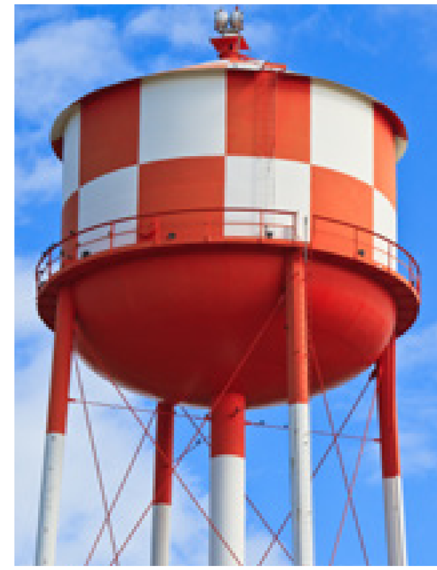

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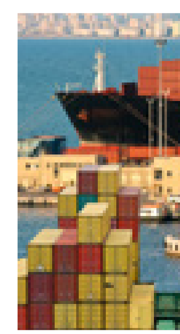

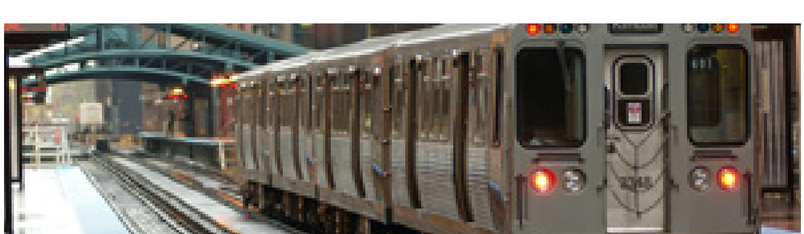

NACE International's IMPACT Breaks New Ground in the Study of Corrosion Management

Over past decades there have been significant studies in various parts of the world on the cost of corrosion and how it affects a country's economy. The often cited 2002 U.S. Federal Highway Administration study, "Corrosion Costs and Preventive Strategies in the United States,"[1] revealed that the total annual estimated direct cost of corrosion was $276 billion—equivalent to approximately 3.1% of the U.S. Gross Domestic Product (GDP). Studies in other countries have shown a similar percentage of GDP.

Over the last two years, NACE International—The Corrosion Authority embarked on a new study that goes beyond the economic effects of corrosion; it emphasizes how to integrate corrosion technology with organizational management systems. By doing this, corrosion decisions are optimized with respect to both cost savings and concern for safety and the environment. IMPACT—the International Measures of Prevention, Application, and Economics of Corrosion Technologies study[2]—is available to the general public at impact.nace.org.

The following pages provide a summary of the scope, approach, and significant findings of the IMPACT study, including corrosion control strategies that could save hundreds of billions of dollars per year. The study determined that reducing what continues to be an astoundingly high cost of corrosion requires a change in how decisions are made. While it is important to continue investment in technology for corrosion control, putting this technology into an organizational management system context and justifying corrosion control actions by business impact is essential. IMPACT provides the data, tools, and framework that enable companies and governments to successfully integrate and execute an effective corrosion management system.

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IMPACT

International Measures of Prevention, Application, and Economics of Corrosion Technologies Study

Report No. OAPUS310GKOCH (PP110272)-1

Report prepared by DNV GL U.S.A., Dublin, Ohio and APQC, Houston, Texas

Launching IMPACT

There have been dozens of studies on the economic effects of corrosion in various industries and countries, going back as far as the 1950s. In 2002, the U.S. Federal Highway Association (FHWA) released a breakthrough study on costs associated with metallic corrosion in a wide range of industries. Results of the study, "Corrosion Costs and Preventive Strategies in the United States," revealed that the total annual estimated direct cost of corrosion was US$276 billion, equivalent to 3.1% of the U.S. Gross Domestic Product (GDP). Along with detailed cost analyses, the FHWA study broadly included preventive corrosion control strategies. While this benchmark study is still widely used and has been updated to account for inflation in the ensuing years, there had been no attempt to extend the study to a more in-depth look at the effects of corrosion as related to overall corrosion management practices, particularly on a global scale. Thus, NACE International, the technical society for corrosion professionals with more than 36,000 members worldwide, initiated the IMPACT study in October 2014.

A primary goal of IMPACT is to examine the role of corrosion management in establishing industry best practices, enabling maximum cost savings, and enhancing public safety and environmental protection. It focuses on segments of four major industries: energy, utilities, transportation, and infrastructure. The study features in-depth research and resources in these areas:

- Updates the global cost of corrosion
- Assesses corrosion management practices across various industries and geographies
- Provides a template for corrosion management in the form of a corrosion management system framework and guidelines
- Provides financial tools that can be used for calculating life-cycle costs and return on investment
- Provides the ability for organizations to benchmark their corrosion management programs with others around the world

Published in March 2016, the IMPACT report can be downloaded at impact.nace.org. This web site also features the study content broken into its various categories, the ability to benchmark corrosion programs against others, and other resources for corrosion control and management.

Assessment of the Global Cost of Corrosion

To determine the overall global cost of corrosion, IMPACT researchers analyzed publically available studies from around the world. A detailed assessment of these is included in the report, revealing that the global cost is an astounding US$2.5 trillion, equating to 3.4% of a country's GDP. By using currently available corrosion control practices, it is commonly estimated that savings of between 15 and 35% could be realized—between US$375 and $875 billion. It is important to note that these costs typically do not include the safety or environmental impacts of corrosion, which cause high financial, regulatory, and legal consequences to an organization.

The currently available, time-proven methods for preventing and controlling corrosion depend on the specific material to be protected; environmental concerns such as soil resistivity, humidity, and exposure to saltwater or industrial environments; the type of product to be processed or transported; and many other factors. The most commonly used methods include organic and metallic protective coatings; corrosion-resistant alloys, plastics, and polymers; corrosion inhibitors; and cathodic protection—a technique used on pipelines, underground storage tanks, and offshore structures that creates an electrochemical cell in which the surface to be protected is the cathode and corrosion reactions are mitigated.

The most critical finding of the IMPACT study, however, is that while it is important to continue investment in technology and systems for corrosion control, putting this technology into an organizational management system context and justifying corrosion control actions by business impact is essential. This can be accomplished by employing a corrosion management system that is understood and supported in every level of an organization involved in protecting assets. The Corrosion Management System Framework is the core deliverable of IMPACT.

The Corrosion Management System Framework

The Corrosion Management System (CMS) Framework is an organizational structure that enables effective corrosion mitigation while providing a positive return on investment (ROI). ROI is a benefit (or return) of an investment divided by its cost. A CMS is a documented set of processes and procedures required for planning, executing, and continually improving the ability of a company to manage the threat of corrosion for existing and future assets and asset systems. Figure 1 shows the interrelation of a pipeline operator's organization management system. Figure 2 is the CMS Pyramid, which is central to the findings and recommendations of IMPACT.

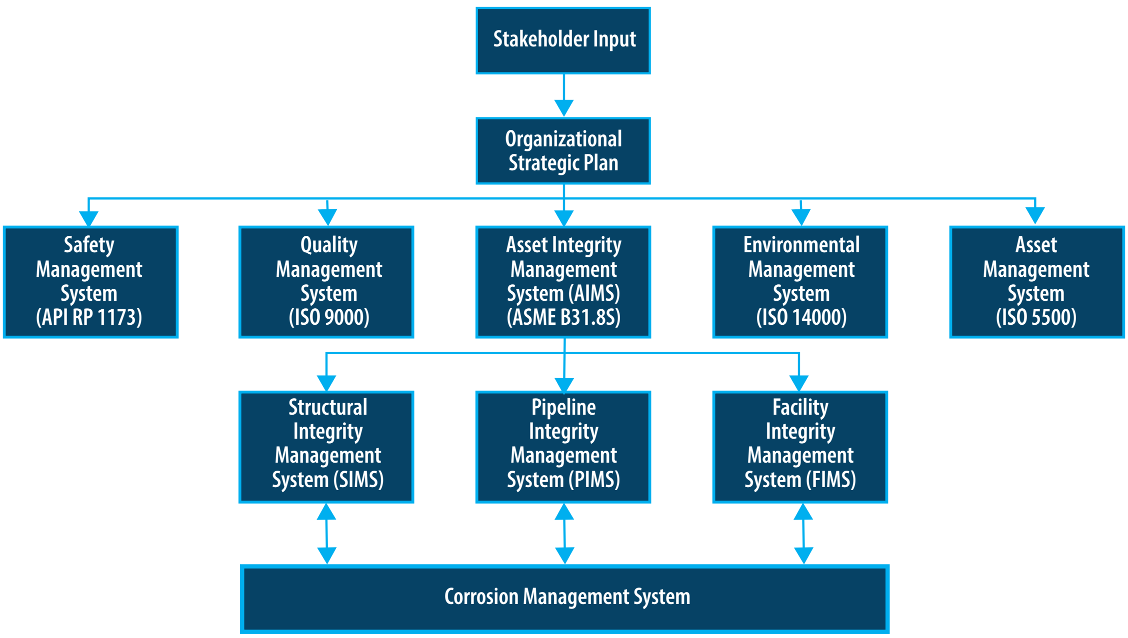


Figure 1. Interrelation of an organization management system. This example is for a pipeline operating company.

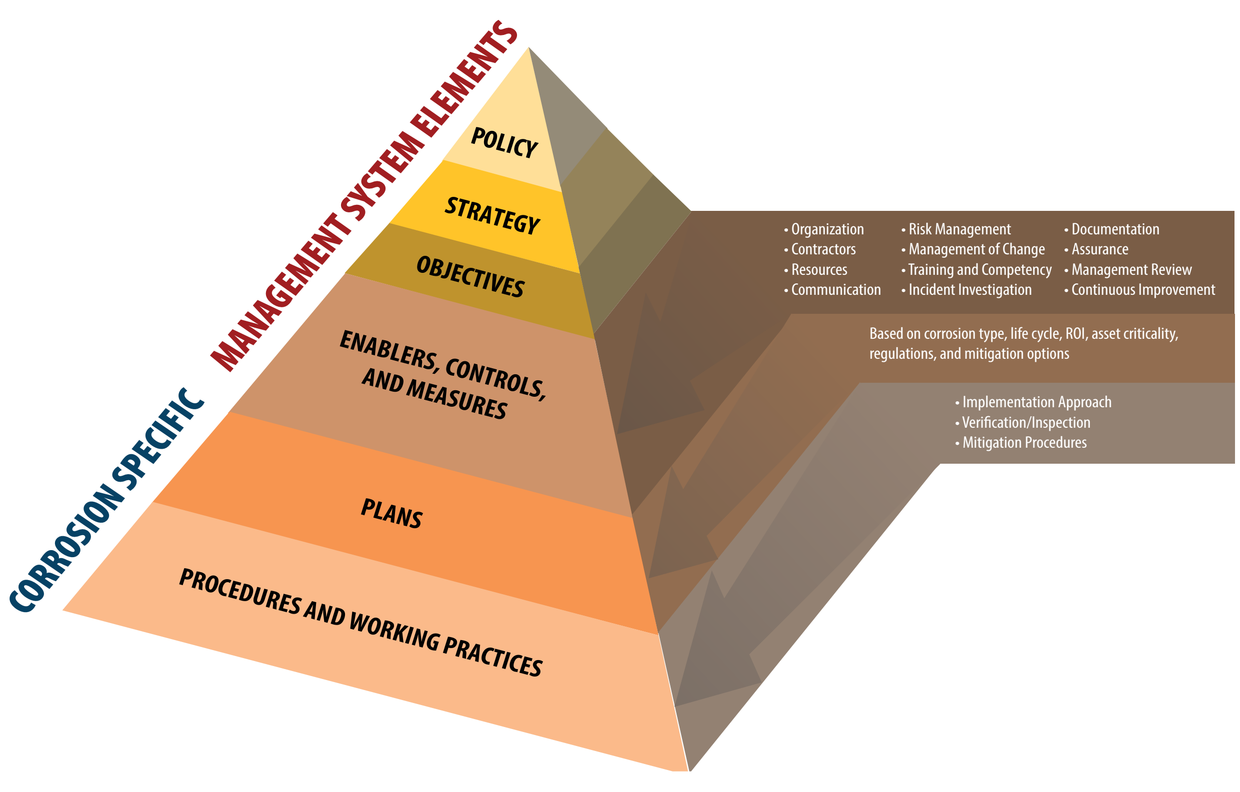


Figure 2. The CMS Pyramid: Hierarchy of general and corrosion-specific management elements.

Managing the threat of corrosion requires consideration of both the likelihood and consequence of corrosion events. According to the report, the consequence, or impact, of corrosion is considered the potential or actual monetary loss associated with the safety or integrity of the corrosion event. This value is typically quantifiable when considering lost revenue, cost of repairs, and clean-up costs, as applicable. Other aspects of corrosion impact include deterioration of an asset to the point where it is no longer fit for its intended purpose (e.g., lost future production).

In general, corrosion threats should be mitigated to a point where the expenditure of resources is balanced against the benefits gained. To determine whether a corrosion management investment is appropriate, it can be compared to the potential corrosion consequence through an ROI analysis. For corrosion management, the costs may include inspection and other maintenance costs. The benefit of ROI is not in capital gains, but in the avoidance of safety or integrity costs.

Investing in CMS activities such as inspections and maintenance may not prevent all corrosion events because the likelihood of failure is rarely zero. Additionally, the consequences of corrosion events, when they occur, may be compounded due to system-related issues such as lack of training, not following procedures, or inadequate emergency response. Therefore, investing in a CMS to frame the corrosion activities with the system elements necessary for planning, execution, and continual improvement should be considered as part of the ROI.

The IMPACT report provides a series of diagrams that graphically depict various components of a CMS, as well as information on CMS policies, strategies, and objectives; enablers, controls, and measures; risk management; and many other resources to enable companies to fully incorporate an effective CMS into their own organizational structure.

Benchmarking

When the IMPACT study was launched, a critical component of the research was to collect data on how organizations in various industries and countries conduct their corrosion control activities, with emphasis on corrosion management practices and how they fall within an overall organization's management system.

First, a Corrosion Management Practice Model (CMPM) was developed to provide a repeatable framework for assessing the structure, approach, and features that comprise a corrosion management system within an organization. From there, a comprehensive 70-question self-assessment survey was developed that encompassed nine management system domains:

- Policy, including strategy and objectives
- Stakeholder integration
- Organization
- Accountability
- Resources
- Communication
- Corrosion management practice (CMP) integration
- Continuous improvement
- Performance measures

Scores for each of the above practices ranged from 0 to 1, with 0 reflecting no capability and 1 reflecting the highest level of capability based upon the provided answer options. Table 1 provides an example of a survey question and answer set.

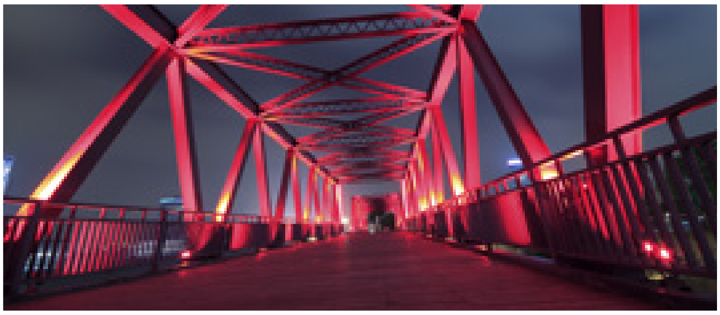
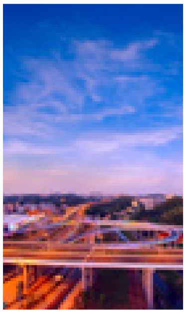




Table 1. Example Survey Question and Answer Set

SURVEY ELEMENT	SURVEY ELEMENT EXAMPLES
Practice from CMPM	The corrosion management strategy is linked to organization strategy.
Survey Question	Is your corrosion management strategy linked to your organization's overall strategy?
Answer Options	a. No b. Yes, but to technical requirements only c. Yes, but to business performance only d. Yes, comprehensively
Scoring	Scoring ranges from "0" Baseline to "1" Best Practice a. 0 b. 0.5 * c. 0.5 * d. 1.0

* *Weighting of intermediate answers can vary depending on the question and options.*

The survey was subsequently conducted in a broad spectrum of industries worldwide that ranged from aerospace and aviation to chemical, petrochemical, oil and gas, and water and waste water. In addition, focus groups of personnel from various management and technical levels were organized in several industries and countries to obtain further insight into their corrosion management philosophies and practices.

Following data collection, the study team performed a series of analyses, two of which included comparisons across geographical regions and industries, and thus derived a set of observations and recommendations that are detailed in the IMPACT report. Figure 3 is a flow chart of how the survey was developed, conducted, and analyzed.

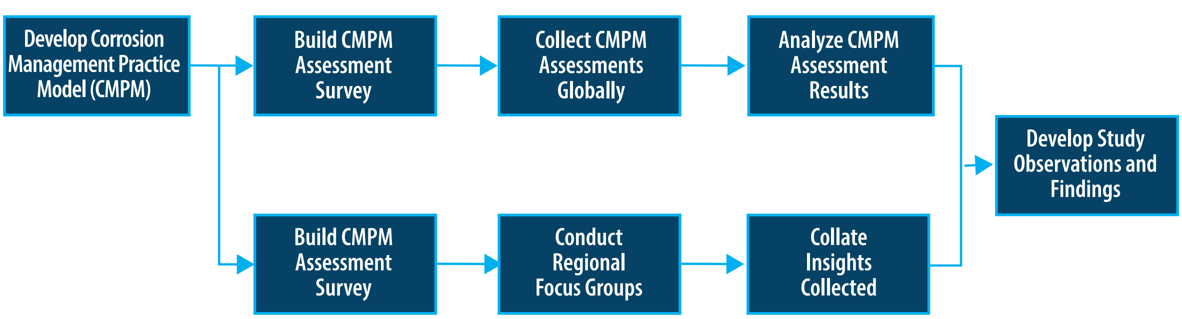
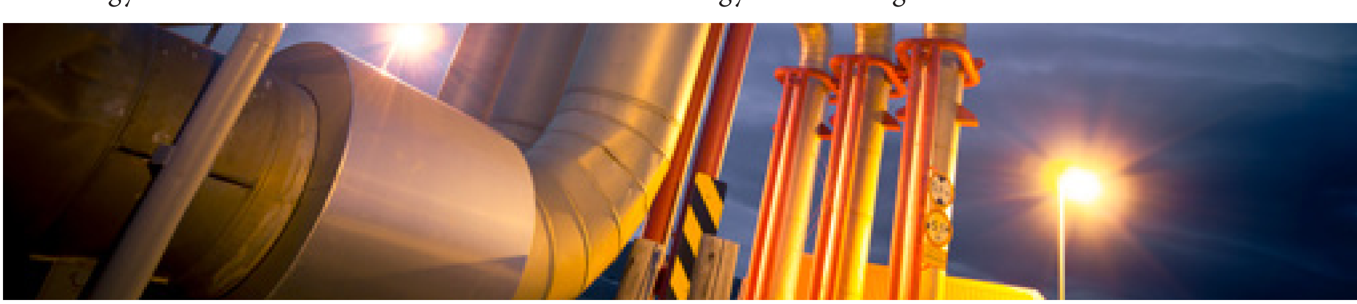


Figure 3. Survey study flow diagram.

A general observation across geographic regions and industries is that companies consistently scored lowest on policy and performance measures, and to some extent stakeholder integration. The researchers explain that corrosion technology currently sits within plans, procedures, and working practices and is not normally incorporated within higher management system domains. A shift toward corrosion management that incorporates technology—the foundation of a CMS—will allow technology to have a higher role.



The IMPACT web site (impact.nace.org) offers the ability for company personnel to take the survey and pull up graphs depicting their corrosion management program results compared to others in their industry, geographic region, or overall. Of particular value would be for personnel at various levels within an organization to take the survey and compare results with one another to identify whether there is alignment or to pinpoint any gaps in their knowledge and approach to corrosion management.

Assessment of Corrosion Management Practices

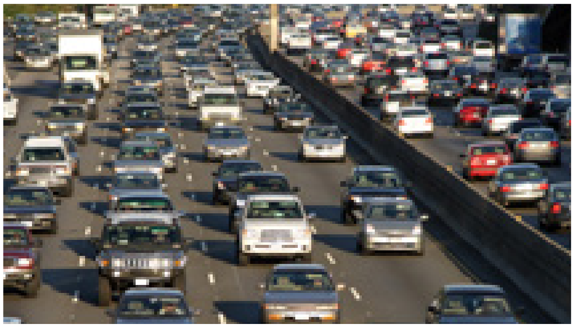
The results of the survey and the focus group discussions with industry subject matter experts (SMEs) demonstrated that corrosion management practices vary significantly based on the type of industry, geography, and organizational culture. These practices range from the absence of corrosion management to full incorporation of a CMS into an organization's management system. Even within the same organization, significant differences can exist, depending on local culture and practices.

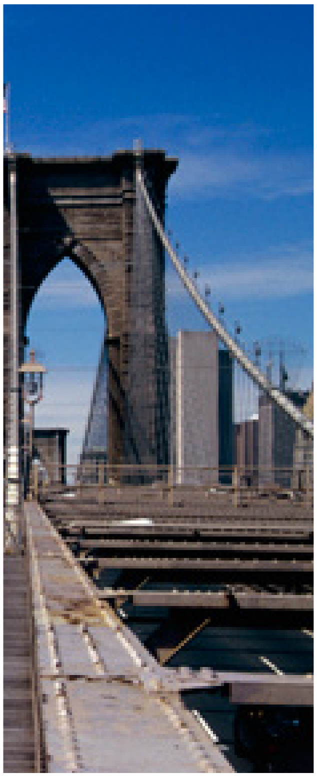
Following a thorough analysis of the survey results, the researchers identified standard and best practices and gaps in corrosion management practices, and provided recommendations of mitigation measures for improvement. In particular the study focused on industries where corrosion has a major impact on safety, the environment, cost of operations, and reputation. These include the oil and gas, pipeline, and drinking and waste water industries. In addition, IMPACT highlights the corrosion management practices within the U.S. Department of Defense (DoD).

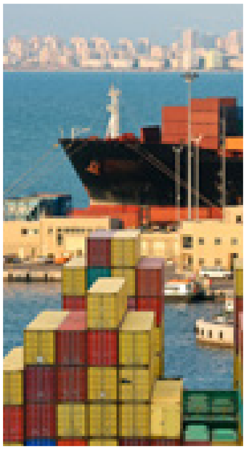
Oil and Gas Industry

The oil and gas industry is capital-intensive, with assets ranging from wells, risers, drilling rigs, and offshore platforms in the upstream segment, to pipelines, liquefied natural gas terminals, and refineries in the midstream and downstream segments. Corrosion is a major cost in the operation of oil and gas facilities and most companies have some sort of corrosion control or management program, the level of which depends on the size, geographic location, and culture of the organization.

The survey captured self-assessment results from both international oil companies (IOCs) and national oil companies (NOCs), as well as those specializing in intermediate and unconventional oil activities in various parts of the world. Figure 4 is a radar diagram benchmarking all NOCs and IOCs that responded to the survey.







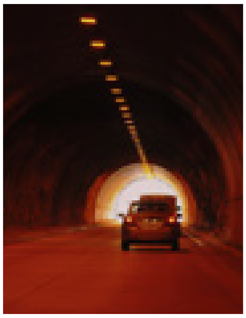


Figure 4. Benchmarking of IOCs and NOCs on the corrosion management system domains.

The diagram reveals similar trends among the IOCs and NOCs, with continuous improvement and communication having the most variation. Overall the report concluded that differences in corrosion management practices within the oil and gas industry could be caused by several factors:

- The scope of the organization
- Strategic national interests
- Differences in corporate philosophy, culture, and risk tolerance
- Effects of local regulations
- Onshore vs. offshore and geographic location
- Financial position

The report includes numerous other benchmarking statistics and comparisons, including by region, as well as specific case studies provided by participating companies.

Pipeline Industry

Within the pipeline industry, it is well known that corrosion is a major contributing factor to pipeline failures because of the corrosive nature of their contents, which include dry gas, wet gas, crude oil with entrained/emulsified water, and processed liquids. Appropriate corrosion control technologies and strict monitoring are required to protect these assets, which should be incorporated into a CMS.

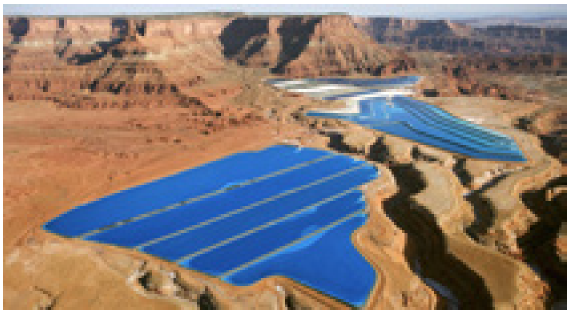
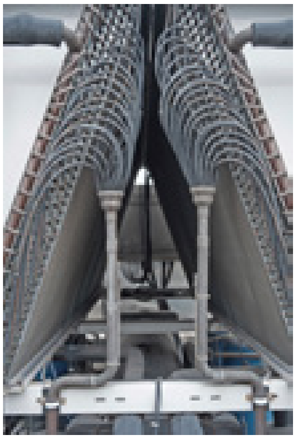
One benchmarking effort focused on selected onshore pipeline operators in the United States, Canada, and India to observe differences in corrosion management for companies that operate under different regulatory environments (Figure 5).

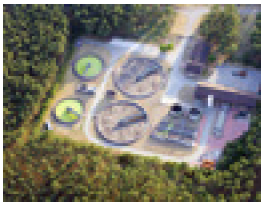
Figure 5. Benchmarking of U.S., Canadian, and Indian onshore pipeline companies.

While the U.S. and Canadian pipeline companies operate under strict national regulations set by the Pipeline and Hazardous Materials Safety Administration (PHMSA) and National Energy Board (NEB), respectively, the Indian companies follow company standards and regulations that are largely based on internal/local standards and recommended practices. In spite of these differences, all three groups show similar scores for the elements of performance measures, CMP integration, and accountability, and show a low score for policy and performance measures. The study concludes that the low scores might indicate an opportunity for improvement by better engaging senior management. The relatively low score for performance measures indicates that there is an inadequate feedback system or related key performance indicators that measure the status and quality of corrosion management.

Drinking and Waste Water Industry

Much of the world's drinking water infrastructure, with millions of miles of pipe, is nearing the end of its useful life. For example, nearly 170,000 public drinking water systems are located across the United States, and there are an estimated 240,000 water main breaks per year, most of which are caused by corrosion. Failures in drinking water infrastructure result in water disruptions, impediments to emergency response, and damage to other types of infrastructure, such as roadways. Unscheduled repair work to address emergency pipe failures may cause additional disruptions to transportation and commerce. In cases where the water does not return to an aquifer, a valuable resource is lost.



In 2012, the American Water Works Association (AWWA) concluded that the aggregate replacement value for more than one million miles (1.6 million km) of pipes was approximately US$2.1 trillion if all pipes were to be replaced at once. Since not all pipes need to be replaced immediately, it is estimated that the most urgent investments could be spread over 25 years at a cost of approximately US$1 trillion.

Capital investment needs for the U.S. waste water and storm water systems are estimated to total US$298 billion over the next 20 years. Pipes represent three quarters of total capital needs.

IMPACT considered a report from the Water Services Association of Australia (WSAA) that records and measures up to 117 indicators from 73 water utilities across the country serving approximately 75% of its population. A number of these indicators were used and examined along with other information to identify costs associated with corrosion, determined according to the following groupings:

- Water loss from pipeline failures
- Intangible costs associated with water and sewer pipe failures and replacement
- Water pipeline corrosion repairs
- Sewage treatment costs due to infiltration
- Capital costs for water and sewer pipeline replacements
- Maintenance and repair of water treatment plants
- Maintenance and repair of other assets such as tanks and pump stations
- Maintenance and repair of sewage treatment plants

Based on the study, the total annual cost in Australia in 2010 was estimated to be US$690 million ± 30%.

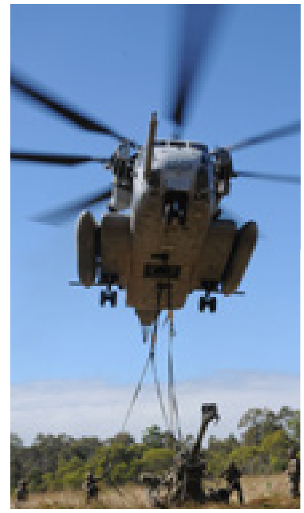
When comparing corrosion management practices of potable water systems in North America and Australia, some significant differences are evident (Figure 6). This radar plot shows distinct differences in continuous improvement, CMP integration, and communication, where the Australian water companies scored significantly higher than the North American water industry. The IMPACT research team found this somewhat surprising considering that the Australian water industry scored low on policy. This suggests that on average the industry has a limited corrosion management policy, which is considered critical to good corrosion management practices. The American water industry appears to have policies, but implementation can be improved.

Figure 6. Comparison of corrosion management practices of potable water systems in Australia and North America.

U.S. Department of Defense

Following the 2002 FHWA cost of corrosion study, the DoD has been in the process of developing and implementing a comprehensive corrosion management program. The 2002 study estimated the cost of corrosion to DoD at approximately US$20 billion, which has been validated through DoD's cost of corrosion analyses. One IMPACT study conclusion is the importance of having top-down support for a CMS, which is epitomized by the DoD's program. The Under Secretary of Defense for Acquisition, Technology and Logistics has been a supporter from the start. The program, which ranges from setting policy to calculating the cost of corrosion of projects, assets, and components, is run by the Corrosion Policy and Oversight (CPO) Office and includes all critical components of a CMS.

The IMPACT report thoroughly covers the strategic plan and organizational structure of the DoD CPO Office and how it is successfully managing corrosion control activities across all of the services. The DoD estimates its composite ROI for protecting assets ranging from vehicles, aircraft, base facilities, and weaponry to be 16:1. An appendix in IMPACT features numerous examples of DoD ROI calculations and the cost of corrosion for projects across all areas.



Corrosion Management Financial Tools

Corrosion management includes all activities that are performed through the lifetime of a structure to prevent corrosion, repair its damage, and replace the asset, such as maintenance, inspection, repair, and removal. These activities are performed at different times during the lifetime of the structure. Some maintenance is a regular activity, characterized by annual cost. Inspections are scheduled as periodic activities, and repair is done as warranted. Rehabilitation may be done once or twice during the lifetime, and the cost is usually high. Applying different corrosion management methods may positively affect the lifetime of a structure of a particular design without increasing the cost.

To meet the corrosion management objectives, tools or methodologies are available to calculate the cost of corrosion over part of an equipment's or asset's lifetime or over the entire life cycle. These methods range from cost-adding to life-cycle costing (LCC) and constraint optimization.

Return on Investment

ROI is a primary performance measure used to evaluate the efficiency of an investment (or project) or to compare the efficiency of a number of different investments. An ROI calculation is used along with other approaches to develop a business case for a given proposal. The complex part of ROI is determining the cost savings and investment costs. To compare investment proposals, ROI must either be annualized or the time over which the ROI is achieved is stated.

Cost-Adding Methodology

This method, which has been developed by the U.S. DoD, calculates the cost of corrosion of an asset or a project by looking from the top down. Programs, projects, and assets are analyzed to determine cost components that are related to corrosion. The top-down corrosion cost assessment removes all cost components that have no corrosion. However, significant gaps can remain that are filled by looking up from the bottom. All corrosion-related expenditures are added and compared with the top-down cost assessment. By comparing the top-down and bottom-up corrosion cost assessment, the DoD has been able to accurately determine direct corrosion costs of a project or asset and to calculate ROI.

Constraint Optimization

A constraint optimization framework is used to determine the optimal corrosion management practice for a specific structure or facility. This method allows application of optimal practices with a fixed or limited available budget. The development of the constraint optimization framework requires three major steps:

1. Optimizing expenditures of the structure
2. Maximizing the service level subject to budget constraints
3. Building a constrained optimization model

Maintenance Optimization

Maintenance optimization calculates the financial benefit of a maintenance action. It allows inspect/repair/replace projects to be justified by financial benefit. When expressed in terms of net present value, scheduling of maintenance projects can also be optimized. One way to monetize corrosion maintenance decisions is through risk, which combines the probability of failure and its consequences, and can be expressed as a cost.

Life-Cycle Costing

LCC is a well-known approach to determine the cost of corrosion of certain assets by examining:

- Capital cost (CAPEX)
- Operating and maintenance cost (OPEX)
- Indirect cost caused by equipment failure
- Material residual value
- Lost use of asset (i.e., opportunity cost)
- Any other indirect cost, such as damage to people, the environment, and structures as a result of failure

The LCC approach makes it possible to compare alternatives by quantifying a long-term outlook and determining the ROI. LCC can be performed by using several costing methods. One method is the cost-adding method discussed above. Other methods include the Bayesian Network approach.

All costing methods are thoroughly described in the IMPACT report, providing valuable assistance and tools to companies for integration into a CMS.

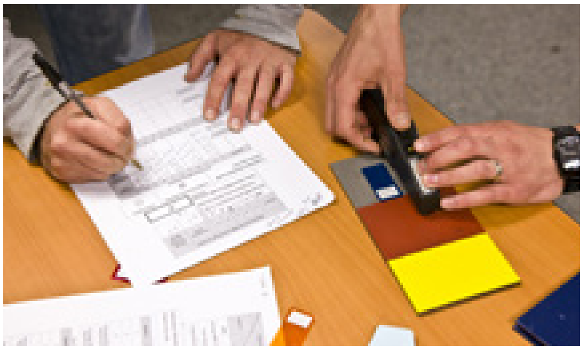
Education and Training

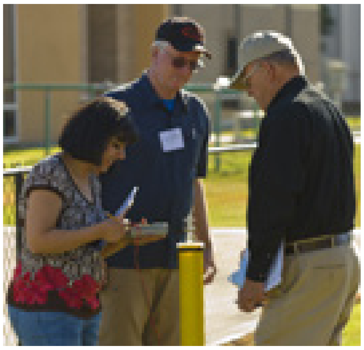
In the next decade a significant transition and turnover in knowledge will occur in the corrosion community. IMPACT cites workforce studies estimating that approximately 25% of the total workforce in the United States is over 50 years old, and the median age of NACE International members is 47. In addition to taking advantage of formal internal and external education and training (E&T) programs, corrosion management systems must have a way to effectively transfer institutional knowledge. Specific on-the-job training and mentoring programs are being used to transfer SME knowledge.

In the university setting, corrosion is multidisciplinary with contributions from materials science, chemistry, and electrochemistry. All deal with the corroding material, the corrosive environment, and the electrochemical reactions at the corroding interface. University faculty teaching corrosion reside in materials science and engineering, chemical engineering, mechanical engineering, chemistry, and others. The University of Akron provides the only bachelor's degree in corrosion engineering in the United States, with the first class graduated in 2015. This program has significant support within the corrosion community and the U.S. DoD, all realizing that a lack of corrosion professionals is going to become a critical barrier to furthering corrosion engineering and corrosion management in the future.

The majority of professional development and vocational training for corrosion professionals is offered by NACE International. More than 16,600 students were trained in 2015 through 840 courses in 40 countries.

From the report it is apparent that the E&T course content is heavily focused on the lower levels of the CMS Pyramid; i.e., Procedures and Working Practices (Figure 2) and there is essentially no content geared for the upper levels of Policy, Strategy, and Objectives. E&T will play an important role in the integration of corrosion management into an organization's management system. In addition, these programs must prepare corrosion professionals to





better communicate to those outside of the profession. Corrosion professionals should not expect outsiders to learn their technical language. In addition, corrosion professional societies must emphasize business strategy and/or public policy when advocating positions to those outside of the corrosion profession. The study states that using the principles of a CMS will make these arguments more persuasive.

Strategies for Successful Corrosion Management

Realizing the maximum benefit in reducing corrosion costs (both direct and consequential) requires more than technology; it requires integrating corrosion decisions and practices within an organizational management system. This is enabled by integrating a CMS within system elements that range from corrosion-specific procedures and practices up through organizational policy and strategy; i.e., all levels of the CMS Pyramid. This figure is central to the IMPACT study goal and is shown throughout the IMPACT report. It is essential that traditional corrosion management procedures and practices (lower levels of the pyramid) be expressed to policy setters and decision makers (higher levels of the pyramid) in the form and terminologies of organizational policies. Simply, the corrosion practices need to be translated into the language of the broader organization. The organization as a whole must commit to ownership of the CMS activities and processes. This means buy-in at all levels.

Table 2 outlines some purposes given for buy-in of a CMS at different levels in an organization. Without buy-in from the top, initiatives have little chance of getting off the ground. To ensure the message is effective, organizations require a business case that includes a clear statement of the problem, outlines its impact on the organization, lists the required resources, and includes the outcome in terms of cost reductions, increased productivity, improved quality, and/or decrease in risk (environmental, safety, business interruption, public relations, etc.).

Table 2. Different Purposes for Buy-In of a CMS

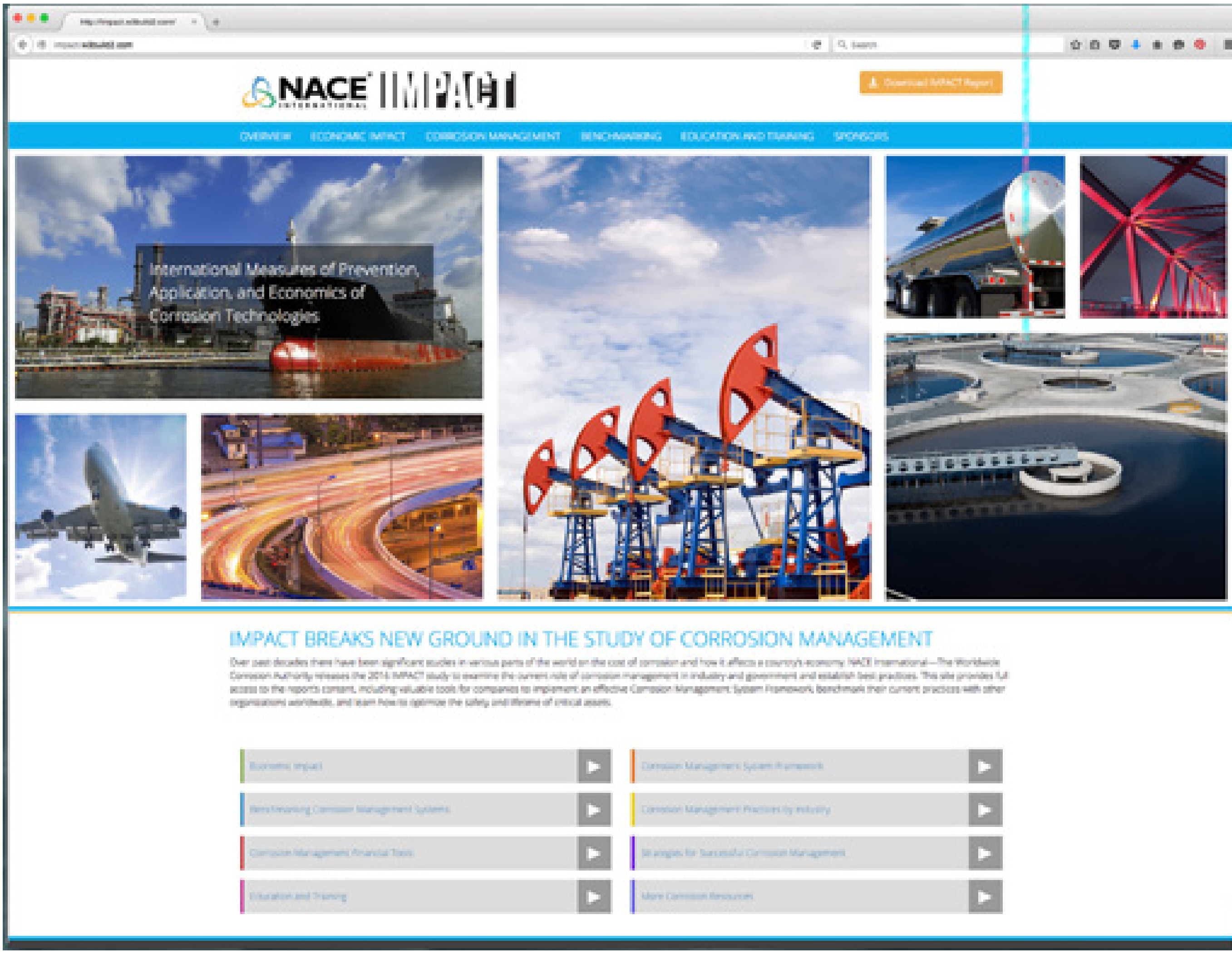
TARGET AUDIENCE	PURPOSES
Senior Management	Gain approval to make the change
	Garner sponsorship and resources
Middle Management	Speed up adoption
	Identify change agents to lead by example
Front-Line Employees	Develop a common understanding of the change
	Ensure widespread adoption and compliance

IMPACT provides tools and examples to help facilitate business communications between corrosion professionals and senior management, leading to integration of a CMS throughout an organization's management system. The U.S. DoD is an excellent example of an organization that affected a cultural change and a commitment to innovation that permitted corrosion management practices to be institutionalized into an entity of its size and diversity. Industries and governments worldwide will benefit by studying and implementing this model of success.

References

1. G.H. Koch, M.P.H. Brongers, N.G. thompson, Y.P. Virmani, J.H. Payer, "Corrosion Costs and Preventive Strategies in the United States," FHWA-RD-01-156 (McLean, VA: FHWA, 2002).
2. G.H. Koch, N.G. Thompson, O. Moghissi, J.H. Payer, J. Varney, "IMPACT (International Measures of Prevention, Application, and Economics of Corrosion Technologies Study," Report No. OAPUS310GKOCH (AP110272) (Houston, TX: NACE International, 2016).

IMPACT Online



The IMPACT web site features access to the full report and other resources.

Visit impact.nace.org to access report content in various sections, including the survey results, the economics of corrosion, the Corrosion System Management Framework, case studies from different countries, useful cost-analysis tools, recommendations on best practices, education and training trends and needs, and more. Companies also have the opportunity to instantly benchmark their own corrosion programs against those of the survey respondents by answering self-assessment questions available on the web site.

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