6. For deck replacement, the increase in the cost of coating the top mat was approximately 0.1 percent and, for rehabilitation, the cost increase was approximately 0.25 percent. The New York State DOT estimates that this small increase in costs for epoxy-coated rebars gives at least a 10-year life extension for the bridge structures. One factor that explains the lower percent increase in the structure cost due to using epoxy-coated rebar is that, in New York, only the top mat of rebar was coated. In addition, the bridge construction costs are higher in New York, making the average percent increase due to using epoxy-coated rebar lower.
Galvanized Rebars
Hot-dipped galvanized coatings for reinforcing steel in concrete have been used since the 1940s. ASTM A767, “Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement,” specifies the requirements for the galvanized coating. A Class I coating has a zinc coating weight of approximately 1,070 g per m2 (3.5 oz per ft2) and a Class II zinc coating has a coating weight of approximately 610 g per m2 (2.0 oz per ft2).

The effectiveness of galvanized rebar in extending the life of reinforced-concrete structures is questionable. In other applications, galvanized steel has been shown to extend the life of structures exposed to atmospheric conditions and low-chloride underground environments, but not high-chloride environments. An FHWA study by McDonald et al. reviewed the performance of galvanized rebar and is summarized here.(16) Several studies conducted in the 1980s and 1990s provided conflicting evaluations for the performance of galvanized steel in concrete. In general, the findings are in agreement with those for other exposure conditions, i.e., (1) zinc corrodes as fast (or faster) than steel in high-chloride environments and (2) zinc corrosion can be accelerated by macro-cell action when a large cathodic area is present. Accelerated macro-cell corrosion can occur when a galvanized upper mat of reinforcement is connected to a bare steel lower mat (in which the concrete surrounding the lower rebar mat has a lower chloride concentration than the concrete of the upper mat). Therefore, both mats of reinforcement should be galvanized. The general consensus is that galvanizing extends the life of the concrete structure due to a higher threshold for chloride-induced corrosion of the zinc-galvanized coating as compared to black steel.

Although galvanized rebar may provide a benefit in certain chloride-containing environments, the majority of the problems are associated with deicing salts and marine exposures where the chloride content of the concrete continuously increases to a point where any benefit of galvanization becomes marginal.

Stainless Steel Rebar
Research in stainless steel rebars has taken two directions, clad stainless steel over a carbon steel substrate and solid stainless steel rebar. If a stainless steel alloy is selected that possesses sufficient corrosion resistance for the service conditions, the primary concerns of cladding are: (1) adherence to rebar substrate, (2) defects formed after bending, (3) uniform cladding thickness [a typical cladding for stainless steel is 0.5 mm (0.020-in) thick], and (4) metallurgical changes due to cladding process that may affect the corrosion resistance. It should be realized that the chloride threshold for pitting in a non-aqueous (non-homogeneous) environment such as concrete can be significantly less than for the same aqueous environment. Therefore, any research must utilize realistic concrete environments. For instance, the use of stainless steel piping in underground service, generally, has been discontinued due to pitting and subsequent perforation of the pipe in the non-homogeneous unsaturated soil environment with relatively low chloride contents. Pitting in conventional reinforced-concrete bridge components may not be as significant a concern as decreasing the average corrosion rate (overall metal weight loss).

Several studies that examined the performance of solid stainless steel rebars were summarized by McDonald et al.(16) These studies showed that the austenitic stainless steel (Types 304 and 316) performed well, while the ferritic stainless steels (Types 405 and 430) developed pitting. In all cases, the stainless steel performance was greatly superior to carbon steel; with the stainless steel rebar generally performing with no (or negligible) corrosion. In a study summarized by Virmani and Clemena, Type 316 stainless steel-clad rebar greatly extended the estimated time to cracking of the concrete beyond that of conventional steel rebar (to 50 years), but not as much as solid Types 304 and 316 stainless steel (100 years).(6) In addition, McDonald et al. reported on two highway structures constructed with stainless steel rebar. Following a 10-year exposure, no corrosion was observed for solid Type 304 stainless steel rebar in a bridge deck in Michigan and for Type 304 stainless steel-clad rebar in a bridge deck in New Jersey.(16) However, at that time, the chloride levels in both bridge decks were below or at the threshold chloride level for corrosion initiation in black steel rebars.

The cost of solid stainless steel rebars is estimated to be $3.85 per kg ($1.75 per lb).

Source:
Exhibit Ten

Coating Options
In addition to the traditional coating methodologies used on steel bridges, research to date has identified several technologies and maintenance methodologies that promise to provide cost-saving alternatives for bridge maintenance painting.

Among these are: (1) the zone painting approach, (2) the use of overcoating or maintenance repair painting techniques, and (3) the selected use of metal spray coatings.

Traditional Coating System
A two- to three-coat system is traditionally applied over a clean, blasted surface. These coating systems include:
-organic zinc primer, epoxy or polyurethane intermediate coat, and aliphatic polyurethane topcoat,
-inorganic zinc silicate primer, chemically curing epoxy or polyurethane intermediate coat, and aliphatic polyurethane topcoat,
-high-build, high solids, good-wetting epoxy primer with aliphatic polyurethane topcoat,
-three-coat waterborne acrylic, and
-three-coat, lead-free alkyd.

Zone Painting
Due to the increasing cost of the repainting of existing bridge structures, it has become economically advantageous to consider the use of zone painting approaches in lieu of wholesale removal and repainting of entire bridge structures. This concept is especially attractive for larger structures and, in fact, has been employed on structures such as the Golden Gate and Bay bridges in California and several of the bridges in the New York City area. These larger bridges have distinctly different exposure environments within the same structure simply because of their size and their location near saltwater. In addition, these bridges are maintained by bridge authorities, who collect tolls and generally have greater resources to focus on intermittent or periodic maintenance activities.

The vast majority of the bridges in this country are neither large nor maintained by toll authorities. Hence, the zone painting approach has not been applied on a widespread basis. This may change as the costs for full removal and repainting of even smaller structures have dramatically risen. The fact is that even on smaller structures, coating breakdown and corrosion is limited to areas where there are measurable levels of salt contamination and significant levels of wetness. For bridges in more coastal or semi-marine environments, this is the entire structure; however, for bridges in non-marine environments (a majority of the bridges), these corrosive areas are generally limited to expansion joints, drainage, traffic splash, and tidal areas. If these areas can be isolated and maintained using a better corrosion protection system, large expenditures can be avoided on the remaining surface area of the bridge. This change in philosophy will require more informed engineering input during specification development and more oversight during repainting operations. In addition, improved inspection procedures and standards will be an essential input into the decision-making process.

Overcoating
Similarly, overcoating has become a more attractive option for state agencies as the cost of full removal and repainting has increased. This approach limits the amount of surface preparation to those areas that have failed paint and corrosion. These areas are spot primed and one or two full coats are applied over the entire structure for uniformity of color. This approach can be effective in less corrosive environments where the condition of the existing coating is relatively good. However, since this method of preservation will usually have a significantly lower initial cost than full repainting, the effect on life-cycle cost of this approach must be examined very carefully.

Metal Spray Coatings
Non-traditional bridge coating systems have been investigated for potential long-term performance benefits. While some of the candidates tested have not shown immediate usefulness (e.g., powder coatings), others, such as metallized coatings, appear to have the benefit of excellent long-term corrosion resistance. Although these systems
are applied at a somewhat higher initial cost, the changing overall economics of bridge repainting operations has made their use more competitive in terms of life-cycle cost.

**Coating Installation - Maintenance Costs**

The coating system installation cost is not easy to define. Over the past several years, there have been significant changes in the methodology of bridge maintenance painting operations. The most significant changes have been in response to dramatic increases in environmental and worker protection regulations that impact these operations. The use of containment structures to capture hazardous waste and pollutants generated during removal of old coatings and the gradual institutionalization of worker health and safety practices associated with the removal of hazardous materials, have introduced significant cost impacts to bridge maintenance painting. This has caused a large diversity in operational practices and in the resultant cost of these operations.

The issue of applying protective coatings to the steel bridges to prevent corrosion is further complicated by the requirement to contain or remove the previously applied lead-based paint, as regulated by the Environmental Protection Agency. Congressional regulations (the Resource Conservation and Recovery Act and the Hazardous and Solid Waste Amendment) now require that all wastes be treated.

According to 1992 National Cooperative Highway Research Program (NCHRP) data,(40) approximately 80 percent of the steel highway bridges have been coated with lead-containing paints. The report estimated that $100 million to $130 million is spent annually on bridge painting. A total of 10 to 20 percent of the costs of bridge painting are incurred because of the requirement to contain paint, abrasive, and dust fallout. In addition, the costs of treatment can range from $0.33 to $0.55 per kg ($300 to $500 per ton) where lead paint removal activities generate an estimated 181 million kg (200,000 tons) of lead-contaminated abrasives.

The overall cost is comprised of the costs for surface preparation, the material itself, and application activities. The estimates for some of the above coating systems are given in table 10.(7) The service life of the coating systems is significantly affected by the service conditions. For example, a two-coat alkyd primer with the topcoat exposed to mild conditions (rural or residential area with no industrial fumes/fallout) would last only 3 years until the next maintenance. On the other end of the spectrum is the triple system consisting of a moist-cured urethane zinc-rich coat, a high-build acrylic urethane coat, and an acrylic urethane topcoat. The expected service life of this coating system in severe conditions (heavy industrial and chemical plant area with high levels of fumes and fallout) is 15 years.

<table>
<thead>
<tr>
<th>System</th>
<th>SSPC Surface Preparation</th>
<th>DFT***</th>
<th>Cleaning Cost ($/m²)</th>
<th>Material Cost ($/m²)</th>
<th>Application Cost ($/m²)</th>
<th>Total Installed Cost ($/m²)</th>
<th>System Life (5-10% breakdown) (years)</th>
<th>Cost/year ($/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-coat alkyd</td>
<td>2*</td>
<td>0.10</td>
<td>$5.92</td>
<td>$1.08</td>
<td>$5.38</td>
<td>$12.38</td>
<td>3</td>
<td>$4.09</td>
</tr>
<tr>
<td></td>
<td>6**</td>
<td></td>
<td>$9.15</td>
<td></td>
<td></td>
<td>$15.61</td>
<td>6</td>
<td>$2.58</td>
</tr>
<tr>
<td>Two-coat epoxy</td>
<td>2</td>
<td>0.15</td>
<td>$5.92</td>
<td></td>
<td>$1.72</td>
<td>$14.10</td>
<td>7.5</td>
<td>$1.83</td>
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<tr>
<td></td>
<td>6</td>
<td></td>
<td>$9.15</td>
<td></td>
<td>$6.46</td>
<td>$17.33</td>
<td>10.5</td>
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<tr>
<td></td>
<td>10***</td>
<td></td>
<td>$10.76</td>
<td></td>
<td></td>
<td>$18.94</td>
<td>12</td>
<td>$1.61</td>
</tr>
<tr>
<td>Two-coat epoxy/urethane</td>
<td>6</td>
<td>0.15</td>
<td>$9.15</td>
<td>$2.26</td>
<td>$7.00</td>
<td>$18.41</td>
<td>9</td>
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<td></td>
<td>10</td>
<td></td>
<td>$10.76</td>
<td></td>
<td></td>
<td>$20.02</td>
<td>10.5</td>
<td>$1.94</td>
</tr>
</tbody>
</table>

*Hand-cleaned surface.
**Commercial blast.
***Near-white blast.
****Dried-film thickness.

Presently, the costs of total paint removal and repainting jobs can range from $43.00 per m² ($4.00 per ft²) to as much as $215.25 per m² ($20.00 per ft²).(41) This range can be partially explained by factors that make each bridge maintenance job unique, such as access for high structures or structures over water, the condition of bridge
deterioration, and unusual traffic control. However, a significant portion of the cost range is attributable to uneven application of regulatory compliance measures for environmental and worker safety issues.

An alternative to paint removal is overcoating, which includes cleaning of the structure, priming rusty areas, and applying intermediate coats and topcoats either over repaired areas or over the full structure. The cost of overcoating for bridges was estimated to range from $11 to $54 per m² ($1 to $5 per ft²), with some evidence that the tighter OSHA standards(42) push the cost up to $86 per m² ($8 per ft²).

The present effort to implement bridge corrosion control maintenance practices, which achieve regulatory requirements and cost-efficiency, cannot be successful without the development of reliable task-based cost data for bridge painting jobs. These data are dependent on a variety of factors, which vary from local cost differences (e.g., labor) to structural differences (e.g., accessibility) to contractor costing rules (e.g., limits on certain items such as mobilization). Development of reliable data and an understanding of regional influences on these data will help to improve analysis of the cost data.

It is estimated that roughly 50 percent of the cost of an average maintenance painting job is now attributable to environmental protection and worker health measures. This increase in "other" job costs has raised the total cost of coating removal jobs from an average of $54.36 per m² ($5.05 per ft²) in 1992 to an average of $114.10 per m² ($10.60 per ft²) in 1995, while the cost for the actual work (surface preparation and coating materials) has stayed relatively constant. Note that the savings incurred by paying slightly less for a less durable coating material are minor as a percentage of the overall cost. This highlights the need for life-cycle cost analysis.

Estimated time to failure for several coating systems is presented in table 11. Table 12 presents the estimated costs for painting options used in the sample analysis. The costs presented in the table are composite figures based on information from several different sources (41,43) and are expected to vary across the United States. Table 11 data show that depending on the surface preparation (i.e., blasting versus overcoating) and the type of coating, the assumed service life (life to 10 percent of degradation) can vary considerably, from as few as 3 years to 30 years.
<table>
<thead>
<tr>
<th>Approach</th>
<th>Coating System</th>
<th>Coating Life (years)</th>
<th>Surface Prep.</th>
<th>No. of Maint. Cycles</th>
<th>Cost Per Maint. Cycle ($/m²/year)</th>
<th>Total Cost in Present Day Dollars ($/m²)</th>
<th>Total Present Value ($/m²)</th>
<th>Annual Costs ($/m²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing lead-based paint, repair and overcoat with three-coat alkyd</td>
<td>3-coat alkyd</td>
<td>3</td>
<td>SP-3</td>
<td>20</td>
<td>$56.94</td>
<td>$1,138.80</td>
<td>$477.92</td>
<td>$34.01</td>
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<tr>
<td></td>
<td>Epoxy/mastic/polyurethane</td>
<td>4</td>
<td>SP-3</td>
<td>15</td>
<td>$59.42</td>
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<td>$458.22</td>
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</tr>
<tr>
<td>Existing lead-based paint, full removal by blasting</td>
<td>85% Zn / 15% Al metingizing at 6 to 8 mls</td>
<td>30</td>
<td>SP-10</td>
<td>2</td>
<td>$158.77</td>
<td>$317.54</td>
<td>$227.44</td>
<td>$16.15</td>
</tr>
<tr>
<td></td>
<td>1OZ/epoxy/polyurethane</td>
<td>15</td>
<td>SP-10</td>
<td>4</td>
<td>$123.68</td>
<td>$494.72</td>
<td>$300.64</td>
<td>$21.42</td>
</tr>
<tr>
<td>Existing lead-based paint, full removal and maintenance over approximately 20% of the surface area every 5 years after the initial 15-year service life</td>
<td>1OZ/epoxy/polyurethane</td>
<td>15</td>
<td>SP-10</td>
<td>1</td>
<td>$123.68</td>
<td>$690.41</td>
<td>$351.01</td>
<td>$24.97</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>5</td>
<td>SP-3</td>
<td>9</td>
<td>$62.97</td>
<td>$325.21</td>
<td>$325.21</td>
<td>$24.97</td>
</tr>
<tr>
<td>Existing lead-based paint, remove and replace</td>
<td>Epoxy/mastic/polyurethane</td>
<td>10</td>
<td>SP-10</td>
<td>6</td>
<td>$120.23</td>
<td>$721.38</td>
<td>$413.33</td>
<td>$29.49</td>
</tr>
<tr>
<td>Existing lead-based paint, repair and overcoat</td>
<td>3-coat alkyd</td>
<td>10</td>
<td>SP-3</td>
<td>6</td>
<td>$56.94</td>
<td>$341.64</td>
<td>$156.72</td>
<td>$11.19</td>
</tr>
<tr>
<td>Existing lead-based paint, full removal</td>
<td>85% Zn / 15% Al metingizing at 6 to 8 mls</td>
<td>60</td>
<td>SP-10</td>
<td>1</td>
<td>$158.77</td>
<td>$158.77</td>
<td>$158.77</td>
<td>$11.30</td>
</tr>
</tbody>
</table>

**Source:**
Exhibit Eleven

Water and Wastewater Corrosion Costs

Corrosion Control and Prevention

Americans consume approximately 550 L of drinking water per person per day, for a total annual quantity of approximately 56.7 billion m³. The treated drinking water is transported through 1.4 million km of municipal water pipes. The water pipes are subject to internal and external corrosion, resulting in pipe leaks and water main breaks.

The total cost of corrosion for the drinking water and sewer systems includes the cost of replacing aging infrastructure, the cost of unaccounted-for water, the cost of corrosion inhibitors, the cost of internal cement mortar linings, the cost of external coatings, and the cost of cathodic protection.

In March 2000, the Water Infrastructure Network (WIN) estimated the current annual cost for new investments, maintenance, operation, and financing of the national drinking water system at $38.5 billion per year, and that of the sewer system at $27.5 billion per year. The total cost of corrosion was estimated from these numbers by assuming that at least 50 percent of the maintenance and operation costs are to replace aging (corrosion) infrastructure, while the other 50 percent would be for system expansion. This results in an estimated cost of corrosion for drinking water systems of $19.25 billion per year and for sewer systems of $13.75 billion per year. WIN stated that the current spending levels are insufficient to prevent large failure rates in the next 20 years.

The WIN report was presented in response to a 1998 study by the American Water Works Association (AWWA) and a 1997 study by the U.S. Environmental Protection Agency (EPA). Those studies had already identified the need for major investments to maintain the aging water infrastructure.

In addition to the costs of replacing aging infrastructure, there is the cost of unaccounted-for water. One city reported a constant percentage of unaccounted-for water of 20 percent in the last 25 years, with 89 percent of its main breaks directly related to corrosion. Nationally, it is estimated that approximately 15 percent of the treated water is lost. The treatment of water that never reaches the consumer results in inflated prices (national lost water is estimated at $3.0 billion per year) and over-capacity in treatment facilities.

Adding these three major cost items results in a total annual cost of corrosion of $36.0 billion per year for drinking water and sewer systems combined.

Opportunities for Improvement and Barriers to Progress

Water transmission and distribution systems can be protected from internal corrosion by using corrosion inhibitors in combination with pH adjusters and alkalinity control. A second method of internal corrosion protection is the application of a cement mortar lining to iron-base pipes. External corrosion protection can be obtained from coatings and cathodic protection.

The cost of corrosion inhibitors added to the drinking water is a percentage of the total treated water cost. AWWA estimated that the annual costs for corrosion inhibitor treatment ranges from $1.00 to $1.50 per residential consumer. With approximately 66 million residential customers, the total cost can be estimated at $82 million per year, which is 2.5 percent of the total annual treated water cost.

New iron and steel pipelines are commonly lined with cement mortar. Cement mortar linings are also used for rehabilitation of older ductile iron, cast iron, and steel water pipeline networks. The linings can eliminate small leaks in pipes and pipe connections as a result of the high resistance of cement mortar to pressure, enhance the hydraulic characteristics of the mains, and prevent further internal corrosion damage. Studies by AWWA show that the cost for water pipe rehabilitation by cement mortar lining ranges from 13 percent to 41 percent of the costs of total pipe replacement.
Several studies show that the direct cost of maintenance and repair of water pipes, and repaving after work is done is approximately 50 percent of the total budget of water departments. Repairs can be prevented if control methods are applied to the system. External corrosion can be effectively mitigated by the application of coatings and cathodic protection. Although these systems have problems of their own, the initial cost for installing coatings and cathodic protection on new systems is almost always warranted because large maintenance cost-savings can be achieved over the life of the piping system.

A major barrier to progress in corrosion management is the absence of complete and up-to-date information on all water systems. Limited communication between water utilities limits the awareness and implementation of available corrosion control technologies, such as new coating systems and cathodic protection. In addition, the lack of information complicates the process of prioritizing maintenance. AWWA maintains partial records on the water systems of its members, and the U.S. EPA collects data from voluntary questionnaires; however, most water utilities do not have complete records on all of their buried pipes. The pipe mileage length, pipe materials, pipe diameters, and their installation dates are, in many cases, unknown. At the local level, corrosion engineers maintain small databases with information on the nature of individual repairs, but often these records are not integrated in a larger data system. Computers provide the opportunity to maintain the records both in local and national databases.

A second barrier to progress in corrosion management is the lack of understanding and awareness of corrosion problems at the local level, and the limited time dedicated to solving corrosion problems. Often, an attitude is taken of burying the water pipe and forgetting about it until it fails. Investigations of corrosion-related parameters in drinking water are an important aid to water utilities. The data should be used to regularly re-evaluate the applied chemical treatment for internal corrosion protection. External corrosion protection can be evaluated by systematic inspection of coatings and inspection of the cathodic protection systems at regular intervals.

New developments in electronic equipment make internal inspection with cameras an option to evaluate the condition of pipe sections. These techniques, however, are not commonly used because they are still quite expensive, the equipment insertion into and extraction from the pipe is usually difficult, and the pipe may have internal obstructions or bends. In addition, analysis of the data is generally time-consuming and difficult.

**Recommendations and Implementation Strategy**

It is recommended that a national effort be initiated in order to decrease the total amount of unaccounted-for water using several available methods. The objective of this effort would be to prevent increasing consumer prices and to more effectively use the capacity of treatment facilities. Furthermore, a decrease in unaccounted-for water will also decrease the total quantity of chemicals used to treat drinking water.

It is recommended that a national resource expertise be created where water utilities can get information about corrosion, where agencies can receive support to develop their corrosion protection plan, and where corrosion awareness training for employees is provided.

It is recommended that a national database be created to which all water utilities must submit complete records on changes to their systems. This will enable water utility managers to better understand the reasons for system growth, to accurately estimate pipe replacement rates, and to prioritize funding for corrosion maintenance and aging system rehabilitation.

Finally, it is recommended that regularly scheduled corrosion inspections be conducted on water treatment facilities, water tanks and towers, and water transmission and distribution systems. The inspections should evaluate the effectiveness of internal and external corrosion protection measures so that the integrity of the aging infrastructure is maintained at the lowest possible cost.

**Corrosion Control in Water Storage Systems**
After treating the raw water in treatment facilities, the clean drinking water can temporarily be stored in utility water towers in aboveground or underground tanks, or underground clear wells. The areas of major corrosion impact are internal corrosion of the storage towers and tanks, and external corrosion due to weather conditions. If left unattended, both internal and external corrosion may pose a structural risk due to loss of wall thickness. Therefore, regularly scheduled corrosion inspections of water tanks and water towers should be conducted. With regular maintenance, water tanks can have a useful life of more than 100 years.

The dominant forms of internal corrosion include general corrosion, galvanic corrosion, and microbiologically induced corrosion in standing water. The microbiological contaminants are regulated under the Surface Water Treatment Rule (SWTR) and the Total Coliform Rule (TCR). Corrosion control methods for these types of corrosion are cathodic protection and lining or painting of the interior of the tanks. Cathodic protection is usually performed on a project basis, while painting generally is performed as part of long-term maintenance programs.

External corrosion originates from moisture, rain, and changing weather. Generally, tanks and water towers are designed with a so-called corrosion allowance. This is an allowable rate of general corrosion. The corrosion rate can be determined by measuring the remaining wall thickness of a storage tank at given time intervals. If the corrosion rates are within the design limits and the remaining wall thickness is thick enough, then the tank is generally expected to be structurally fit for service. The common corrosion control method is painting the tower or tank. Deterioration of the appearance of water towers by external corrosion is another consideration for painting.

The costs for corrosion control for water storage tanks are determined by the type of cathodic protection and the type of protective coatings utilized. In 1991, Robinson(26) presented comparative case studies of the economics of corrosion protection systems. Robinson argued that many thousands of dollars are spent unnecessarily to re-coat and repair interior coatings when cathodic protection would mitigate further corrosion activity and prolong the necessity of coating maintenance. Using economic models, this author determined that long-term cost benefits can be realized with the application of cathodic protection to water storage tanks.

**Corrosion Control in Water Transmission Systems**

The water is pumped from the temporary storage or is pumped directly from the treatment facilities through large-diameter transmission water pipes. The transmission water piping system is regulated with large valves, where water quantities are measured using large-capacity water meters. The most common materials of construction for transmission pipe include cast iron, ductile iron, prestressed concrete, asbestos concrete, PVC, and welded steel piping. Except for PVC, all of the above materials contain ferrous metal components that must be protected.

Table 1 shows that approximately 67 percent of the U.S. transmission water lines are built from cast iron and ductile iron. Ductile iron pipe is manufactured in 5.5- or 6.1-m (18- or 20-ft) nominal laying lengths and 7.6- to 163-cm (3- to 64-in) diameters in a range of standard pressure classes and nominal wall thicknesses. Since its introduction in the marketplace in 1955, ductile iron pipe has been used extensively for drinking water and wastewater systems. Pipes are made from the manufactured sections of pipe, with a bell-and-spigot connection sealed with rubber O-rings.

The most common failure mechanisms of such pipes are uniform corrosion (external or internal), graphitization, and pitting under unprotected corrosion scales. Loose rust tubercles may cause blockage of a water pipe where these particles reach consumers. The only corrosion control methods for loose particles is prevention through the addition of corrosion inhibitors to protect the inside pipe walls or internal lining of the pipes. For ductile iron and cast iron pipes, a standard portland cement mortar lining is the most common internal lining. Other lining types include specialty cement mortars, epoxies, polyethylene, and polyurethane. In some instances, coal tar has
been used for internal linings; however, concerns about possible health effects and oily organic residue given off by coal tar coatings limit their use.

Table 1 further shows that a steel pipe is only used for approximately 4 percent of the U.S. transmission water lines. The use of steel water pipe dates back to the California Gold Rush of 1849,(27) when it was produced from thin riveted wrought pipe that could be slipped together. In 1905, a pressure-locking seam pipe was developed. In the early 1930s, methods of automatically welded steel pipe from rolled stock were developed. Since World War II, U.S. manufacturers have primarily produced spiral-welding steel pipe. The most common corrosion control methods for external corrosion of steel pipes are coatings or coatings and cathodic protection.

Developments in electronic equipment make internal inspection with cameras an option to evaluate the condition of pipe sections. However, these techniques are still quite expensive, the equipment insertion into and extraction from the pipe is usually difficult, and the pipe may have internal obstructions or bends. In addition, analysis of the data is generally time-consuming and difficult.

Effect of Reduced Pipe Wall Thickness
Significant problems occur in older transmission pipes made from cast iron and ductile iron, as the wall thickness is reduced by corrosion until a leak occurs. Problems in newer iron pipes are similar to those found in older iron pipes, but occur after shorter periods of time because of decreased wall thickness. During the last 100 years, utilities have applied pipes of thinner wall because of the improved mechanical properties of steel; however, corrosion rates are generally independent of the strength of a material. For a given corrosion rate, a thinner wall will corrode through in less time than a thicker wall. Therefore, an effective corrosion control method is the selection of thicker wall pipe to provide a larger corrosion tolerance to wall thinning. Although thicker wall pipe is more expensive, this approach may be very cost-effective because of its long life and relatively low need for maintenance.

Degradation of Cement-Based Materials
Approximately 17 percent of the U.S. transmission water lines are built from concrete and asbestos concrete materials (see table 1). Pipes made from these materials are usually assembled on location from factory-made pipe sections. Internal steel reinforcement wires and bars (rebar), steel mesh, and steel plates are used to provide tensile strength. Cement-based pipes are susceptible to corrosion when aggressive ions, such as chloride, migrate to the steel surface. The corrosion products take up more volume than the original steel, causing cracking of the concrete, further accelerating corrosion.

In asbestos cement pipes, asbestos fibers are used as reinforcement for tensile strength. With these pipes, the main concern is the release of asbestos fibers into the drinking water. Other effects of cement-based material deterioration include calcium dissolution (increased water hardness), increased pH values, increased alkalinity, and migration of aluminum into the drinking water. A common corrosion control method for concrete pipe is the application of internal protection using a cement mortar lining, which can be applied as a factory lining or as an in situ lining. One method of determining the quality of a lining is to measure its calcium oxide (CaO) leaching resistance, a function of the mortar density.

Cement Mortar Linings
New iron and steel pipelines are commonly lined with cement mortar. Cement mortar linings are also used for rehabilitation of older ductile iron, cast iron, and steel water pipeline networks. The linings can eliminate limited leaks of pipes and pipe connections as a result of the high resistance of cement mortar to pressure, enhance the hydraulic characteristics of the mains, and prevent further internal corrosion damage. Table 11 shows the estimated costs for water pipe rehabilitation by cement mortar lining as a percentage of pipe replacement costs, as estimated by the AWWA.(20) The rehabilitation cost is broken down into four components: (1) cleaning and cement mortar lining; (2) excavation, pipe fitting, and restoration of the road surface; (3) materials; and (4) labor costs. The right column shows the percentage cost for rehabilitation compared with total pipe replacement.

External Corrosion of Transmission Piping
External corrosion mechanisms on transmission water piping include general or localized corrosion due to corrosive soils, galvanic corrosion through connections to other utilities and structures, MIC, ac stray current corrosion from power lines, and dc stray current corrosion from cathodic protection (CP) systems on nearby structures. Corrosion control methods to mitigate these forms of corrosion include the application of coatings and CP by installation of impressed current or sacrificial anode systems. External coatings on older water pipes include asphalt coatings and coal tar enamel coatings, while external coatings on new pipes include coal tar enamel coatings, polyethylene-based coatings, and fusion-bonded epoxy coatings.

**Corrosion Control in Sewage Water Systems**

Sewage water is transported back to treatment facilities through a sewer water piping system that is connected to, but separate from, the drinking water system. The National Center for Environmental Research and Quality Assurance (The Office of Research and Development, U.S. EPA) reports that the current U.S. investment in sewage lines alone approaches $1.8 trillion. Waste water is collected through relatively small-diameter pipes from bathrooms, kitchens, and sinks from each house and business and is then transported to treatment plants through larger diameter pipes. Rainwater will only enter the sewer system if it is collected through sewage grates collecting run-off water from streets and parking lots. All other rainwater and water used for activities such as watering a lawn or washing a car are simply absorbed by the earth, and do not run into the sewage system. Common materials of construction for sewage water systems include concrete piping, steel piping, and ductile iron piping.

The mechanisms of material degradation in sewage piping are generally similar to those in potable water systems. However, internal corrosion may be more severe because the water is not clean. In addition to the sewage waste, chlorine from salt winterizing treatments of roads comes into contact with the pipes. Cement-based piping deteriorates by corrosion of the reinforcement steel. The corrosion control method most commonly used in sewage piping is increased wall thickness. This is true for metal pipes and cement-based pipes. The thicker wall provides for a larger corrosion tolerance and, generally, a longer design life.

**Source:**

Exhibit Twelve

Waste Water Treatment

- Modern treatment standards for Publicly Owned Treatment Works (POTW) set by the EPA’s Clean Water Act in the 1970s.
- In 2008 there were 21,594 POTW in operation, treating waste from 226.4 million people
- 4% of all US electricity is used for wastewater treatment
- Average useful life of plant components is 20 years
- Average useful life of the collection system is 50 years
- 600,000 miles of US sewer
- Estimated that 44% will be beyond useful life by 2020
- 2008 Estimates Renovations were:
  - $105.2 billion for updating WWTPs
  - $82.6 billion for collection sewer repairs
  - $63.6 billion for elimination of combined sewer overflows

Source:

Local and State Sewer Expenditures

<table>
<thead>
<tr>
<th>Year</th>
<th>Combined State and Local Government ($ thousands)</th>
<th>Local Government ($ thousands)</th>
<th>State Government ($ thousands)</th>
<th>Percent Local Government (%)</th>
<th>Local Government Capital Outlay for Sewer ($ thousands)</th>
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<tr>
<td>2004-2005</td>
<td>$36,372,359</td>
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<td>$908,048</td>
<td>95.68</td>
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</table>

73% Increase from 1991 to 2005 in Total Expenditures

Source:
Design Life of Water Systems

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<th>Components</th>
<th>Years of design life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collections</td>
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<td>Treatment Plants—Concrete Structures</td>
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</tr>
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<td>Treatment Plants—Mechanical and Electrical</td>
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</tr>
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<td>Force Mains</td>
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<tr>
<td>Pumping Stations—Concrete Structures</td>
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<td>Pumping Stations—Mechanical and Electrical</td>
<td>15</td>
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<tr>
<td>Interceptors</td>
<td>90–100</td>
</tr>
</tbody>
</table>

Exhibit Thirteen

City of Youngstown Wastewater Treatment Plant Photos

Photograph 1 – Flow Valve and Piping
Photograph 2 – Ceiling Degradation Caused by Rebar Corrosion 6’ X 8’ Area on Ceiling of Plant Building

Photograph 3 – Rebar Corrosion Causing Tank Failure
Photograph 4 – Rebar Corrosion Causing Tank Failure

Photograph 5 – Corrosion on Interior Gas Lines
Photograph 6 – Corrosion on Overhead Booms

Photograph 7 – Corrosion of Valves and Piping
Photograph 8 – Pump Corrosion
Exhibit Fourteen

Airport Corrosion

The United States has the world’s most extensive airport system, which is essential to national transportation. Airports, which are among the most important and widely used facilities, play a major role in generating economic activity for the United States. According to the Bureau of Transportation Statistics, in 1999, there were 5,324 public-use airports and 13,774 private-use airports in the United States. The airports used by the scheduled air carriers are virtually all public facilities run by an agency of a state or local government, or a commission or port authority established by the state legislature. Since airports resemble small cities, they are organized accordingly, with departments for purchasing, engineering, finance, administration, etc.

A typical airport infrastructure is relatively complex, and components that might be subject to corrosion include the natural gas distribution system, jet fuel storage and distribution system, deicing storage and distribution system, water distribution system, vehicle fueling systems, natural gas feeders, dry fire lines, parking garages, and runway lighting. Generally, each of these facilities is owned or operated by different organizations and companies, and the impact of corrosion on an airport as a whole is not known or documented; however, the airports do not have any specific corrosion-related problems that have not been described in other sectors, such as corrosion in water and gas distribution lines, corrosion of concrete structures, and corrosion in aboveground and underground storage tanks.

Because of the diversity of airport facilities and different accountabilities, the costs due to corrosion are not apparent and, therefore, cannot be addressed in a systematic manner. In order for airports to reduce and control their corrosion costs, it is recommended that the airports establish databases that will allow engineers to track corrosion and corrosion costs and raise awareness.

AREAS OF MAJOR CORROSION IMPACT

A typical airport infrastructure is relatively complex, and the components that might be subject to corrosion include the following:

- Natural gas distribution system.
- Jet fuel storage and distribution system.
- Deicing storage and distribution system.
- Water distribution system.
- Vehicle fueling systems.
- Natural gas feeders.
- Dry fire lines.
- Parking garages.
- Runways and runway lighting.

Generally, each of these infrastructure components is owned and/or operated by different organizations and companies. Given the above, airports do not have any specific corrosion-related problems that cannot be found in other sectors of the national economy (e.g., corrosion of heat, ventilation, and air-conditioning systems; corrosion of a reinforced-concrete floor in a parking garage; or corrosion of buried metallic structures). The latter issue, corrosion of buried metallic structures, is primarily manifested in underground storage tanks (USTs) or buried fuel lines transporting fuel from the tank farms. Larger airports generate considerable volumes of wastewater during the deicing season and may have wastewater treatment facilities (which often are not owned by the airports).

The issue with USTs became particularly acute with the passing of an Environmental Protection Agency (EPA) regulation deadline in 1998, which mandates installation of corrosion protection on existing regulated USTs (see Appendix G, Hazardous Materials Storage).

Considering that the scope of the problem is rather limited, there is no available information on corrosion
control costs. For the most part, these costs are contained within the maintenance budgets, but are not tracked separately. To complicate the issue, in many cases, the structures subject to corrosion, such as tank farms, while technically owned by the airports, are leased by the airport tenants. The sources of funds are multiple, including rent and gross-receipt fees paid by the airport-based businesses, landing fees, and sometimes parking and fueling fees paid by the airlines. Sometimes a structure, such as a parking garage, is built for exclusive use by an airline and, therefore, is owned and maintained by it. Furthermore, outside contractors often perform whatever corrosion control maintenance is scheduled. Because a basis was not identified to estimate corrosion-related cost, no estimates were made. Given the lack of information on the subject, no estimates of corrosion-related costs were attempted.

**Source:**

**Source:**

**Source:**
Exhibit Fifteen

Oil & Gas Corrosion

A summary of current issues is listed below -

<table>
<thead>
<tr>
<th>Summary of Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase consciousness of corrosion costs and potential savings.</td>
</tr>
<tr>
<td>Change perception that nothing can be done about corrosion.</td>
</tr>
<tr>
<td>Advance design practices for better corrosion management.</td>
</tr>
<tr>
<td>Change technical practices to realize corrosion cost-savings.</td>
</tr>
<tr>
<td>Change policies and management practices to realize corrosion savings.</td>
</tr>
<tr>
<td>Advance life prediction and performance assessment methods.</td>
</tr>
<tr>
<td>Advance technology (research, development, and implementation).</td>
</tr>
<tr>
<td>Improve education and training for corrosion control.</td>
</tr>
</tbody>
</table>

Figure 1

Exhibit Sixteen

Pipeline Corrosion Control and Prevention
The corrosion-related cost to the transmission pipeline industry is approximately $5.4 to $8.6 billion annually. This can be divided into

- 10% - the cost of failures
- 38% - capital improvements
- 52% - operations and maintenance (O&M)

The most significant of these, from a cost point of view, is the requirement for pipeline Inspections. The significant cost of pipeline inspection is estimated to be as high as $35 billion. If operators cut conventional corrosion O&M costs while pursuing pipeline inspection, corrosion prevention will suffer.

The overall goal of the pipeline industry must be to preserve the pipeline as an asset ($541 billion replacement cost) which a gain presents an opportunity for NAC-10

In the United States, there are approximately 60 major natural gas transmission pipeline operators and 150 major hazardous liquid pipeline.

- Liquid Pipelines
- Natural Gas Pipelines

General Corrosion
There are several different modes of external corrosion identified on buried pipelines. The primary mode of corrosion is a macro-cell form of localized corrosion due to the heterogeneous nature of soils, local damage of the external coatings (holidays), and/or the disbondment of external coatings

Stray Current Corrosion
Corrosion can be accelerated through ground currents from dc sources. Electrified railroads, mining operations, and other similar industries that utilize large amounts of dc current sometimes allow a significant portion of current to use a ground path return to their power sources. These currents often utilize metallic structures (pipelines) in close proximity as a part of the return path. This “stray” current can be picked up by the pipeline and discharged back into the soil at some distance down the pipeline close to the current return. Current pick-up on the pipe is the same process as cathodic protection, which tends to mitigate corrosion. The process of current discharge off the pipe and through the soil of a dc current accelerates corrosion of the pipe wall at the discharge point. This type of corrosion is called stray current corrosion

Microbiologically Influenced Corrosion (MIC)
Microbiologically influenced corrosion (MIC) is defined as corrosion that is influenced by the presence and activities of microorganisms, including bacteria and fungi. It has been estimated that 20 to 30 percent of all corrosion on pipelines is MIC-related. MIC can affect either the external or the internal surfaces of a pipeline.

Stress Corrosion Cracking
SCC is defined as the brittle fracture of a normally ductile metal by the conjoint action of a specific corrosive environment and a tensile stress. On underground pipelines, SCC affects only the external surface of the pipe, which is exposed to soil/groundwater at locations where the coating is disbanded. The primary component of the tensile stress on an underground pipeline is in the hoop direction and results from the operating pressure. Residual stresses from fabrication, installation, and damage in service contribute to the total stress. Individual cracks initiate in the longitudinal direction on the outside surface of the pipe. The cracks typically occur in colonies that may contain hundreds or thousands of individual cracks. Over

AREAS OF MAJOR CORROSION IMPACT
Areas of major economic impact associated with the corrosion of pipeline systems include capital cost related to corrosion control, general maintenance for corrosion control, replacement/repair costs, and costs associated with corrosion-related failures. The costs of each of these areas are discussed below. Corrosion plays a major role in
decision-making concerning pipeline systems in both direct and indirect ways. Although the direct costs (costs to the owner or operator) regarding the impact of corrosion on pipelines are difficult to determine with accuracy, they are relatively easy to understand. On the other hand, indirect costs (costs to third parties) associated with corrosion of pipelines are more difficult to understand and are even more difficult to assign a value. The following are examples of indirect costs:
- Costs associated with damages to the environment or disruption to the public due to release of products (costs not directly paid by the operator as part of clean-up).
- Public relations costs for dealing directly with the public are increasing. Public opinion runs high against new pipelines in “their backyard.” The public is becoming concerned about aging pipelines, primarily due to a lack of information and a few recent high-visibility failures. This public attitude makes it difficult to obtain new rights-of-way and these are at a much higher cost than in the past. In addition, the negative public attitude will probably force decisions on the pipeline operators that are not necessarily the most optimal and cost effective.
- Legal costs associated with a failure have become staggering when the failure has resulted in injury or death ($280 million in a case involving one fatality). These costs include defending against negligence on the part of the operator, criminal defense for officers in the company, and punitive damages awarded to the estate of the deceased or injured. Indirect costs would be the lost productivity of staff and public costs associated with the judicial process.
- Lost revenue for the producers arising from not being able to ship their product while the section of pipeline is out of service due to rupture.
- Lost revenue or increased costs to the end users for disruption of service or higher costs for alternative sources of fuels.

Cost of Corrosion in Pipeline Construction
The average cost of new construction (onshore pipelines) for North American gas pipeline projects in 1998 and 1999 was $746,000 per km ($1.2 million per mi).(4,7) For 1998, there were approximately 2,576 km (1,600 mi) of pipeline constructed in the United States. These costs are broken down into the following categories: materials (line pipe, pipe coating, and cathodic protection), labor, miscellaneous (surveying, engineering, supervision, contingencies, telecommunications equipment, allowances for funds used during construction, overheads, and regulatory filling fees), and ROW (costs for obtaining right-of-way and allowing for damages).

Cost of Pipeline Coating and CP
The cost of corrosion, in terms of materials, is incorporated in the $237,400 per km ($382,000 per mi) materials cost, i.e., pipeline coating, cathodic protection (CP), etc. The cost of coating is estimated at 7 percent to 10 percent of the material cost of the pipe, or $17,000 to $24,000 per km ($27,000 to $38,000 per mi).(8) The cost of an average CP system for new construction is approximately $12,000 for 24 km (15 mi) of pipeline, or $500 per km ($800 per mi).(9) The coating and CP costs discussed above are inclusive of the cost of materials and cost of labor associated with application/installation.

Cost of Corrosion Allowance
Although, a safety factor is built into the design calculations, corrosion allowance has not been specifically made a part of the design calculations. In addition, pipe wall thickness in high-risk areas is increased still further to provide an overall increased level of safety from integrity threats. Although corrosion is accounted for in the typical design safety factor for pipe wall thickness, without that safety factor, a corrosion allowance would be required. It is estimated that the cost of the corrosion allowance for the pipe wall thickness accounts for 5 percent to 10 percent of the material cost, or $12,000 to $24,000 per km ($19,000 to $38,000 per mi).(10)

Total Cost of Corrosion for Construction
A total cost of corrosion can be estimated for new pipeline construction of $32,500 to $55,500 per km ($51,800 to $89,300 per mi) of pipeline, or 4.4 percent to 7.6 percent (average of 6 percent) of the total cost of pipeline construction. This breaks down into:
- $17,000 to $24,000 per km for pipeline coating.
- $500 per km for CP system.
- $12,000 to $24,000 per km for corrosion allowance.
- $3,000 to $7,000 per km for specifications/designs.
Replacement Cost of Pipeline Infrastructure
With the cost of new pipeline construction at $694,100 per km ($1,117,000 per mi) (total cost minus right of way (ROW) cost) and 778,900 km (484,000 mi) of the needed transmission pipelines, the cost of replacement of the transmission pipeline infrastructure is $541 billion. This is compared to the total book asset value of $93.1 billion for pipeline operations.

Portion of Capital Cost Due to Corrosion
Annual Cost of Capital for Pipeline Replacement
It is assumed that 25 percent of the new capital costs of $8.1 billion is for replacement of aging pipeline. Furthermore, it is assumed that all of the replacement is related to corrosion. Therefore, the annual capital cost due to corrosion for replacement of pipeline infrastructure is $2.02 billion.

Annual Cost of “Non-Replacement” New Capital
The “non-replacement” new capital expenditure is $6.08 billion ($8.1 billion minus $2.02 billion). Assuming that the average percentage of construction costs attributed to corrosion (4.4 to 7.6 percent) can be applied to capital costs, the capital expenditure related to the cost of corrosion is $268 million to $462 million (4.4 to 7.6 percent of $6.08 billion)

Total Capital Costs
The total cost of corrosion for capital items is estimated at $2.50 billion to $2.84 billion ($2.02 billion for replacement capital, $0.27 billion to $0.46 billion for new capital, and $0.21 billion to $0.36 billion for depreciation of existing capital.

Operations and Maintenance (Corrosion Control)
Significant maintenance costs for pipeline operation are associated with corrosion control and integrity management. The driving forces for the expenditure of maintenance dollars are to preserve the asset of the pipeline, which is equal to $93.3 billion in book value and $541 billion in replacement value, and to ensure safe operation without failures that jeopardize public safety, result in loss product and throughput, and cause property and environmental damage, which is estimated at $470 million to $875 million per year (see “Corrosion-Related Failures”).

External Corrosion
The primary cause of loss of corrosion protection was due to coating deterioration and inadequate CP current. Other contributing causes included shorts or contacts (12 percent) and stray current (7 percent). The majority of general maintenance is associated with monitoring and repairing these problems. Integrity management concerns are focused on condition assessment, mitigation of corrosion, life assessment, and risk modeling.

Composite Sleeve-$19,000
Steel Sleeve-$ 25,100
10-FT PIPE REPLACEMENT $ 69,500
There are also costs associated with Corrosion Testing;
- In-Line Inspection
- Hydrostatic Testing
- Direct Assessment

Source:
Exhibit Seventeen

Electricity Corrosion

Corrosion on Electrical structures also presents another infrastructure opportunity for WinTec. As detailed in the paragraphs below, there are several items within this infrastructure that opens vast opportunities for WinTec.

The corrosion portion of the annual O&M cost was estimated at $698 million for fossil fuel, $2.013 billion for nuclear facilities, and $75 million for hydraulic power, for a total of $2.786 billion. Thus, the total cost of corrosion in the electrical utilities industry in 1998 is estimated at $6.889 billion per year.

The cost of corrosion for electrical utilities estimated that the cost of corrosion to consumers of electricity was approximately $17.27 billion per year, which represents approximately 7.9 percent of the total cost of electricity to the consumers of $218.4 billion.

There are different types of Plants
- Nuclear Steam Supply Systems
- Fossil Fuel Steam Supply Systems
- Hydraulic Plants

Transport and Distribution Systems - The electrical utilities transport systems include switchyard equipment, overhead towers, poles and conductors, and underground conductors and equipment. The types of structures and equipment that are included in electric distribution systems are switchgear and batteries, overhead towers, poles and conductors, underground conductors and equipment, transformers, connecting wires, meters, and street lighting. The impact of corrosion on electric utility systems can be divided into the fraction of utility costs for depreciation and operation and maintenance that are attributable to corrosion.

Total Cost of Operation, Maintenance, and Depreciation

The total 1998 cost of electricity of $218.4 billion can be divided into three main categories: operation, maintenance, and depreciation. The fraction of the cost for these categories for the major investor-owned and publicly-owned utilities for 1998 are reported in various government-compiled statistics distribution between the three categories and indicates that the majority of the cost is for the Operation category.

Operation and Maintenance Costs by Facility Type

Fossil Fuel $117.6 billion
Nuclear $ 38.6 billion
Hydraulic $ 2.4 billion
Other Power Generation $ 6.0 billion
Transmission $ 5.4 billion
Distribution $ 12.6 billion

Corrosion Percentage of Operation and Maintenance

Nuclear Steam Supply Systems
- Partial Power Outages - total U.S. nuclear generating capacity yields a total estimated corrosion cost for partial power reduction of $5.05 million
- Zero Power Outages - total U.S. nuclear generating capacity yields a total corrosion cost for zero power of $665 million.
- Operation and Maintenance - total U.S. nuclear generating capacity results in a total cost of $2.013 billion

Fossil Fuel Steam Supply Systems
The total cost of corrosion in fossil stations with coal as fuel is estimated at $28.773 million and in combined-cycle plants at $1.239 million. Extrapolating these costs to the U.S. fossil fuel steam supply systems, using the ratio of Duke Power fossil fuel generating capacity, (4.3 percent) to the total U.S. fossil fuel generating capacity, results in $669.14 million ($28.773 million / 0.043) for the coal-fired plants and $28.81 million ($1.239 million / 0.043) for the combined cycle plants, for a total cost of corrosion of $698 million per year.

**Hydraulic Production**
The total cost of corrosion in hydraulic power stations is estimated at $1.571 million. The total U.S. generating capacity results in a total cost of $75 million.

**Nuclear Steam Production**
Reactor Vessel and Reactor Coolant System (Nuclear Steam Supply System):

**Turbine Generator System:** Corrosion affects the turbine generator system mainly by requiring the design to be modified to prevent stress corrosion and corrosion fatigue of rotors, disks, blades, and bolting. This requires use of more resistant materials (e.g., alloy 17-4 PH versus carbon steel for blades), tighter control of water chemistry, and special design features to reduce stresses and eliminate crevices (e.g., use of monoblock design versus shrunk-on-disk design).

**Heat Exchangers and Piping:** Corrosion, including erosion-corrosion or environmentally assisted cracking, affects the cost of heat exchangers, such as condensers, feedwater heaters, and moisture separators, by: (1) requiring the use of more corrosion-resistant materials (e.g., copper alloys, stainless steels, or titanium versus carbon steel) in many applications, (2) placing limits on flow velocities if carbon steel or copper are used, thereby increasing equipment size, (3) requiring installation of flow baffles to prevent impingement effects, and (4) increasing required wall thicknesses to allow for corrosion, thereby decreasing efficiency and increasing original equipment size. For heat exchangers cooled using raw service-water, corrosion control concerns often require installation of water treatment systems (e.g., for biocides, or even the use of dual systems, with only one heat exchanger exposed to raw water and the other cooled using a closed cooling water system). For condensers, corrosion concerns often require the installation of sponge ball cleaning systems.

**Miscellaneous Power and Instrumentation and Control:**
Miscellaneous Power Plant Equipment: This equipment includes the main condenser heat removal system, cranes for lifting and moving waterwheels and electric generators for maintenance, and machine shop equipment. Corrosion affects the original cost of this equipment by requiring the use of protective coatings and some design features to protect sensitive parts.

**Fossil Fuel Steam Production**
Boiler: Corrosion affects the initial cost of the boiler by requiring the use of thicker walls on the carbon steel-tubed water walls and by requiring the use of more expensive corrosion-resistant materials for the superheater and reheater tubes. However, use of the more expensive materials is also required to provide creep resistance; thus, the entire extra cost is not chargeable to corrosion. Water chemistry control equipment that is used to control corrosion of the boiler materials is also an extra cost due to corrosion. This equipment includes make-up water purification equipment, condensate demineralizers, and chemistry laboratory and chemistry monitoring equipment.

**Turbine-Generator System:** Corrosion affects the turbine generator system mainly by requiring the design to be modified to prevent stress corrosion and corrosion fatigue of rotors, disks, blades, and bolting.

**Heat Exchangers and Piping:** Corrosion, including erosion-corrosion or environmentally assisted cracking, affects the cost of heat exchangers, such as condensers, feedwater heaters, and moisture separators, by: (1) requiring the use of more corrosion-resistant materials (e.g., copper alloys, stainless steels, or titanium versus carbon steel) in many applications, (2) placing limits on flow velocities if carbon steel or copper are used, thereby increasing...
equipment size, (3) requiring installation of flow baffles to prevent impingement effects, and (4) increasing required wall thicknesses to allow for corrosion, thereby decreasing efficiency and increasing original equipment size. For heat exchangers cooled using raw service-water, corrosion control concerns often require installation of water treatment systems (e.g., for biocides, or even the use of dual systems, with only one heat exchanger exposed to raw water and the other cooled using a closed cooling water system). For condensers, corrosion concerns often require the installation of sponge ball cleaning systems. Corrosion, including erosion-corrosion or environmentally assisted cracking, affects piping systems by: (1) requiring thicker walls to provide corrosion allowances, (2) requiring the use of more corrosion-resistant materials in some areas, especially steam drains, (3) requiring the use of more corrosion-resistant materials for special applications such as valve seats and trim, and (4) using more stress corrosion- and corrosion fatigue-resistant materials for special parts, such as pump shafts, valve stems, and bolting.

**Coal-Handling Equipment:** This equipment includes conveyor belts, pulverizers, and similar equipment. Corrosion is considered to have little impact on this equipment since most of the problems, and thus the design, are dominated by mechanical wear and fatigue. However, some original cost increase does result from the need for coatings.

**Flue Gas Systems:** Flue gas systems, especially the wet flue gas desulfurization systems, are strongly affected by corrosion because of the corrosive nature of flue gas impurities (e.g., sulfur dioxide). This requires use of expensive corrosion-resistant materials for the scrubber equipment, such as the nickel-base alloys C-276 and C-22.

**Ash-Handling Equipment:** Ash-handling equipment takes ash from the bottom of the boiler and transports it to locations where it can be transferred to off-site storage. The ash is typically handled as water slurry to allow pumping or similar transport. While the slurries are corrosive, they are typically designed using carbon steels and are not affected much by anti-corrosion design considerations.

**Electric Power and Instrumentation and Control:** Corrosion affects the costs of electric power and instrumentation and control equipment mainly by requiring design features to exclude corrosive atmospheres and the use of special materials for some corrosion-sensitive parts, such as switches.

**Miscellaneous Power Plant Equipment:** This equipment includes the main condenser heat removal system, cranes for lifting and moving waterwheels and electric generators for maintenance, and machine shop equipment. Corrosion affects the original cost of this equipment by requiring the use of protective coatings and some design features to protect sensitive parts.

**Hydraulic Production (Including Pumped Storage)**
The types of structures, equipment, and property included in this category are land; structures and improvements (e.g., office buildings); reservoirs, dams, and waterways; waterwheels, turbines, and generators; accessory electric equipment; miscellaneous power plant equipment; and roads, railroads, and bridges.

**Reservoirs, Dams, and Waterways:** The main impact of corrosion on the original costs of these items is for initial protective coatings on reinforcing bars, and design and fabrication provisions to minimize corrosion of rebar, forms, etc. during the construction process.

**Waterwheels, Turbines, and Generators:** Corrosion affects waterwheels, turbines, and associated piping systems (e.g., valves) by requiring the use of corrosion- and erosion-corrosion-resistant materials such as specialty grades of stainless steels (e.g., Nitronic 60) for either the pressure boundary or for trim.(10) The electric generator is affected by the need to have a chemistry control system for the cooling water system, and by the need for protective coatings for steel parts.

**Accessory Electric Equipment and Instrumentation and Control:** Corrosion affects the costs of electric power and instrumentation and control equipment mainly by requiring design features to exclude corrosive atmospheres and the use of special materials for some corrosion-sensitive parts, such as switches.
Miscellaneous Power Plant Equipment: This equipment includes cranes for lifting and moving waterwheels and electric generators for maintenance, and machine shop equipment. Corrosion affects the original cost of this equipment by requiring the use of protective coatings and some design features to protect sensitive parts. Roads, Railroads, and Bridges: Corrosion affects the original cost of this equipment by requiring the use of protective coatings, and some design features to provide for drainage to minimize water-induced corrosion.

Other Production
The types of structures, equipment, and property included in this category are land, structures and improvements (e.g., office buildings), fuel holders and accessories, prime movers (e.g., diesels, combustion turbines), generators, accessory electric equipment, and miscellaneous power plant equipment.

Fuel Holders and Accessories: Corrosion affects the initial cost of fuel oil tanks and oil pumping equipment by requiring the use of protective coatings and a small amount of water detection and removal equipment.

Prime Movers: Corrosion affects the cost of combustion turbines (the main prime mover in this category) by requiring the use of more corrosion-resistant materials.

Generators: Corrosion affects the cost of generators by requiring the use of more corrosion-resistant materials (copper alloys) for the cooling system and by requiring a water chemistry control system for the cooling system. In addition, coatings are used on steel parts to provide resistance to corrosion for the casing and support structure.

Electric Power and Instrumentation and Control: Corrosion affects the costs of electric power and I&C equipment mainly by requiring design features to exclude corrosive atmospheres and the use of special materials for some corrosion-sensitive parts, such as switches.

Transmission
The types of structures, equipment, and property included in this category are land, structures and improvements (e.g., office buildings), switchyard equipment, overhead towers, poles and conductors, underground conductors and equipment, and roads and trails. The effect of corrosion on each of the major categories of structures, equipment, and property for transmission facilities is discussed below. Switchyard Equipment: Corrosion affects the initial cost of transformers and switching equipment by requiring the use of protective enclosures, protective coatings, and more corrosion-resistant materials for some applications.

Overhead Towers, Poles, and Conductors: Corrosion affects the cost of this equipment by requiring the use of more corrosion-resistant materials, protective coatings, and cathodic protection systems for towers.

Underground Conductors and Equipment: Corrosion affects the cost of this equipment by requiring the use of protective coatings and cathodic protection systems.

Distribution
The types of structures, equipment, and property included in this category are land; structures and improvements (e.g., office buildings); switchgear and batteries, overhead towers, poles, and conductors; underground conductors and equipment; transformers, connecting wires, meters, and connections; and street lighting.

Switchgear and Batteries: Corrosion affects the initial cost of switching equipment and batteries by requiring the use of protective enclosures, protective coatings, and more corrosion-resistant materials for some applications.

Overhead Towers, Poles, and Conductors: Corrosion affects the cost of this equipment by requiring the use of more corrosion-resistant materials, protective coatings, and cathodic protection systems for towers.

Underground Conductors and Equipment: Corrosion affects the cost of this equipment by requiring the use of protective coatings and cathodic protection systems.
Connecting Wires, Meters, and Connections: Corrosion requires the use of weathertight enclosures, protective coatings, and, in some applications, corrosion-resistant materials.

General and Miscellaneous
The types of structures, equipment, and property included in this category are land, structures and improvements (e.g., office buildings), office furniture and equipment, and tools and miscellaneous equipment of various types (e.g., shop, garage, laboratory, communications, and power-operated equipment).
Structures: Structures include reinforced concrete buildings, metal-roofed and metal-sided buildings, reinforced concrete docks, intake and discharge structures, etc. The main effects of corrosion on the costs of these items are for initial protective coatings and for the use of more corrosion-resistant materials (e.g. aluminum siding versus steel sheet siding).
Office Furniture and Equipment: Corrosion affects the initial cost of office furniture and equipment by requiring the use of protective coatings and more corrosion-resistant materials for a few applications.
Tools and Miscellaneous Equipment: Corrosion affects the cost of this equipment by requiring the use of more corrosion-resistant materials, protective coatings, and weatherproof enclosures.

TOTAL COST OF CORROSION
The total direct cost of corrosion to U.S. electrical utilities owners can be divided into the corrosion fractions of forced outages, depreciation, and O&M. The sum of these direct costs to be $6.889 billion per year.
A study for the Electric Power Research Institute (EPRI)(4) to estimate the cost of corrosion for the electrical utilities industry estimated that the cost of corrosion to consumers of electricity was approximately $17.27 billion per year, which represents approximately 7.9 percent of the total cost of electricity to consumers of $218.4 billion.

Source:
Exhibit Eighteen

Railroad Corrosion

Every year, the United States spends approximately $10 billion because of corrosion and its detrimental effects. The National Association of Corrosion Engineers, Battelle Memorial Institute, and the U.S. Department of Commerce estimate that five percent of this cost, or $500 million, is attributable to stray-current corrosion, mostly due to electrified DC transit systems in Railroads.

One area where corrosion has been identified is in electrified rail systems, such as those used for local transit authorities. Stray currents from the electrified systems can inflict significant and costly corrosion on non-railroad-related underground structures such as gas pipelines, waterlines, and underground storage tanks. Railways are having problems with the bridge tusses, support structures, and stray current corrosion from electric railways.

The elements of construction subject to corrosion include metal members, such as
- rail
- steel spikes for wooden ties
- buried pipelines
- and cables

As far as the railroads are concerned, corrosion damage to the rail itself is limited and often goes unreported. It was estimated that the damage to the rail is primarily caused by stray current that occurs on the electrified rail systems.

The transit authorities acknowledge that corrosion-related problems exist, as manifested by the accelerated corrosion of the insulators of the rail fasteners. For example, wood tie spikes need to be replaced after 6 months instead of the anticipated 25 years.

While there is corrosion damage to other railroad-owned property, such as bridges, railyard structures, etc., from exposure to the elements, the railroad systems apparently do not consider it to be a major expense and, therefore, do not track this data.

Freight railroads have re-invested more than $460 billion back into their operations from 1980-2009, creating a national network second to none worldwide.

Corrosion in the foot of the rail is particularly difficult to identify. Despite this difficulty, rail networks need to assess the likelihood of rail damage by identifying the extent of any rail foot corrosion.

Despite a relatively mature technology for its control, corrosion caused by stray current from electrified rapid-transit systems was estimated in 1995 to cost the USA approximately $500 million annually. Part of that cost is the result of corrosion of the electrified rapid-transit system itself, and part is the result of corrosion on neighboring infrastructure components, such as buried pipelines and cables.

There are more than twenty transit authorities operating electrified rail systems in major urban centers in United States. Ungrounded systems represent the other extreme of traction power system design. An ungrounded system has no direct metallic connection between earth and the rectifier bus at the substations. Rail fastener insulation is also important so that high, rail-to-earth resistances are maintained.

Approximately 300 tons of 100-pound rail is purchased each year. Of this amount, about one third is for replacement of corroded rail. At $730 per ton of rail, and labor at half of the material cost, rail replacement due to
stray-current corrosion is estimated at $110,000 per year. Repairs such as these have been on-going since 1962 for a total approximate cost of $3.7 million.

Significant figures
- Rail replacement due to stray-current corrosion is estimated at $110,000 per year.
- Approximately 300 tons of 100-pound rail is purchased each year.
- Stray current from electrified rapid-transit systems was estimated in 1995 to cost the USA approximately $500 million annually
- Freight railroads have re-invested more than $460 billion back into their operations from 1980-2009

Regulations in Railroads

Staggers Rail Act of 1980.
Railway Antitrust laws

Source:
(2011) Railinc Website, Retrieved April 10, 2010
https://www.railinc.com/rportal/web/guest/home

Source:

Source:

Source:
Hazardous Material Storage Corrosion

According a study carried out in 2006, there are approximately 8.5 million regulated and non-regulated above ground storage tanks (ASTs) and underground storage tanks (USTs) for hazardous materials (HAZMAT) in the United States. This is the point where WinTec can exploit or explore so as to see how WinTec NAC 10 can be utilized from the point of manufacture of the tanks.

The total cost of corrosion for storage tanks is $7.0 billion per year (ASTs and USTs). The cost of corrosion for all ASTs was estimated at $4.5 billion per year. A vast majority of the ASTs are externally painted, which is a major cost factor for the total cost of corrosion. In addition, approximately one-third of ASTs have cathodic protection (CP) on the tank bottom, while approximately one-tenth of ASTs have internal linings.

**ANNUAL CORROSION COST**

**ALL ASTs**
- $2.8 billion for external coatings
- 1.2 billion for cathodic protection
- $0.5 billion for internal linings

**ALL USTs**
- $1.4 billion for gasoline stations
- $1.1 billion for the remaining USTs

Bulk storage of hazardous liquid and gaseous materials is normally done in large steel tanks. The largest aboveground tanks are used at refineries and manufacturing plants. These range from 15 m (50 ft) to more than 61 m (200 ft) in diameter and may have a capacity of more than 3,785 m³ (1 million gal). Transportation and distribution terminals of storage facilities for these materials can have a mix of aboveground and underground tanks. Liquid petroleum products at the point of sale and at the point of use are normally stored in direct buried underground tanks ranging from 1.9 to 114 m³ (500 to 30,000 gal) in capacity. Hazardous chemicals are usually stored in vaulted underground tanks or aboveground facilities. Storage tanks for pressurized materials can be spherical in shape, while storage tanks for unpressurized materials can be constructed from welded steel.

**Aboveground Storage Tanks**

**Internal Corrosion**

There are several different corrosion conditions in the interior areas of an aboveground tank. Vapor phase corrosion can occur in the areas exposed to the vapor above the stored product, and includes general, crevice, and pitting corrosion, depending on the temperature and the characteristics of the material. Product side corrosion can occur on the internal wall plate when corrosive materials are stored. This type of corrosion includes general and pitting corrosion. Aqueous phase corrosion can occur when water contamination and settling in petroleum products result in a layer of water on the bottom of the tank. Although the product may be non-corrosive, the presence of contaminants such as sludges and deposits may result in internal bottom and wall general corrosion, crevice corrosion, and pitting corrosion damage. In addition, microbiologically influenced corrosion (MIC) can be a problem under anaerobic conditions. The internal corrosion problems are exacerbated by the stresses and flexing that the metal undergoes during fluctuations in product levels.

**External Corrosion**

Atmospheric corrosion of the external wall and the roof is a result of general corrosion and crevice corrosion damage. Aboveground tanks suffer from external corrosion as a result of the tank bottom sitting on a grade with a variety of corrosive padding materials or on a back-filled concrete ring wall. Both types of tank bottom supports...
can cause external pitting of the bottom plate steel. Small aboveground tanks suffer from external atmospheric corrosion, but to a lesser degree because they can be supported off the ground and the rounded surface minimizes crevice corrosion opportunities.

**Underground Fuel Storage Tanks**
Underground fuel storage tanks are a very large and dominant portion of the hazardous materials storage sector. Corrosion is estimated to be responsible for approximately 65 percent of tank failures, while 35 percent is due to other causes such as third-party damage. Experience has shown that the vast majority of underground storage tanks (USTs) and piping failures are associated with external corrosion, while a small percentage can be attributed to internal corrosion.

One of the primary causes of external corrosion is exposure to corrosive soils. The electrical and chemical characteristics of soil and water are closely related to corrosivity.

It is important for Wintec to note that in recent years, the federal government has given a lot of attention to the environmental impact of leaking ASTs and USTs. The EPA Spill Prevention Countermeasure and Control (SPCC) plan and the EPA Office of Underground Storage Tanks (OUST) maintain databases on the number of active tanks. The remediation and spill costs for cleaning soil and water around leaking tanks can be significant. These indirect corrosion costs are estimated at $1.171 billion per year and are attributed to leaks caused by corrosion.

**Source:**
Exhibit Twenty

Waterway and Port Corrosion

Waterways also presents another infrastructure opportunity for WinTec. According to a study carried out in 2006, the annual expenditure on waterway corrosion control was noted to be $293.4 billion. Corrosion is currently primarily controlled by the surface coating systems and sacrificial cathodic protection systems. This presents an opportunity for Wintec to use nanotechnology.

U.S. Army Corps of Engineers
- Maintenance @ 5% - $70.00 billion

U.S. Public Ports
- Corrosion-Related Maintenance-$ 87.3 billion
- Corrosion- $95.0 billion

U.S. Coast Guard
- Lighthouse Maintenance- $23.5 billion
- Replace Steel Ocean Buoys-$ 2.0 billion
- Corrosion-Related Maintenance-$ 8.6 billion
Total annual corrosion-related costs - $293.4 billion

Significant Data
- The estimated annual cost of corrosion-related maintenance in the U.S. public ports is $87.3 million.
- The U.S. Coast Guard spends approximately $2 million to purchase 5,000 to 7,000 replacement river buoys.
- The steel river buoys, made of sheet metal with a foam filling, cost between $170 and $330 each.
- Annual cost of corrosion-related maintenance for 1999 can estimated at $8.6 million.
- The life expectancy of the coatings and sacrificial anodes are approximately 15 to 20 years.

Costs of Corrosion

U.S. Public Port.
83 port authority members in the United States had spent a total of $919 million on O&M in 1998. Corrosion costs are likely to be higher as coastal terminals have much higher atmospheric and splash zone corrosion rates. In addition, coating costs for berthing structures and cranes at saltwater marine terminals would be substantially greater than those for the freshwater facilities.

It is estimated that 5 percent of freshwater facility costs and 10 percent of saltwater marine port costs are corrosion-related. The estimated annual cost of corrosion-related maintenance in the U.S. public ports is $87.3 million.

The U.S. public ports is expected to spend $1.9 billion per year on construction and modernization, and that much of this infrastructure construction is necessary to accommodate growth and handling of the larger modern container ships. Even if only 5 percent of this expenditure is spent on replacing corrosion-damaged berthing facilities, $95 million can still be attributed to the annual cost of corrosion.

The analysis above indicates that the annual cost of corrosion in the public port authority sector of the ports and waterways can be estimated at $182.3 million ($87.3 million + $95 million).

U.S. Coast Guard
The U.S. Coast Guard maintains navigational aids such as light structures and buoys that are continuously exposed to harsh environments in both fresh water and seawater. According to the U.S. Coast Guard, (8) there are more than 21,000 navigation structures nationwide that range in size and complexity from simple unitl day beacons (a single wooden "telephone pole" driven into the bottom) to massive, multi-million dollar offshore lights and range structures. The majority of the navigational aids are found in the Gulf Coast and are considered to be "simple" structures, such as a single-pile or a multiple-pile steel or wood construction. (8) Single-pile structures are not maintained and are, in fact, allowed to rust until they are replaced. Estimated costs are $15,000 per single-pile structure. Larger light structures are protected using epoxy coatings and zinc sacrificial anodes. New structure costs can range from $300,000 to $600,000, while the coating and sacrificial anode costs are estimated at $20,000 per system. The life expectancy of the coatings and sacrificial anodes are approximately 15 to 20 years. Older lighthouses, initially constructed of iron in the 1800s and weighing approximately 600 tons, are still in use today. These massive structures require maintenance and sandblasting every 15 to 20 years at an estimated cost of $750,000 each.

There are 615 of these structures in the United States, with average annual routine maintenance expenditures of $750 per unit, for a total cost of $461,250 per annum. The combined cost of the lighthouse maintenance is therefore estimated at $23.5 million. The U.S. Coast Guard maintains foam, plastic, and steel buoys of different sizes and shapes in both fresh water and seawater.

According to the U.S. Coast Guard, (8) approximately $2 million is spent each year to replace steel ocean buoys that cost between $15,000 and $18,000 each. It is estimated that there are 11,640 steel buoys with an expected service life of 40 years for each buoy. These buoys are often hit by boats and are continuously in harsh environments; however, epoxy and anti-fouling paints, which are to be reapplied every 6 years, can protect them. The estimated costs for labor and supplies to paint buoys are $5 million a year. About 75 percent of river buoys are lost within a year of being put into service, the remainder of the river buoys often last 2 to 3 years. (8) The steel river buoys, made of sheet metal with a foam filling, cost between $170 and $330 each. Given the relatively small cost of the river buoys compared to the steel ocean buoys, river buoys are viewed as consumables and are replaced if they sink or are lost; therefore, they are not considered maintenance expenditures. Annually, the U.S. Coast Guard spends approximately $2 million to purchase 5,000 to 7,000 replacement river buoys. Calculated as $750,000 / 20 x 615 + $460,000

Corrosion-Related Maintenance Costs
In 1999, the U.S. Coast Guard spent an estimated $60 million on the east coast (10) and $31 million in the Pacific on maintenance costs.
- $60 million on the east coast
- (10) and $31 million in the Pacific on maintenance costs.

These costs include maintenance performed on land and sea facilities, corrosion related repairs, and any other activity necessary to maintain the safety of the waterways. Applying the corrosion-related O&M budget fractions estimated for the U.S. Army Corps of Engineers (5 percent for fresh water and 10 percent for saltwater) and a similar assumption that 90 percent of the structures maintained by the U.S. Coast Guard are in a saltwater marine environment and the remaining 10 percent are in a freshwater environment, the annual cost of corrosion-related maintenance for 1999 can be estimated at $8.6 million.

Typical corrosion control methods for freshwater structures include coatings for atmospherically exposed steel and corrosion allowances for submerged and splash zone steel. Dielectric coatings are normally used for structural steel above water, while galvanizing is often used for railings, ladders, gates, and gratings. Copper-bearing steel alloys are sometimes utilized for structural elements and sheet pile walls. These alloys, which form a tenuous oxide film in the atmosphere, provide little help when buried or submerged. Cathodic protection (CP) is occasionally used on submerged steel elements. Marine corrosion control methods also include coatings for atmospherically exposed steel elements and a corrosion allowance for submerged and splash zone steel structures. Specialty marine dielectric coatings are normally used for structural steel above and often below water. Although galvanizing is used for railings, ladders, gates, and gratings, non-ferrous alloys provide better service in
the aggressive saltwater marine conditions. Structures with higher initial capital costs are more likely to be protected either by coatings and/or CP. These include lock gates, dam gates, and other water-containing devices, which are protected to ensure their proper operation.

The choice and development of coatings have also been affected by (e.g., regulations have minimized the amount of volatile organic compounds (VOC) that can be used in coatings. Coatings with 100 percent solid content have been developed that contain no volatile solvents (before, coatings with 25 percent to 50 percent solid content were used). In addition to the epoxy coatings, anti-foulants are applied to submerged sections of the structure to prevent microbiologically induced corrosion (MIC).

- Epoxy coatings - $4.7 to $5.3 per L ($18 to $20 per gal),
- Anti-foulants -$11.8 to $21.1 per L ($45 to $80 per gallon).

Piers and docks are being constructed with steel-reinforced concrete. To improve the lifespan of the structure and prevent corrosion of the reinforcing steel, fusion-bonded epoxy-coated reinforcement or corrosion-inhibiting admixtures are sometimes utilized in the concrete mix.

Regulations
Clean Water Act
40 CFR, Chapter I-Environmental Protection Agency,
Subchapter R-Toxic Substances Control Act

References
Source:

Source:

Source:

Source:
Exhibit Twenty One

American Society of Civil Engineers
American Infrastructure Report Card

Source:
### Exhibit Twenty Two

**American Society of Civil Engineers**
**Infrastructure Spending Forecasts**

#### Estimated 5-Year Investment Needs in Billions of Dollars

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>5-YEAR NEED (BILLIONS)</th>
<th>ESTIMATED ACTUAL SPENDING*</th>
<th>AMERICAN RECOVER AND REINVESTMENT ACT (P.L. III-005)</th>
<th>FIVE-YEAR INVESTMENT SHORTFALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aviation</td>
<td>87</td>
<td>45</td>
<td>1.3</td>
<td>(40.7)</td>
</tr>
<tr>
<td>Dams</td>
<td>12.5</td>
<td>5</td>
<td>0.05</td>
<td>(7.45)</td>
</tr>
<tr>
<td>Drinking Water and Wastewater</td>
<td>255</td>
<td>140</td>
<td>6.4</td>
<td>(108.6)</td>
</tr>
<tr>
<td>Energy</td>
<td>75</td>
<td>34.5</td>
<td>11</td>
<td>(29.5)</td>
</tr>
<tr>
<td>Hazardous Waste and Solid Waste</td>
<td>77</td>
<td>32.5</td>
<td>1.1</td>
<td>(43.4)</td>
</tr>
<tr>
<td>Inland Waterways</td>
<td>50</td>
<td>25</td>
<td>4.475</td>
<td>(20.5)</td>
</tr>
<tr>
<td>Levees</td>
<td>50</td>
<td>1.13</td>
<td>0</td>
<td>(48.87)</td>
</tr>
<tr>
<td>Public Parks and Recreation</td>
<td>85</td>
<td>36</td>
<td>0.835</td>
<td>(48.17)</td>
</tr>
<tr>
<td>Rail</td>
<td>63</td>
<td>42</td>
<td>9.3</td>
<td>(11.7)</td>
</tr>
<tr>
<td>Roads and Bridges</td>
<td>930</td>
<td>351.5</td>
<td>27.5</td>
<td>(549.5)</td>
</tr>
<tr>
<td>Schools</td>
<td>160</td>
<td>125</td>
<td>0</td>
<td>(35)</td>
</tr>
<tr>
<td>Transit</td>
<td>265</td>
<td>66.5</td>
<td>8.4</td>
<td>(190.1)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.122 trillion</strong></td>
<td><strong>903 billion</strong></td>
<td><strong>71.76 billion</strong></td>
<td>(1.176 trillion)</td>
</tr>
</tbody>
</table>

**Source:**
Exhibit Twenty Three

Composition of Coatings:

Fusion Bonded Epoxies

Essential components of a powder coating are:

1. Resin
2. Hardener or curing agent
3. Fillers and extenders
4. Color pigments

The resin and hardener part together is known as the "Binder". As the name indicates, in Fusion bonded epoxy coatings the resin part is an "epoxy" type resin. “Epoxy” or “Oxirane” structure contains a three membered cyclic ring; one oxygen atom connected to two carbon atoms, in the resin molecule. This part is the most reactive group in the epoxy resins. Most commonly used FBE resins are derivatives of bisphenol A and epichlorohydrin. However, other types of resins are also commonly used in FBE formulations to achieve various properties, combinations or additions. Resins are also available in various molecular lengths, to provide unique properties to the final coating.

The second most important part of FBE coatings is the curing agent or hardener. Curing agents react either with the epoxy ring or with the hydroxyl groups, along the epoxy molecular chain. Various types of curing agents, used in FBE manufacture, include dicyandiamide, aromatic amines, aliphatic diamines, etc. The selected curing agent determines the nature of the final FBE product — its cross linking density, chemical resistance, brittleness, flexibility etc. The ratio of epoxy resins and curing agents in a formulation is determined by their relative equivalent weights.

In addition to these two major components, FBE coatings include fillers, pigments, extenders and various additives, to provide desired properties. These components control characteristics such as permeability, hardness, color, thickness, gouge resistance etc. All of these components are normally dry solids, even though small quantities of liquid additives may be used in some FBE formulations. If used, these liquid components are sprayed into the formulation mix during pre-blending in the manufacturing process.

Market Share of Various Coatings

The architectural paint market "has benefited from solid consumer spending on remodeling, and improved weather in parts of the country',' says, "Donald Carson, analyst at Merrill Lynch. Carson says paint makers, including PPG Industries, Sherwin-Williams, and Valspar had "healthy" third-quarter sales or volume growth in their architectural segments. Sherwin-Williams posted an 8.1% rise in third-quarter net income, to $120.3 million, on sales up 5.4%, to
$1.5 billion. The company's Paint Store segment sales grew by 5.4%, to $989 million, and its consumer segment sales increased 4-7%, to $128.9 million. "The third-quarter sales increase was due primarily to stronger architectural sales at some of this segment's largest retailers, and increased sales of aerosol and wood-care products," the company says.

PPG reported a 5% volume increase in its Architectural business in the third quarter, Carson says. PPG says that coatings account for a little more than half of its sales. Overall coatings sales grew 7%, to $1.22 billion, due to CO strengthening of foreign currencies and improved volumes across all businesses, off- set in part by lower prices in the automotive OEM business. Operating earnings grew 3.8%, to $185 million, which PKJ attributes to increased volumes, lower overhead costs, improved manufacturing efficiencies, and favorable effects of foreign currency translation. PPG reported overall net income down 4%, to $147 million, on sales up 7%, to $2.21 billion.

Valspar's packaging and architectural sales have remained healthy, Garson says. Valspar reported net income up 5%, to $40.1 million, for its fiscal third quarter ended May 31, on sales up 4%, to $598.2 million. The company's architectural and packaging coatings lines drove earnings growth, but the industrial coatings unit was bit by soft demand, Valspar says. The weak economy and high raw material costs crimped earnings growth, the company says. Valspar is scheduled to report results for its fiscal fourth quarter later this month, and says it expects that sales in its industrial segment will improve as there are signs of an upturn in industrial end markets.

DuPont does not break out automotive OEM paint sales, which are included along with all DuPont finishes and the company's titanium dioxide business in its Coatings and Color Technologies unit. DuPonts' third-quarter sales for that unit climbed 8%, to $1.4 billion, says Eric Melin, V.P., and general manager/refinish systems at DuPont. However, the increase was largely due to favorable currency exchange rates and an acquisition, Melin says. Paint volume declined 1% in the quarter. The company says car builds are down about 2% in the U.S. and about 3%- 4% in Europe; collision and repair work "continues to he on the soft side" both in Europe and the U.S.; consumer confidence is low; and growth in the general industrial sector is slow.

Source: Paints and Coatings, Seeking a Window of Opportunity

Types of Coatings
Various coating systems have been tried over the past 45 years and they have evolved with time and with innovation of new materials. Today, five main coating systems are commonly used for pipelines: three layer PE (3LPE), three layer PP (3LPP), fusion bonded epoxy (FBE or Dual FBE), coal tar enamel (CTE), asphalt enamel and polyurethane (PUR). The different systems are specified by pipeline owners and consultants based on various factors, including short-term cost, long-term cost, captive usage, regional availability of the coating material, control on handling, transportation and installation of pipelines, and technical reasons.
3LPE coating is dominant worldwide – with 50 per cent market share – for onshore pipelines, with the exception of North America. The trend is increasing with a greater number of projects coated with 3LPE in China, India and the Middle East. The increased acceptance of 3LPE is due to its broad operating temperature range (from -45°C to +85°C) and ability to withstand very rough handling and installation practices without damage to the coating.

3LPE systems consist of an epoxy primer, a grafted copolymer medium density (MDPE) adhesive to bond the epoxy primer with a high density (HDPE) topcoat. 3LPP systems are recognized as excellent systems for offshore projects with elevated operating temperature (0°C to +140°C) and extreme mechanical stress on the pipes. Recent projects in the North Sea, Africa, Gulf of Mexico and Arabian regions have set new standards for 3LPP coatings, which provide access to deeper gas and oil fields. 3LPP system consists of an epoxy primer, a grafted copolymer PP adhesive to bond the epoxy primer with a PP topcoat.

FBE is dominant in North America, United Kingdom and a few other countries but the trend is declining in favor of 3LPE and PP Systems. Some pipeline owners have graduated from coal tar coating to Dual FBE as the cost has become quite competitive after increases in coal tar prices. Coal tar and asphalt enamel are both still used in some countries. For many refineries, which have their own pipelines, coal tar is the cheapest coating option, being their own product. Both systems are declining and suffer from health and environmental concerns.

Providers of innovative, value creating plastics solutions, Borealis and Borouge have over 40 years of combined experience in the polyolefins industry and a record of engaging with parties throughout the value chain. Borealis is pre-eminent in Europe with a strong leadership position in the industry whilst Borouge has a strong growing market presence in the Middle East, Asia-Pacific and Africa. Their long experience and expertise in the plastic pipe industry includes more than 20 years in steel pipe coating. In the 80s and 90s, the group supplied an extensive number of projects all over the world, initially with low density (LDPE) and MDPE compounds for pipe coating. With continuous research and development, Borouge and Borealis’s first bimodal high density PE system with grafted MDPE adhesive was introduced in 1997 and it remains a leading 3LPE system. In 1990, Borealis introduced its first PP system.

Borouge and Borealis employ their unique Borstar technology to produce differentiated, high performance PE and PP polymer solutions for steel pipe coating. Borstar technology combines excellent processability and melt strength of the polymer with very high properties like notch resistance, abrasion resistance, improved impact at low and elevated temperatures, peel strength and indentation resistance. The HDPE and PP top coat are supplied in compounded form to withstand long-term thermal ageing and light ageing. A high level of investment in research and development in close co-operation with customers ensures the continual development of innovative new products and pipe system solutions. Several new products are under development including a PE top coat with very high resistance to slow crack growth, machine applied PE for field joint coatings, PP weight coating and PP injection molded systems for field joint coating. The result of this approach is a long pipeline service life with minimum
maintenance cost for the pipeline owner, fast production and high output for the pipe coater, easy installation without repairs for the installers and peace of mind and reliability for the engineering consultant.

Source: Pipeline International
Exhibit Twenty Four

Slow adoption of 3LPE and 3LPP in United States:
Coating systems have evolved over past 45 years with the innovation of new materials. Today 5 main coating systems used globally include-

1. 3LPE
2. 3LPP
3. FBE
4. Coal Tar Enamel (CTE)
5. Asphalt enamel and polyurethane (PUR)

Choice specified by pipeline owners and consultants is based on –

1. ST and LT costs
2. Capacity Usage
3. Regional availability
4. Control on handling
5. Transportation and installation of pipelines
6. Technical reasons

Basic Requirements in all new innovations – toughness of the coating, secure LT properties and increased operating temperature ranges. 3LPE is the most dominant coating worldwide with almost 50% share in the market for offshore pipelines with the exception of North America. A number of reasons have been identified for this:

1. Increased acceptance of 3LPE in China, India and Middle East is due to its broad operating temperature range (from -45°C to +85°C) and ability to withstand very rough handling and installation practices without damage to the coating. Asian region Pipe coating needs are unique. The Gulf region, which is the hub of pipeline projects, presents many environmental challenges like high water table, aggressive Sabkha soil, high ambient temperature and UV radiation, pipeline often getting direct exposure to sunlight due to shifting of sand cover etc. India and many Asian countries pose the challenge of poor road condition, rough transportation and insufficient handling infrastructure, high ambient temperature and humidity, high rainfall in many areas and difficult terrain in many parts. Many such conditions do not prevail in North America, hence the slow penetration in the U.S market.

2. The developments in 3LPE coatings for the past 25 years have been led mainly by the European PE majors like Neste Chemicals (currently Borealis), BASF (currently Lyondell Basell) and others, in bringing out innovative solutions in top coat and adhesives. A product put forth by a foreign developer and researcher may be a reason for slow adoption of this technique in the U.S.

3. Many foreign companies (working primarily with LPE coatings) have been directing their industry research to focus on emerging markets of Middle East and Asia in the recent years. Marketing to a particular segment could also be a reason.
4. The investment required in storage or distribution system in petroleum industry is very large and the systems design life is typically 25-years minimum. If the system fails for any reason the products stops flowing and the daily cost of a system shut costs millions per day. Keeping this in mind, there have been many instances where new technologies like LPE and LPP have failed in certain international operations. This could be another reason that North America has been hesitant in adopting these new technologies. Often corrosion engineers want a technology that has a proven track record of about 10-15 years. As a result, they ignore the new technologies.

5. The Oil and gas industry has always been conservative because of high cost of capital, higher cost of exploration due to remote locations of new oilfields, higher cost of construction, materials, design and installation. A simple reason for slow adoption of LPE and LPP could be the inertia set in the American pipeline market of following similar practices over the years which have worked well in the past.

**Dominance of FBE in North America:**

**Outline** - For more than 35 years, fusion bonded epoxies have been the premium choice for plant applied pipe coating technology in North America. While my previous document outlined major possible reasons for such dominance, this paper will try to explore a few of them in detail.

**The Present Scenario:**

Over the past few years many world manufacturers of FBE have established a North American presence to compete in its lucrative domestic markets. To gain market share against 3M and Du Pont, offshore competitors have been reducing prices since 2000 by more than 30% of what they were. Prices have dropped and so have the profits and this is likely to cause possibly detrimental long term strategies amongst FBE powder manufacturers. The markets are competing now based on better formulations, enhanced applicator or technical support and manufacturing excellence. Future is headed towards higher standards and quality products. The business model has been changing as powder source decisions are increasingly being based on price of user approved material. Pipeline owner companies have even asked applicators to share any financial benefit based on powder selection. Manufacturers are questioning their product development direction and cost of advancing the FBE pipe coating technologies. The FBE market in North America is undergoing changes because of the following trends-

5. **Cheaper Formulations** – The current trend looking at diminishing profits is to consider cheaper raw materials, organizing ingredients by cost, assessing risk of product failure and financial fears.
6. **Loss of Human Expertise** – The manufacturers are trying to recover from low prices by staff reductions which have led to loss of key relationships and personal energy invested by people in support activities to their industry.
7. *Loss of Support for Associations* – Industry associations have been mutually benefitting manufacturers by sharing common goals but now dues as well as event sponsorships are being carefully scrutinized for expenses.
8. *Loss of Major FBE Manufacturers* – The historical decision by FBE applicators to share volumes between suppliers to ensure healthy competition is almost impossible now.

The FBE manufacturers are now faced with 2 choices
1. Adapt to the new fiscal product realities.
2. Cease to participate in low profit margin and high potential liability driven pipe coating markets.

Looking at the above scenario, WinTec has the right opportunity to enter the market as a substitute product that could suit the requirements of low cost, high profitability and long term benefits. While WinTec holds a great chance for the entry of NAC-10 coating, the above discussion also gives us food for thought as to why FBE has not been replaced by LPP and LPE coatings when they have taken a majority share in the markets of other countries. Clearly the FBE market is under intense pressure as the strong industry bonds are breaking and prices are getting competitive. The above mentioned FBE industry trends have emerged slowly and yet there has not much stated about overtaking by LPE and LPP coatings.

**A Case Analysis:**

According to an October 2006 article from Pipeline and Gas Journal, Exploratory inspections of FBE coated pipeline segments installed more than 30 years ago have provided valuable, positive information on the historical performance of FBEs. The pipeline segments were installed in 1975 for storage field service and a thorough inspection was performed based on the following parameters-

1. **Inspection Site Selection** – based on importance of pipeline to field gathering system and maximum gas temperatures flowing through the pipelines during withdrawal periods.
2. **Pipeline Data** – e.g. for Site A pipeline- 10.75 inches, .562 wall thickness, 5LX52 grade pipeline with MAOP of 3,000 psig. Historical withdrawal gas temperatures of 115-120 degrees F.
3. **Visual Inspection** – suggested that FBE could not shield cathodic protection current.
4. **Coating Thickness Tests** – revealed consistency.
5. **Adhesion Tests** - moderate to good results.
6. **Lab Evaluations** – Porosity and DSC analysis.

The figures below show the cathodic protection history and the test summary for the two sections of pipelines tested at two different sites. The final result proved that FBEs were found to be effective even after 30 years of service.
This rigorous case study makes a strong case for FBEs from Nap-Gard which is a functional coating line of DuPont Powder coatings, USA. The idea to discuss this case here is to show how North America has tested FBE coatings and found them suitable for a design life of greater than 25-years. The tests performed above have made the corrosion engineers reliant on the FBE technology and tests performed above gauge the evaluation minutely. So far I think I have established the preference of FBEs in North America with the discussion of market trends and a case analysis. My next step is to prove the reason for a lack of LPP and LPE market share. This can be augmented by revelation of the development trends in the International Coating Standards.

Development of International Coating Standards for Pipelines:
In this section, I attempt to explain the structure for standard development (ISO) for the pipeline coatings. As a candidate for global standards FBE coating were the first and so far the only coating system to complete the entire ISO process for the preparation and publication of a standard in the years 2007-08. ISO external coating standards have been driven by two factors –

3. Time and finances in developing and publishing standards for a relevant coating.
4. Expedited publication of the standards if they are to meet the industry needs and ISO publication schedules.

In 2008, a need was identified to publish standards on 2 and 3 layer PE and PP coatings, FBE, girth-weld coatings and concrete coatings. The new family of international standards (2010) is intended to create minimum standard requirements for coating raw materials, application processes, testing and inspection methods as well as handling and storage of coated pipes. The ISO draft goes through 4 main stages (1) the committee draft (CD), (2) draft international standard (DIS), (3) Final Draft International Standard (FDIS) and (4) published international standard.

In 2008, the developing of a single standard for 2 and 3 layer coatings became impractical and as a result was split into 2 separate standards. The structure of the development of ISO coating standards was-

6. WGI4-1 Three-Layer PE/PP Coatings; Josef Gronsfeld (Germany). (ISO/DIS 21809-1 Petroleum and natural gas industries – External Coatings for Buried or Submerged Pipeline Used in Pipeline Transportation Systems – Part 1; Polyolefin Coatings ((three-layer PE and three-layer PP)).
7. WGI4-2 Fusion-Bond Epoxy Coatings; Keith Coulson (Canada).
8. WGI4-3 Field Girth Weld Coatings; Marcel Roche (France). (ISO/DIS 21809-3 Petroleum and natural gas industries - External Coatings for Buried or Submerged Pipeline Used in Pipeline Transportation Systems - Part 3: Field Joint Coatings.)
9. WGI4-4 Two Layer PE Coatings; Dennis Wong (Canada). (ISO/DIS 21809-4 Petroleum and natural gas industries - External Coatings for Buried or Submerged Pipeline Used in Pipeline Transportation Systems - Part 4: Polyethylene Coatings ((2- layer PE))).
10. WG 14-5 Concrete Coatings; Betty Friedman (USA). (ISO/DIS 21809-5 Petroleum and natural gas industries - External Coatings for Buried or Submerged Pipeline used in Pipeline Transportation Systems - Part 5: External Concrete Coatings.)

In the case of FBE coatings (Work Group WGI4-2), there was extremely wide interest in participating on the preparation of the standard. With 23 P voting countries, the 21809-2 standard for external FBE coatings was accepted by a vote of 19. All this was in 2008, the standards for each of the different categories of coatings are in a different stage of development as of 2010.

The FBE coatings standard — ISO 21809- 2:2007 — Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 2: Fusion-bonded epoxy coatings — was published in 2007, but ISO decided in April 2010 to change the title of the standard to single layer fusion-bonded epoxy coatings and to revise the standard to include single-layer high temperature FBE coatings in its scope. The field
joint coatings standard — ISO 21809-3:2008 — Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 3: Field joint coatings — was published by ISO in December 2008 and has already been re-opened for an amendment that is in the committee draft stage. The 2LPE coating standard — ISO 21809-4:2009 — Petroleum and natural gas industries — External coatings for buried or submerged pipelines used in pipeline transportation systems — Part 4: Polyethylene coatings (2-layer PE) coating was published in November 2009.

The 3LPE/PP coating standard (ISO/DIS 21809-1) has faced challenges in its development as the different involved stakeholders — raw material producers, coating applicators, and pipeline operators could not agree on some high profile topics, such as type of coatings covered by the standard. After several rounds of negative votes from the ISO countries, the standard is still in DIS stage. On the other hand, FBE standard has already been published and there is an ongoing development effort to create more standardized regulations of FBE coatings. FBE coatings standard will be revised before the end of 2012. Although amendments are being continued on 3LPE/PP standard draft, the FBE standards have come a long way. This has been identified as a strong reason for the stakeholders to be choosing FBES instead of LPE/PP coatings as the ISO standards on one exist and continue to improve while the other remains debatable. All the major competitors like 3M, PPG, Bredaro Shaw etc are ISO certified as can be seen on their websites. The discussion here shows that the stakeholders clearly agree on major aspects of FBE coatings while they have failed to do so in case of LPE/PP coatings. Based on the previous discussion and the detailed analysis in this paper, quite a few potential reasons for the slow adoption of LPE/PP in North America can be enumerated.

Sources:


Exhibit Twenty Five

Overview of Fusion Bonded Epoxies:

Fusion bonded epoxy (FBE) was introduced in Europe in 1953 for the coating of electrical equipment by the fluidized bed dipping method. In the early '60s it was introduced to the pipeline industry for the protection of small diameter water and oil field production piping. The first FBE for large diameter pipe was supplied in the mid-sixties.

By the late seventies, FBE became the most widely used pipeline coating in the U.S., Canada, Saudi Arabia and the U.K. Presently, FBE is used on every continent for the protection of line pipe, production tubing and drill pipe for the oil and gas industries. It has also gained acceptance for the protection of reinforcing steel (rebar) in the U.S., Canada, the U.K. and the Middle East.

Fusion-bonded-epoxy (FBE) powder coatings, first developed by 3M Co., are used worldwide where long-term corrosion protection is critical such as on oil, gas and water pipelines. However, the performance requirements for FBEs are challenging because the hard, highly cross-linked coatings are expected to survive demanding pipe manufacturing processes and installation conditions as well as field performance at elevated temperatures. It may be possible to improve the performance of FBE coatings for pipeline corrosion protection by increasing the toughness of the coating.

Although FBE is extremely successful as a corrosion protection system for underground pipelines, there are some inherent limitations, which make it difficult to achieve total corrosion protection with coatings alone. Some of these limitations are due to the chemical nature of organic materials in the coating and some are related to coating application procedures.

To overcome the deficiencies and achieve total corrosion protection, another alternative method, cathodic protection (CP), is used in conjunction with the coating. Presently, FBE with the CP system is the most effective and economical corrosion control system for underground pipelines, but the success depends on the coating’s ability to become an integral part of the “CP coating” combination system.

Epoxy resin-based powder coatings have been the standard corrosion protection system for pipelines in the oil, gas and water industry for many years because of their outstanding adhesion, chemical resistance, temperature resistance, and corrosion protection. These coatings are factory applied on pipeline segments, and then the pipeline segments are transported to the field and welded in place.

The welded joints are protected with a special field- applied powder coating process or with other systems such as liquid coatings or shrink-wrap sleeves. These coatings are expected to last between 20 and 30 years without requiring a significant amount of oil monitoring or repair. To achieve this level of durability, the coatings must be perfectly applied with literally no bare metal exposed to the environment.

However, the coatings may be damaged during transportation or installation, especially when the pipe is installed in remote areas with difficult access or rocky terrain. To overcome this problem, a multi-layer coating system was developed in the mid-eighties, which involved adding a layer of high-density polyethylene (HIDPE) or polypropylene over the epoxy coating. The enhancement of fusion-bonded epoxies in the past decades clearly demonstrates the ability of this toughening technology to
dramatically enhance the flexibility and impact resistance of FBE coatings. Essentially, FBE has been the market leader in industrial coatings.

Exhibit Twenty Six

Rig Fleet Count Segmentation

To provide better segmentation of the market, the analysis located sources that provided segmentation for the offshore rig fleet counts by operator, manager, region and rig type. This information could be essential to WinTec for the full assessment and targeting of NAC-10 within the market segment.

The segmentation can be found at the following linked locations:

Provided below is a sample of the segmentation by Rig Operator:

<table>
<thead>
<tr>
<th>Operator Name</th>
<th>Rig Fleet</th>
<th>Photos</th>
</tr>
</thead>
<tbody>
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<td>view 1 rig photos</td>
</tr>
<tr>
<td>Abuqir Petroleum</td>
<td>2 rigs</td>
<td>view 2 rig photos</td>
</tr>
<tr>
<td>ADC</td>
<td>1 rigs</td>
<td>view 0 rig photos</td>
</tr>
<tr>
<td>Addax</td>
<td>3 rigs</td>
<td>view 2 rig photos</td>
</tr>
<tr>
<td>ADMA/OPCO</td>
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<td>view 5 rig photos</td>
</tr>
<tr>
<td>ADOC (NOC)</td>
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<td>view 1 rig photos</td>
</tr>
<tr>
<td>Aera Energy</td>
<td>1 rigs</td>
<td>view 0 rig photos</td>
</tr>
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<td>Afren</td>
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<td>view 2 rig photos</td>
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<td>Agip</td>
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</tr>
<tr>
<td>AIOC</td>
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<td>view 2 rig photos</td>
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<tr>
<td>Al Khafji Joint Operations (KJO)</td>
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<td>Anadarko</td>
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<td>Apache</td>
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<td>Arena</td>
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<td>BG</td>
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<td>BHP Billiton</td>
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<td>BP</td>
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<td>Burullus Gas Co.</td>
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<td>Cairn Energy</td>
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Exhibit Twenty Seven

Firms Providing Rig Corrosion, Cathodic Protection, Coatings and Insulation

The analysis team felt it was imperative to provide WinTec with an overall list firms providing corrosion protection within the industry and firm profiles. The information can be found at:

http://www.offshore-technology.com/contractors/corrosion/

Company Profiles Include:

- **3M**, Corrosion Protection Products for Oil and Gas Pipelines
- **A&E Group**, Offshore Anti-Corrosion Coatings, Subsea Coatings, Underwater Coatings, Flange Protection and Mothballing
- **Abbey Gritblasting Services Coatings**, Grit and Bead-Blasting Preparation and Anti-Corrosion Protective Coating
- **Abdulla Fouad Impalloy**, Cathodic Protection Systems and Services
- **Accoat**, Advanced Corrosion Protection and Flow Enhancement
- **ACI**, Coatings for the Oil and Gas Industry
- **AIL Industries**, Aluminium and Zinc Sacrificial Anodes for the Offshore Industry
- **Armacell**, Thermal and Thermal-Acoustic Insulation Systems for the Offshore Industry
- **Bayou**, Anti-Corrosion Pipe Coating and Welding Services
- **Bodycote Metallurgical Coatings**, High Performance HVOF Applied Tungsten Carbide Coatings and Plasma Sprayed Ceramic Coatings
- **Carboline**, Protective Coatings for the Onshore-Offshore Oil and Gas Industry
- **Cathodic Protection Co Ltd**, Marine Growth Anti-Fouling Systems
- **Corrocoat**, Anti-Corrosion Coatings
- **CORROLESS**, VCI Corrosion Inhibitors, Hydrotest Additives and Coatings for Offshore Corrosion Protection
- **Corrosion Solutions**, Corrosion Protection and Control Specialists, Vapour-Phase Corrosion Inhibitors, Protective Coatings and Cortec VpCI
- **Environmental Protection Engineering**, Cathodic Protection and Aluminium and Zinc Anodes
- **Eurogrit**, Surface Preparation Abrasives
- **GCP**, Cathodic Corrosion Protection Systems and Services for Offshore Structures
- Hempel, Corrosion Protection to Protect Offshore Assets
- iicorr, Cathodic Protection System Engineering and Corrosion Monitoring Equipment
- Master Bond, Polymers and Adhesives for Offshore Oil and Chemical Processing
- MCU-Coatings, Moisture Cure Urethane (MCU) Marine Paint and Protective Coatings
- MTM Metalizing, Metalizing Corrosion Protection for the Offshore Industry
- Muehlhan Surface Protection, Marine Surface Protection
- NDT & Corrosion Control Services, Cathodic Protection Systems
- Norisol, Heat, Cold and Sound Insulation
- Oil States MCS, Offshore Swaging Tools and Abrasive Water Jet Cutting Services
- Pittsburgh Corning, FOAMGLAS® Cellular Glass Insulation Systems
- Stopaq, Splash Zone Coating System
- Temati Group, Insulation Protection Coatings and Sealants, and Ancillary Plastic, Foils and Tapes
- WRS Marine Inspections and Services, Hull Assessment, Repair and Cathodic Protection Systems