Proceedings of the Materials Forum 2007: Corrosion Education for the 21st Century

Michael H. Moloney, Editor, Corrosion Education Workshop Organizing Panel, National Research Council

ISBN: 0-309-10894-2, 46 pages, 8 1/2 x 11, (2007)

Proceedings of the Materials Forum 2007

Corrosion Education for the 21st Century

Michael H. Moloney, Editor

CORROSION EDUCATION WORKSHOP ORGANIZING PANEL
NATIONAL MATERIALS ADVISORY BOARD
DIVISION ON ENGINEERING AND PHYSICAL SCIENCES

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by Contract No. HR0011-07-P-0008 between the National Academy of Sciences and the U.S. Department of Defense. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-10893-5
International Standard Book Number-10: 0-309-10893-4

Available in limited quantities from

National Materials Advisory Board
500 Fifth Street, N.W.
Washington, DC 20001
nmab@nas.edu
http://www.nationalacademies.edu/nmab

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

CORROSION EDUCATION WORKSHOP ORGANIZING PANEL

FIONA M. DOYLE, University of California, Berkeley, *Chair*
RALPH ADLER, Army Research Laboratory
RAM DAROLIA, GE Aviation Engines (retired)
GERALD S. FRANKEL, Ohio State University
RONALD M. LATANISION, Exponent, Inc.
DAVID H. ROSE, Quanterion Solutions, Inc.
JOHN R. SCULLY, University of Virginia
MARK L. WEAVER, University of Alabama

Staff

MICHAEL H. MOLONEY, Senior Program Officer
TERI TOROWGOOD, Administrative Coordinator

NATIONAL MATERIALS ADVISORY BOARD

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Paul Citron, Medtronic (retired),
Carol A. Handwerker, Purdue University,
Srdjan Nesic, Ohio University, and
Lyle H. Schwartz, Consultant.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Preface

The U.S. industrial complex and its associated infrastructure are essential to the nation's quality of life, its industrial productivity, international competitiveness, and security. Each component of the infrastructure—such as highways, airports, water supply, waste treatment, energy supply, and power generation—represents a complex system requiring significant investment. Within that infrastructure both the private and government sectors have equipment and facilities that are subject to degradation by corrosion, which significantly reduces the lifetime, reliability, and functionality of structures and equipment, while also threatening human safety. The direct costs of corrosion to the U.S. economy represent 3.2 percent of the gross domestic product (GDP), and the total costs to society can be twice that or greater.[1] Opportunities for savings through improved corrosion control exist in every economic sector.

Better education for the nation's engineers is essential to improving corrosion control and management practices throughout the national infrastructure. In this regard, an assessment of the corrosion curricula of undergraduate engineering schools is timely. With this in mind, the National Research Council (NRC) convened the 2007 Materials Forum on March 30th, 2007 to address corrosion education as it exists today.

The workshop, Corrosion Education for the 21st Century, brought together corrosion specialists, leaders in materials and engineering education, government officials, and other interested parties. The workshop was also attended by members of NRC's Committee on Assessing Corrosion Education,[2] who are carrying out a study on this topic. The workshop panelists and speakers were asked to give their personal perspectives on whether corrosion abatement is adequately addressed in our nation's engineering curricula and, if not, what issues need to be addressed to develop a comprehensive corrosion curriculum in undergraduate engineering. This proceedings consists of extended abstracts from the workshop's speakers that reflect their personal views as presented to the meeting.

I would like to express my sincere appreciation to the members of the Corrosion Education Workshop Organizing Panel for their hard work in preparing for and executing a very valuable workshop. I would also like to thank the speakers, panelists, and participants who attended the workshop for their critical contributions. Finally, I'd like to acknowledge the contributions of the NRC staff members Michael Moloney and Teri Thorowgood, without whom none of the good plans would have come to fruition.

Fiona M. Doyle
Chair

---

[1]See *Corrosion Costs and Preventive Strategies in the United States*, available at <http://www.corrosioncost.com/downloads/pdf/index.htm>. Accessed April 2007.

[2]For more information, see <http://www.nationalacademies.org/corrosioneducation>. Accessed April 2007.

Contents

Session I: Motivation

NEIL THOMPSON
CC TECHNOLOGIES

Corrosion of metallic structures has a significant impact on the U.S. economy. In a congressional study, the total economic impact of corrosion and corrosion control applications was estimated to be $276 billion annually, or 3.1 percent of the U.S. gross domestic product (GDP).[1] Analyses of two key sectors show that indirect (user) costs, sometimes referred to as social costs, can exceed the direct cost by a factor of between 2 and 10.

Cost-of-corrosion studies have been undertaken by several countries; these studies show that corrosion has a major impact on the economies of industrial nations. Table 1 summarizes the costs of corrosion that have been gathered in studies undertaken in several countries since 1949.[1] The total corrosion costs are shown as a percentage of gross national product (GNP) of the respective economies and vary between 1.5 and 5.2 percent. This variation clearly depends on the particular country and economy being examined but also on the method used to conduct the study.

TABLE 1 Corrosion Cost in Selected Nations

Country	Total Annual Cost of Corrosion	Percent of GNP	Year
United States	$5.5 billion	2.1	1949
India	$320 million	–	1960
Finland	$54 million	–	1965
West Germany	$6 billion	3.0	1967
United Kingdom	£1.365 billion[a]	3.5	1970
Japan	$9.2 billion	1.8	1974
United States	$70 billion	4.2	1975
Australia	$2 billion	1.5	1982
Kuwait	$1 billion	5.2	1987
United States	$276 billion	3.1	2002

[a]Not reported in U.S. dollars.

[1]G.H. Koch, M.P.H. Brongers, N.G. Thompson, Y.P. Virmani, and J.H. Payer. *Corrosion Cost and Preventive Strategies in the United States*, Appendix A, FHWA-RD-01-156, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 2002.

The most recent U.S. cost study (normalized to 1998 costs) was performed by CC Technologies Laboratories, Inc., under the auspices of the U.S. Department of Transportation (DOT) through the Transportation Equity Act for the 21st Century in a cooperative effort with the DOT's Federal Highway Administration (FHWA) and the National Association of Corrosion Engineers (NACE) International–The Corrosion Society.[2] In this study, the cost of corrosion was determined for 27 specific industry sectors. Data collection, type of economic analysis, and elements included in the analysis differed significantly from sector to sector, depending on the type and availability of data for each sector. For many of the sectors, the information was public and was obtained from government reports and other public documents. Discussions with industry experts provided the basis for other industry sectors. Corrosion cost information from private industry sectors was often even more difficult to obtain. When available, records on operation, maintenance, and capitalized asset costs provided the basis for estimating the economic impact of corrosion.

The industry sectors selected for corrosion cost analyses represented approximately 25 to 30 percent of the total U.S. economy. The total cost of corrosion was estimated by determining the percentage of the GDP made up by those industry sectors for which direct corrosion costs could be estimated and then extrapolating these numbers to the total U.S. GDP. The direct cost used in this analysis was the cost incurred by owners or operators of the structures, manufacturers of products, and suppliers of services.

Summary of Industry Challenges

Corrosion Awareness in Government and Industry

The cost of corrosion is staggering. The direct costs are equivalent to 3 percent of the GDP, greater than the contribution of agriculture to the GDP. Corrosion is a process that produces waste. By preventing corrosion we are preventing waste; that is, savings that go straight to the bottom line, savings that can be used for new business development and expansion of the economy. An industry-wide effort to implement current technologies and best practices could result in savings of $80 billion annually, with even greater savings as new technologies are brought online.

The Hurdle of Long-Term Investments

Corrosion savings typically do not affect net income in near-term quarterly returns. Often the results of doing nothing or even of cutting current corrosion maintenance costs are not immediately seen. The government and industry must address the issue of incentives for investments in corrosion control that will significantly reduce the long-term costs of corrosion.

Best-Practice Maintenance Program

The best way to impact corrosion costs is through a best-practice maintenance program. Such a program must be initiated and implemented top-down, becoming a part of the culture within a company. Once implemented, the long-term costs of repairs and replacement can be brought under control, the reliability of assets will increase, and information feedback to design and purchasing will optimize the future costs of goods. In many industries employee safety, public safety, and environmental concerns

[2]G.H. Koch, M.P.H. Brongers, N.G. Thompson, Y.P. Virmani, and J.H. Payer. *Corrosion Cost and Preventive Strategies in the United States*, Appendix A, FHWA-RD-01-156, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 2002.

related to corrosion are critical issues related to a specific operation or the transport of products or goods. The related costs are also increasing rapidly, resulting in an even greater focus on operational failures as a means to control these costs.

New and Improved Corrosion Control Practices

New corrosion control, monitoring, maintenance, and construction practices are critical to safe operation and to long-term savings in corrosion-related costs. Funding for new technology and science is often the most challenging because the payoff period is so long. This continues to be one of the greatest hurdles for the corrosion industry. Corrosion scientists and engineers must work together to meet long-term, broad-based industry needs as well as to develop technologies for specific applications. More than ever, there is a need for scientists to reach out to the engineering community to ensure that both practical, applied research and more fundamental research are being carried out.

Preventive Strategies

While corrosion management has improved over the past several decades, the United States is still far from implementing optimal corrosion control practices. There are significant barriers to both the development of advanced technologies for corrosion control and the implementation of those advances. Preventive strategies from the FHWA study on the cost of corrosion included these:

- Increase awareness of the costs of corrosion and the potential for cost savings.
- Correct the misconception that nothing can be done about corrosion.
- Change policies, regulations, standards, and management practices to lessen the costs of corrosion through sound corrosion management.
- Teach staff how to control corrosion.
- Implement advanced design practices for better corrosion management.
- Develop advanced methods to predict lifetimes and assess performance.
- Improve corrosion technology first through research and development, and then through implementation of the new technology.

Incorporating the latest corrosion strategies requires changes in industry management and government policies, as well as advances in science and technology. It is necessary to engage a larger constituency that brings together the primary stakeholders, government and industry leaders, the general public, and consumers. A major challenge is the dissemination of the corrosion awareness and expertise that are currently scattered throughout government and industry organizations. In fact, there is no focal point for the effective development, articulation, and delivery of programs to save the costs associated with corrosion.

DANIEL DUNMIRE
DEPARTMENT OF DEFENSE

Corrosion and its effects are recognized as a major problem throughout the military as well as in the civilian community. While we accept its existence because it is a natural phenomenon, that acceptance does not diminish the fact that corrosion is pervasive, insidious, and costly. And while it is preventable and treatable, it is also misunderstood and often ignored.

We see corrosion in our bridges, vehicles, aircraft, pipelines, structures, and other systems and equipment. It often results from improper material selection, inadequate design, or poor production and assembly practices. Design and production decisions often sacrifice life-cycle cost savings for up-front savings. As a result, most of our corrosion dollars go to the detection, assessment, and treatment of corrosion on fielded systems and infrastructure or to the repair of corrosion-damaged equipment or facilities. We should instead be spending these corrosion dollars on preventing the onset or growth of corrosion by isolating corrosion mechanisms and protecting corrosion-prone materials. But this would require a cadre of corrosion-knowledgeable graduates in science and engineering to undertake the needed corrosion-related research, development, design, and production and to influence decision makers on how best to spend their corrosion dollars.

When Congress read the 2003 Government Accountability Office (GAO) report estimating Department of Defense's (DoD's) annual cost of corrosion at between $10 and $20 billion, they enacted corrosion legislation. The legislation directed DoD to establish a corrosion prevention and mitigation program to develop strategies and take action to reduce the incidence and impact of corrosion. The strategies had to include the sharing of information and the development of a coordinated research and development (R&D) program. DoD responded to the congressional mandate by setting up an organization and policies and documented these in the DoD Corrosion Prevention and Mitigation Strategic Plan.

The organization, policies, and strategies in the Strategic Plan reflect a clear requirement to address corrosion education and training needs. The Working Integrated Product Team (WIPT) for training and certification was one of seven WIPTs established to generate and implement strategies and actions to transcend the traditional approach to fighting corrosion. It recognized that education and training were paramount because decision makers, designers, engineers, and technicians at all levels do not comprehend the serious nature and effects of corrosion. Design trade-offs during system or facility development frequently do not take corrosion into account. In the operational world, because corrosion is considered an inherent element of maintenance, corrosion-related funding usually is not forthcoming. And in academia, if corrosion is taught, it is normally included in related technical or engineering curricula.

It is not hard to understand why DoD supports corrosion education. Implementing a strategy to deal with corrosion depends on having educated scientists and engineers who can design systems and facilities to prevent or retard corrosion and to select appropriate materials, manufacturing processes, and assembly methods. Corrosion scientists and engineers are also needed to develop state-of-the-art inspection, detection, diagnostic, and prognostic technologies and methods; materials protection technologies; and better maintenance and repair techniques. In addition, the broad commercial/industrial community needs corrosion-knowledgeable scientists, engineers, and decision makers to reduce the impact (and cost) of corrosion on our country's infrastructure and its industrial base. It is for these reasons that DoD is helping to fund the Materials Forum 2007 and this associated corrosion education workshop, as well as the NRC study being carried out by the Committee on Assessing Corrosion Education, which will assess corrosion education, provide information and expert support as required, publicize the initiative, and facilitate meetings with academia, industry, and government.

In summary, a crucial part of DoD's overall strategy is focused on corrosion education. DoD recognizes the need to prevent or retard corrosion during design and manufacture, mitigate corrosion effects and improve maintenance when prevention fails, and reduce the tremendous cost of corrosion in terms of dollars, readiness, and safety. DoD is convinced that higher education will play an important role in helping it achieve its objectives.

LEWIS SLOTER
OFFICE OF THE DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

DoD has a longstanding commitment to education and developing the technical workforce of the future. The future DoD force will include scientists and engineers vital to development and delivery of the military systems needed to retain technical superiority. DoD has several highly focused programs that support the development of the future technical workforce. Under the National Defense Education Program, DoD sponsors initiatives that encourage, stimulate, support, and educate the students that are vital to our future workforce. The Science, Mathematics, and Research for Transformation Defense Scholarship Program competitively awards scholarships and fellowships to U.S. citizens in defense-critical Science and Engineering (S&E) disciplines. Scholars are obligated to work 1 year at DoD in return for each year of scholarship support received. The National Security Science and Engineering Faculty Fellows creates an attractive, competitive award program for outstanding, clearable university faculty scientists and engineers that is long enough to produce solid research results. Pre-engineering curricula modules are practical middle school and high school curriculum enhancements that tie physical science and mathematics concepts to real-world applications and increase students' interest in science and engineering, stress the value of college preparatory high school courses, and make college-bound students better prepared to succeed in science and engineering. The Materials World Modules program is an important part of this initiative.

Corrosion is an especially important and interesting subject for discussion and exploration and warrants inclusion in general and higher education. Most engineers will be called upon to make design and materials selection decisions that will impact the environmental performance of products and systems. DoD recognizes that intelligent choices early in design and development can have a positive impact on environmental performance and the ultimate cost-effectiveness of systems. Choices and actions over the lifetime of a system, ranging from the scheduling of maintenance and the repair or replacement of coatings, to the application of new technology, also impact the longevity, affordability, and overall fitness-for-purpose of systems. Giving engineers and program managers the educational and experiential tools to make intelligent choices are important issues for us today.

The challenge in engineering education continues and in all likelihood always will be balancing valuable didactic breadth with specialized disciplinary depth. Although there is a critical place for the specially educated corrosion scientist and engineer, the pervasiveness of corrosion suggests that general knowledge and a framework for understanding corrosion mechanisms and consequences are important for most engineers and scientists. For illustration, let us consider four aspects of corrosion prevention and mitigation that have proven useful in discussions related to defense systems:

- First, *prevent.* The prevention of corrosion requires an understanding of both materials and protective schemes and the environment of operation, especially the corrosivity of that environment. Many subtle factors are important when considering environmental interactions, including the weather; the chemistry of the environment and interfaces; and mechanical interactions at the macro scale like abrasion and the micro scale like corrosion fatigue. The probable performance of materials and the necessary mitigation schemes, such as coatings and application of corrosion prevention compounds, need to be part of the earliest design process and system choices.
- Second, *assess*. Corrosion prevention requires constant vigilance and ever improved tools for evaluation. Not surprisingly, the earlier corrosion is detected, the better in terms of taking remedial action in a deliberate rather than an emergency way. Some understanding of the progress of corrosion and the tools available to the field engineer or artisan is important.
- Third, *predict.* Elegant science and practical engineering come together in the area of prediction. Corrosion by its very nature is both environment- and time-dependent, often very complexly so. Great progress has been made in our ability to predict the probable progress of

corrosion, especially when tracking sensors can be included in the assessment. Nevertheless, prediction remains very much an area for the corrosion specialist. The important inclusion in education would appear to be an awareness of the techniques available and their capability and applicability.

- Fourth, *manage.* The affordable control of corrosion comes together in management—both technical management and systems engineering management. It is important that all engineers have a grasp of the implications of decisions for good or ill in corrosion management. The DoD Corrosion Initiative places great emphasis on improving the specificity and efficiency of continuing education for program managers to impart an appreciation for the intelligent integration of corrosion mitigation and control in the overall area of systems engineering and systems management.

Specifically to address corrosion management, corrosion content was added to selected Defense Acquisition University (DAU) courses for program managers, acquisition logisticians, systems engineers, facility engineers, and contracting personnel. In addition, the Corrosion Initiative affected the development of a completely new DAU Continuous Learning Module (CLM) on corrosion. The corrosion prevention and control overview (CP&CO) CLM supplements classroom education with additional corrosion information for those students most likely to influence corrosion-related acquisition decisions or practitioners who must implement corrosion-prevention initiatives. The distance learning module consists of these six modules that students can self-navigate to cover specific subject areas:

- Introduction to corrosion;
- Planning, implementation, and management;
- Corrosion characteristics, effects, and treatment;
- Preventing corrosion;
- Controlling corrosion; and
- Nonmetallic material degradation.

Two additional DAU CLM courses are planned: (1) corrosion prevention and control management and (2) corrosion prevention and control leadership. The three courses will, when fully developed, consist of an escalating level of comprehension from awareness to comprehension and, finally, application. This overall program will give DoD's acquisition community the knowledge necessary to fully consider corrosion when making acquisition decisions.

It is hoped that this program will assist in the discussion of the appropriate level of corrosion information and instruction associated with engineering curricula. The DoD Corrosion Initiative and the participants in all the activities of the CP&CO integrated products team are reaching out to managers, engineers, logisticians, artisans, and anyone who can assist in the perennial battle against corrosion to impart better understanding and provide the tools to make a difference.

AZIZ I. ASPHAHANI AND HELENA SEELINGER
NACE FOUNDATION

Materials are essential to daily living and to our quality of life. The degradation of materials owing to corrosion is a critical issue for many industrial sectors and governmental entities. Such degradation is of great concern as it endangers public and personnel safety, hampers environmental protection, and negatively impacts cost effectiveness and competitiveness.

Despite the high cost (direct and indirect) of materials degradation and the threats of corrosion, many entities involved in corrosion protection and prevention rely on personnel with less-than-desired proficiency in corrosion in their formal education. Also, various U.S. industrial companies do not have corrosion engineers in residence. This is the result of cost-cutting (through layoffs and early retirement) coupled with an overall reduction in the number of college engineering degrees awarded, along with a paucity of corrosion courses in many engineering curricula. Furthermore, it is often difficult to find operators, technicians, and maintenance personnel who have been adequately trained in corrosion control.

A survey by the National Association of Corrosion Engineers (NACE) of its U.S. members in March 2007 reports as follows:

- Over one-half (~54 percent) of corrosion protection practitioners have not taken a course on corrosion during their formal education.
- A large number (~44 percent) of these practitioners began employment at the technician level, before moving into the field of corrosion control.
- A large number (~45 percent) of the active corrosion technologists plan to retire or move to another position in the next 10 years.
- About one-half of the respondents think his or her position will be filled by someone with similar credentials/experience.
- When asked about the future educational requirements, a large number (~43 percent) of respondents stated that their companies demand a 4-year technical degree for the position.

From the last response and from the huge identified costs of corrosion, there is apparently a dire need to establish a curriculum for corrosion engineering at the university or college level. Also, it appears equally important to offer corrosion courses and corrosion control training to operators and technicians.

In addition, there is a need to heighten awareness of the devastating impact of corrosion and to interest students in pursuing education in corrosion science and engineering. Professional engineering societies such as NACE have been providing training and certification to practitioners of corrosion control, along with getting high school students (and their teachers) interested in corrosion engineering. Interest is being raised through participation in the Materials Camp programs sponsored by the American Society of Materials (ASM) Foundation. The camps are succeeding not only because materials are able to whet students' interest in science classes but also because the Materials Camp experience includes interactions with outstanding engineers, who are effective role models for these students.

While great benefits are expected to be realized from a focused effort to improve corrosion education in the workforce, there is continuing concern about how to create demand on the part of employers for corrosion technologists. There is a correspondingly urgent need to connect corrosion education with metrics related to the ongoing major concerns of industry and governmental entities about safety, security, the environment, and overall competitiveness and cost effectiveness. Finally, collaboration and constructive interaction are needed between universities, colleges, schools, industries, and state/federal governmental agencies on the subject of corrosion education.

Session II: Current Practice— The Teaching of Corrosion at Colleges and Universities

DAVID H. ROSE
QUANTERION SOLUTIONS

An informal study assessing corrosion education within engineering curricula at our nation's institutions of higher learning was conducted in 2004 by the Advanced Materials and Processes Technology Information Analysis Center (AMPTIAC), an information analysis center (IAC) sponsored by the Defense Technical Information Center. The results from that initial study were then employed by another DoD-sponsored IAC, the Reliability Information Analysis Center, to continue the analysis.

The informal AMPTIAC study was designed to support DoD's emerging interest in corrosion by investigating whether inadequate coverage in undergraduate engineering curricula could be partly responsible for the current problem. The focus was on undergraduate education since most engineers responsible for developing, producing, and sustaining products do not seek advanced degrees.

When the study was complete, the presenter co-authored a white paper,[1] which DoD submitted to the Senate Armed Services Committee. That paper described the findings from AMPTIAC's study and articulated the view that insufficient subject-matter knowledge and focus within engineering curricula lead to inadequate consideration of corrosion prevention and control during design. Without proper up-front design analyses, unanticipated and costly corrosion problems are far more likely to occur over a product's life cycle than would otherwise be the case. In direct response to the congressional interest that was generated by the white paper, DoD's Office of Corrosion Policy and Oversight sponsored the workshop and its outcome, the upcoming NRC study being carried out by the Committee on Assessing Corrosion Education.

Corrosion Content in Undergraduate Curriculums

Using *U.S. News & World Report*'s 2004 listing of top engineering schools as a guide, the curricula of 20 engineering schools were examined as part of the AMPTIAC study. These schools included the top 10 Ph.D.-granting universities and the top 10 4-year colleges. The universities included the Massachusetts Institute of Technology, Stanford, University of California, Berkeley, the California Institute of Technology, the Georgia Institute of Technology, the University of Illinois, the University of Michigan, Carnegie Mellon University, Cornell University, and Purdue University. The 4-year engineering schools included Embry-Riddle University, the U.S. Air Force Academy, St. Louis University's Parks College, the U.S. Naval Academy, the Rose-Hulman Institute of Technology, Cooper Union, Bucknell University, the U.S. Military Academy, Cal Poly-San Luis Obispo, and Harvey Mudd College.

Two different courses of study were examined: materials engineering and mechanical engineering. Materials engineering was examined for its obvious focus on the development and behavior of materials. While design engineering encompasses many different specialties, resource limitations precluded an analysis

[1] D.H. Rose and S. Firstman. 2004. *Corrosion Prevention and Control for Defense Assets: A Whitepaper.* Alion Science and Technology Corporation.

of all of them. For this reason, mechanical engineering was selected to be representative of the design engineering community.

Design engineering was included in the study because corrosion problems can often be traced back to decisions made during materials selection, a process routinely conducted by designers. Some industries such as aerospace, chemical processing, and oil production have active corrosion prevention and control programs that start early in the design process. Because of cost, safety, reliability, warranty, or product liability concerns; these industries have rigorous procedures embedded within their materials selection processes that are designed to ensure up-front consideration of corrosion. However, this is not the case for most industries and applications. It is the author's belief that neglecting corrosion considerations during materials selection is the root cause of many problems currently seen.

A number of factors were investigated. These included whether the curricula included courses on materials selection and/or corrosion, whether corrosion was taught as part of another course, and if it was taught, whether it addressed both the mechanisms of corrosion and the processes for selecting corrosion-resistant materials and related protective technologies such as coatings.

Only 1 of the 20 mechanical engineering departments examined under this study, that at the U.S. Naval Academy, required a materials selection course. Three schools required a corrosion course: the U.S. Air Force Academy, the U.S. Naval Academy, and St. Louis University's Parks College. These results seem to indicate that the U.S. military has taken some steps to increase its future graduates' awareness of corrosion. Six of the schools studied taught corrosion as part of another required course, but only 3 of them taught the subject from the perspective of materials selection. The other 3 schools focused on the mechanisms of corrosion. It is the author's belief that focusing on the mechanisms alone has limited value if no attempt is made to also teach what should be considered when selecting materials and associated coatings, platings, surface treatments, or other corrosion preventative technologies.

Of the 20 schools examined in this study, only 2 had materials engineering departments that required a materials selection course, and only 1 required a course on corrosion. Five departments taught it as part of another required course and 3 taught it from the standpoint of materials selection.

Conclusions

The purpose of the informal AMPTIAC study was to determine the content and focus of corrosion education at our nation's top engineering schools. It was based entirely on an examination of online resources, so it is possible that some factors pertaining to specific programs were overlooked. Nonetheless, it seems reasonable to conclude that, overall, corrosion receives little attention in current engineering curricula.

The cost of corrosion can be significantly reduced, but only if a unified approach to corrosion education is developed and implemented. Doing this will first require identifying the stakeholders in corrosion and the role they play in product life cycle. Designers, materials engineers, and corrosion specialists are certainly part of this stakeholder community, but so too are the maintainers, system operators, buyers, and supporting technical specialists, including those responsible for reliability, manufacturing, and systems engineering. Just improving materials engineering curricula or focusing efforts on narrow constituencies will do little to reduce corrosion costs if there is no complementary effort to educate the other stakeholders as well.

A "unified approach" does not mean that all engineers must become corrosion specialists. Rather, what is needed is to develop a culture of corrosion-savvy engineers who correctly employ corrosion control technologies and, when appropriate, engage corrosion specialists. Design and other engineers could be taught using a modular approach, where bits and pieces of corrosion knowledge are taught over several subject areas so that when the students graduate, they possess the level of understanding needed to put corrosion prevention and control technologies to work at the appropriate points in a product's life cycle. If successful, this approach will transform current practice so that corrosion prevention and control is built in, which will reduce the cost of corrosion across the board.

GERALD S. FRANKEL
FONTANA CORROSION CENTER, OHIO STATE UNIVERSITY

The Fontana Corrosion Center (FCC) at Ohio State University (OSU) has a long tradition in corrosion education. Mars Fontana was active at OSU starting in the 1940s. He might be considered the "father of corrosion engineering" because he was one of the first to apply the scientific principles being developed in the middle of the past century to practical engineering problems. He formalized the different kinds of corrosion, a critical step in the understanding of corrosion phenomena, and wrote the book *Corrosion Engineering*. This book and its later edition, with sections on the electrochemistry of corrosion added by N.D. Greene, were used around the world for decades to train corrosion engineers. The corrosion curriculum at OSU in the laboratory now named for Fontana follows this tradition. The FCC resides in the Department of Materials Science and Engineering (MSE), in which students are working toward B.S., M.S., or Ph.D. degrees. Degrees are not offered specifically in corrosion science or engineering, however, and corrosion courses must fit into the broader degree curricula.

Currently three courses in corrosion are offered by MSE: a senior undergraduate course, a general graduate course, and an advanced graduate course. The undergraduate course is required for undergraduate students specializing in metallurgical materials and biomaterials, and is a technical elective for MSE students with other specializations. Approximately 75 percent of MSE undergrads take the course. Each year a few students from other departments, primarily welding engineering, take the course, but students from mechanical and chemical engineering do not. The course involves both lectures and weekly laboratories. The goal is to provide the students with a basis for understanding corrosion, tools for measuring the corrosion rate, some knowledge of common corrosion phenomena, and a foundation for selecting materials based on their resistance to corrosion.

The graduate-level course is intended for any graduate student in MSE, and about 50 percent of the grad students take it. There is no weekly lab, but one lab session is arranged to give the students experience in a range of electrochemical corrosion measurement techniques. This course provides much more detailed fundamental information about electrochemistry and electrochemical kinetics than the undergraduate class. The phenomenological aspects of corrosion are also discussed in more detail. This course is offered for distance learning by students living far away. The lectures are recorded using a tablet PC and made available for asynchronous viewing.

The advanced graduate-level material is targeted at graduate students doing research in corrosion. The goal is to provide advanced theories of specific corrosion phenomena and promote critical reading and independent analytical skills. Student participation in discussions is promoted using a range of pedagogical techniques, and students are assessed in large part on such participation.

FCC faculty members are also very involved in a short introductory course on corrosion offered every year for professionals at Penn State University, and the center also periodically offers an advanced-level short course for professionals.

Two other universities with corrosion programs should be mentioned. The Center for Electrochemical Science and Engineering in the Department of Materials Science and Engineering at the University of Virginia (UVA) has a strong program in corrosion. Its course offerings and educational philosophy are similar to those at OSU. Because there is no undergraduate program in MSE at UVA, its undergraduate corrosion course is taken by students from a range of other departments. The University of Manchester in the United Kingdom offers an M.Sc. degree in corrosion control engineering. The 1-year program consists of nine taught courses and a research dissertation. The course offerings are more comprehensive than what is available at any U.S. institution.

MATT BEGLEY
DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
UNIVERSITY OF VIRGINIA

This talk will review common practices in the undergraduate education of mechanical engineers and attempt to answer two central questions: (1) How are materials concepts integrated into the mechanical engineering curricula? and (2) Do materials topics cover corrosion? It will also attempt to identify best practices and to compare examples that represent the normal way of covering corrosion in a curriculum with examples that represent the most rigorous coverage.

A preliminary study of a diverse range of programs shows that the most common practice is to cover materials-related topics in two courses: (1) a typically mandatory "properties of materials" survey course and (2) a design-oriented course on fracture and fatigue, which if not always mandatory is in any case a very popular elective. These courses typically cover corrosion in a cursory manner, not in any detail. To complement these two most common courses, a number of institutions offer materials electives that either (1) cover materials from a broader perspective that has a less "constitutive behavior" emphasis than specialized courses in mechanical engineering or (2) are specifically focused on corrosion. Judging from the admittedly limited survey, MSE-oriented courses are popular electives for mechanical engineers, although not many students are enrolled in specialized corrosion courses, possibly due to the infrequency of their offering.

In a tangential way, a limited number of materials-related issues are raised in other courses related to design and fabrication. An emerging trend appears to be integration of the topic "materials selection in design" into a survey course. Another way is keeping it as an independent elective for students in the "solids track" of mechanical engineering. This is often done using the material selection maps pioneered by M.F. Ashby. This approach (that is, Ashby's text) addresses corrosion in a qualitative way; there does not appear to be a quantitative framework for materials selection. Nevertheless this trend may represent the best opportunity to integrate corrosion education with design.

With regard to the content of usually mandatory survey courses designed to familiarize mechanical engineering studies with materials science, corrosion is not commonly addressed. The reason appears to be the breadth of materials science and the limited number of course hours into which an increasingly broad curriculum must be fitted. Two compounding factors are (1) such courses are typically taught by faculty with expertise in mechanical behavior as it pertains to failure and design—that is, faculty with limited exposure to corrosion, and (2) the chosen text has treated corrosion in a rather limited way or not at all. The next section reviews a half-dozen or so commonly used texts in terms of their corrosion content.

Typical Texts Used in Materials Survey Courses for Mechanical Engineers

The following texts are listed in order of corrosion content, from most to least:

- J.P. Schaffer, A. Saxena, S.D. Antolovich, T.H. Sanders, and S.B. Warner. 1999. *The Science and Design of Engineering Materials*, 2nd ed. WCB/McGraw-Hill, "Materials–environment interactions," pp. 614-661. Seems like an excellent introduction to the fundamental mechanisms. Aside from one table summarizing polymer resistance to inorganics (bad, good, excellent), nothing on materials selection. Direct dissolution mechanisms, electrochemical corrosion-half-cell potentials, kinetics of corrosion reactions, types of corrosion (e.g., uniform, galvanic, pit/crevice, H-embrittlement, stress-assisted corrosion), gas-solid interactions, friction–wear, radiation damage.
- L.H. Van Vlack. 1982. *Materials for Engineering: Concepts and Applications.* Addison-Wesley Publishing Company, "Materials in hostile environments," pp. 428-462. Very broad and descriptive coverage of basic corrosion concepts. Corrosion reactions, polarization, passivation,

stress corrosion, corrosion control (protective surfaces, cathodic protection, avoidance of galvanic cells, stainless steels). Concludes with high-temperature mechanisms (creep, oxidation, decarburization), refractory metals, materials at subnormal temperatures.

- C.R. Barrett, W.D. Nix, and A.S. Tetelman. 1973. *The Principles of Engineering Materials.* Prentice Hall, "Environmental degradation of materials," pp. 179-189. Brief introduction to chemical mechanisms of corrosion and corrosion-related effects on materials. What it lacks in depth it makes up for in conciseness and accessibility at the undergraduate level. Topics: polymeric materials, metallic oxidation, metallic corrosion (electrode potentials, galvanic series).
- M. Ashby and D.R.H. Jones. 1996. *Engineering Materials I*, 2nd ed. Butterworth-Heineman, Part F: "Oxidation and corrosion." Includes section on oxidation of materials and case studies in dry oxidation and in wet corrosion.
- J. Shigley and C. Mischke. 1989. *Mechanical Engineering Design*, 5th ed. McGraw-Hill. One-paragraph discussion of corrosion effects on endurance limits.
- D.R. Askeland and P.P. Phule. 2004. *Essentials of Materials Science and Engineering*. Thomson Publishing. One paragraph.

ROBERT SCHAFRIK
GE AVIATION

Corrosion is a key degradation mode that can occur in jet engines. It is rarely the primary cause of failure for a structural component, but it can accelerate other failure modes, such as fatigue. The corrosion process of interest varies considerably depending on the environmental conditions, such as temperature. At the lower temperature end, aqueous corrosion can manifest itself as galvanic corrosion, stress corrosion cracking, etc. Above 590ºC (1100ºF), hot corrosion can occur by means of deposits (salt, debris, upstream engine products, etc.) that electrochemically react with substrate materials.

Because corrosion can lead to high maintenance and repair costs, GE Aviation has developed design practices and procedures to apply the large knowledge base from test data and past results to guide the design and selection of materials to avoid corrosion-induced failures. Materials application engineers make the final selection of the materials, which can include coatings. A team of senior design and materials experts reviews these selections when they involve major components. While past experience guides new designs, there is imperfect knowledge of the environment that will be experienced by new engines or by new engine users. For instance, there are differences in the ways airlines operate their engines that affect temperature gradients in those engines; in the locations where airplanes are based; and in the chemistry of the fuel used. All of these factors and others add uncertainty to analyses regarding the potential for corrosion.

Undergraduate courses in materials, mechanical engineering, and chemical engineering generally touch only briefly on corrosion, and mostly on aqueous corrosion at that. A few universities have faculty members with expertise in hot corrosion who incorporate that topic into their course material. But it has been our experience at GE that undergraduate courses typically contain few practical examples of corrosion, and students have little hands-on experience with it (hot corrosion particularly) until their first job. Furthermore, we rarely find new graduates who have a real understanding of corrosion.

GE Aviation uses its experts to teach a number of technical courses to new engineers. Corrosion is covered in these courses, primarily from a heuristics viewpoint. The courses are open to all engineers and mandatory for all new materials engineers. They are relatively popular, and many design engineers have taken them:

- There are several sessions on corrosion in the failure analysis course. It uses real-world examples, and it contains broad guidelines for avoiding corrosion in its introduction to design practices.
- The superalloy course offers a rationale for the chemistry of the alloys that GE uses and teaches GE's experience in alloying to minimize corrosion.
- The coatings course goes into great detail on the mechanisms of hot corrosion, with many examples of what has occurred and how the problem was mitigated.

GE addresses these critical tasks in designing and supporting its hardware:

- Design to avoid corrosion,
- Recognize corrosion in fielded hardware when it occurs, and
- Develop and qualify improved field actions and design changes to mitigate corrosion.

Material application engineers use their experience and design practice guidelines to select materials that will avoid corrosion. Senior engineers with the department who are experts in corrosion provide advice and guidance to new engineers. This approach works particularly well when the design conditions resemble past experience. When conditions are dissimilar, estimating the potential for corrosion can be challenging. Models that can quantitatively predict hot corrosion performance of materials under severe environmental conditions would be quite useful.

The recognition of corrosion once it occurs in field hardware is generally excellent. A knowledge base that would support the accurate prediction of the effectiveness of various mitigation strategies is a significant need. Similarly, qualifying a design change is also a challenge since accelerated laboratory tests for hot corrosion do not correspond directly to field conditions, so that qualifying design changes can become an expensive, lengthy trial-and-error process.

The ideal situation would be for a few universities to have well-funded research programs that extend the fundamental knowledge surrounding aqueous and hot corrosion. The faculty could then incorporate this knowledge into its materials curriculum. In any event, more attention should be devoted to the teaching of corrosion fundamentals, including hot corrosion, in the undergraduate curriculum. The teaching would be done not only in specialized courses but also in the context of materials courses that teach other mechanisms that degrade materials, such as fatigue and creep.

RAMESH SHARMA
RAYTHEON MISSILE SYSTEMS

During the design phase there is always the pressure of schedule and of cost to design. Designers must only prove that a concept works; life-cycle costs are of little concern for many of them. Even good designers can have limited exposure to the optimum selection of materials. Consideration of corrosion during the design phase is rare in a number of industries, and some design engineers are not even aware of corrosion. Perhaps there are several reasons for that.

Several universities do not offer any corrosion classes for design engineers, leaving them little or no chance of learning anything about corrosion during their college education. The few who had an opportunity to attend a corrosion course may have learned only about what was relevant to their teacher's work in research and theoretical fields.

Industry does not always have experts at hand who can help a design engineer to plan for corrosion, resulting in little chance for them to learn about it during their working life. Corrosion education is not considered "jazzy" and often does not feature in a corporation's work plan. Add to this the fact that many times a company's corrosion expert may have had no formal training in corrosion science and engineering—for example, a chemist may accidentally become a corrosion expert. Notwithstanding those in industry who have become highly qualified technical professionals through a process of lifelong learning, it remains that many in industry and elsewhere do not know what they do not know.

Those who are exposed to some practical aspects of corrosion and design guidelines for managing corrosion come to realize corrosion's significance. Typically they say "I didn't know corrosion could be that significant" or "Why don't the universities teach corrosion to design engineers?"

Once in a while corrosion becomes evident during testing and failure analyses. The cost of redesign efforts is not well documented, nor is the full impact of losses due to corrosion known. For a design engineer to benefit from information about managing corrosion, the information must be simple, easy to understand, and precise.

Lunch Talk

LUIS M. PROENZA
UNIVERSITY OF AKRON

The Challenge of Change in a Change-Resistant Environment

Rapid and dramatic change is transforming traditional business paradigms in both industry and academia. Indeed, the primacy that America has long enjoyed is being challenged by the same forces of technological innovation that America itself unleashed. Just as staying on the leading edge of technology and fostering a culture of adaptability are critically important to the future of industry, universities are faced with similar challenges but have been slow to adapt. In this dynamic environment, universities are increasingly called upon to respond to market-driven needs for educational programs and to adopt an industry-like approach to just-in-time delivery of those products. This type of change will not come easily, however. Those institutions that can foster an environment of innovation and adaptation can be successful in not only capturing niche markets but also by serving as a catalyst for sustaining and growing an industry sector. Highlighting the University of Akron's Corrosion Education Initiative, an overview will be presented on how universities can deliver the human resources of intellectual capital by providing the research and educational programs necessary to keep pace with nontraditional program development opportunities.

Session III: Implementation

GEORGE E. DIETER
UNIVERSITY OF MARYLAND

A case has been made that engineering students, particularly those in design-intensive disciplines such as mechanical, civil, and aerospace engineering, need a better understanding of corrosion and how it can be mitigated through design and other prevention measures. These remarks will focus on mechanical engineering, where the speaker has been teaching design courses for the past 10 years.

ABET requires that all undergraduate engineering students take a capstone design course before graduating. The course should teach students to use the concepts of engineering science and the growing body of knowledge in systematic design to create a design that addresses a need of society. In addition, many engineering students take a design course in their first year. Also, most mechanical engineering programs devote two semesters to a design course, often back to back in the senior year or as a preliminary course in the junior year and a capstone project in the senior year.

Essentially all engineering students take a course in the fundamentals of materials science. All textbooks include a chapter on corrosion, typically 30 to 40 pages, but devote very little space to the design aspects of corrosion. Mechanical engineering texts that deal with the design process ignore corrosion, as they do most other aspects of materials and manufacturing. A few texts on the design of machine components (machine design) have a few pages on corrosion but say little about design against corrosion. It is clear that the designers need information on corrosion that is not readily available to them.

Are Research-Intensive Engineering Schools Able to Do the Job?

More than half the bachelor's degrees in engineering in the United States are granted by the 50 or so engineering schools that have sponsored research expenditures of more than $50 million a year and where research-related issues generally prevail over educational/curricular issues. This has a number of consequences:

- Deciding who to hire is usually based on the research skills a candidate would bring to the department.
- Estimates of a candidate's potential to attract funding in his or her area of research are a strong factor in deciding who to hire.
- Industry experience is discounted.
- New hires negotiate for the lowest possible teaching load.
- Often the most qualified faculty are the busiest and cannot be persuaded to develop a new course outside their direct area of research interest.

Venues for Teaching Design for Corrosion to Undergraduates

There are a number of courses in undergraduate engineering curricula that could include a focus on design-for-corrosion:

- *Fundamentals of materials*. In a one-semester course, most instructors devote no more than 2 hours to corrosion. This might be doubled to 4 hours if design emphasis is added. Since the course is usually taken in the sophomore year or the first half of the junior year, it would often be before the student had taken a real design course or had enough experience to appreciate the corrosion problem. Moreover, mechanical engineering students typically dislike chemistry (that is why they are mechanical engineering students).
- *Design*. All engineering disciplines require design courses, usually taught late in the junior and senior years. Mechanical engineering has developed a generalized approach to design, with emphasis on a stylized design process consisting of conceptual design, embodiment design, and detail design. The emphasis is on teaching methods to define a problem—such as quality function deployment—concept generation methods, and decision making and evaluation techniques. Rarely is anything about materials, failure, or manufacturing taught in these courses, because these topics are assumed to have been covered elsewhere in the curriculum. Because so many other topics are already neglected, it is unlikely that instructors in these courses would give priority to teaching design for corrosion.
- *Design of machine components (machine design)*. Not all mechanical engineering departments require the traditional machine design course, which typically comes after the students have completed the mechanics of materials. Other mechanical engineering departments offer this as an elective. A machine design course extends the analysis of stress and strain to more complex component geometries, such as gears and bearings, and types of loading, such as fatigue and brittle fracture. However, fewer than half of the machine design texts examined by this speaker even mention the word “corrosion,” yet alone talk about how to design for its prevention. The range of traditional topics covered in this field is so large that I think it would be difficult to get instructors to introduce even a modicum of design for corrosion.
- *Technical electives*. Most engineering departments offer their students the opportunity to take from three to eight technical electives. Often they encourage their students to build a minor by the proper selection of elective courses. This would seem to be the ideal place in a curriculum to offer an in-depth exposure to corrosion and design. The problem, as discussed above, would be finding faculty with the proper background, or even the motivation, to teach this course. It would be the rare mechanical engineering department, or maybe even the rare materials science and engineering department, that would already have such a person on the faculty. The difficulty of hiring new faculty to teach this course is outlined above. Recruiting a qualified part-time instructor from industry or government would seem to be the best way to initiate such a course.

Incentives and Possible Solutions

A number of possible incentives and solutions might improve the coverage of corrosion in engineering curricula:

- Make a really compelling case for the need that clearly shows that it is not just another scientific/technical lobbying effort.
- Prepare compelling instructional materials that are easy to use and dramatic in their application.
- Train engineering faculty who want to teach a technical elective course in design for corrosion, possibly at summer institutes.
- Develop a directory of qualified corrosion engineers who want to teach an elective course in design for corrosion.

ROBERT H. DODDS, JR.
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Civil engineers have primary responsibility for our nation's built infrastructure, including our critically important transportation system. Valued in the hundreds of billions of dollars, bridges remain particularly susceptible to damage by corrosion. In their 2003 study, Yunovich and Thompson[1] provided a conservative estimate of $6.5 billion per year just to maintain the existing 500,000 steel and concrete bridges, to replace failed and closed structures, and to replace concrete decks on otherwise functional superstructures. These estimates represent direct costs attributable primarily to corrosion and do not reflect economic losses caused by out-of-service structures.

Undergraduate engineering students at Illinois receive minimal exposure to the causes, effects, and prevention of corrosion. The Department of Materials Science and Engineering offers a full-semester course on corrosion of metals to about 20 upper-division undergraduate and graduate students. In the Department of Civil and Environmental Engineering, we offer a course on the properties of materials every semester to about 110 students per year. The 4-credit-hour course has 45 lecture hours and 12 physical laboratory sessions. This course is required for undergraduate students electing to focus on structural engineering or construction materials. One lecture hour of this course is devoted to the fundamentals of corrosion. The elective undergraduate/graduate course on properties of concrete devotes two lectures to corrosion effects in concrete. This course is taught once a year and typically draws 30 students. Corrosion is not discussed (formally) in our senior undergraduate or M.S.-level design courses for the structural engineering program, which has more than 200 undergraduate students and more than 75 master's candidates.

The invitation to participate in this forum prompted several discussions in our department about the coverage of corrosion in our civil and environmental engineering curriculum. An undergraduate or (M.S.-level) graduate course on corrosion does not appear likely. The 133-credit-hour requirement of our undergraduate program already exceeds the national average and challenges many students to finish in 4 years. We have processes in place to reduce the 133-hour program and to broaden the undergraduate experience to reflect developments in American Society of Civil Engineers (ASCE) Policy 465. Our M.S. program requires nine courses (36 credit hours) for the nonthesis option.

We are now considering adding a laboratory experience on corrosion to our properties and materials course since a significant portion of the course focuses on structural metals. At the M.S. level we teach a series of elective special topics on the durability of materials. With our new campuswide efforts on environmental sustainability, our department expects renewed interest in formalizing a crossdisciplinary course on sustainability at the M.S. level in the next year or so. The durability of construction materials, including the impacts of corrosion and its prevention, will certainly be included in the course. Other opportunities to teach corrosion prevention exist in our structural design courses—we simply need to make this is a new point of emphasis and help the structural engineering professors in those courses to become more aware of corrosion themselves. Although these observations derive from our civil and environmental engineering program at Illinois, we expect they hold generally in other such programs across the nation.

NOTE: Presentation prepared with John S. Popovics, also at University of Illinois at Urbana-Champaign.

[1]M. Yunovich and N. Thompson, "Corrosion of highway bridges—Economic impacts and concrete methodologies," *Concrete International* 25 (1), 2003.

DAVID J. DUQUETTE
RENSSELAER POLYTECHNIC INSTITUTE

To stimulate undergraduate programs in corrosion science, universities must have active faculty who are qualified and willing to develop courses, laboratory experiences, and support undergraduate research activities. Those faculty will come from the graduate programs at research universities. However, the driving force behind hiring faculty who are both capable of training future academics and qualified to teach corrosion is the ability to attract research funding, either from government or industry. In the present research climate, corrosion science and engineering, and metallurgy in general, are not hot-button items, and few new faculty are being hired to replace the aging cadre of faculty who have recently retired or will be retiring soon. The number of active corrosion research programs at universities has decreased considerably over the last decade, a trend that will not be reversed soon. Funding from the agencies that have traditionally supported fundamental corrosion research—for example, DoD and DOE—is either decreasing or has been diverted to short-term problem-solving programs. This workshop should serve as a wake-up call for the nation. If minimizing the corrosion of the country's infrastructure, transportation systems, and defense armament is to be an economic and technical priority, substantial government and industry funds for fundamental corrosion research will have to be provided. It will not be sufficient to simply dictate that undergraduate engineering programs whether in materials science and engineering, or in the broader context of engineering education, should include some modicum of education in corrosion science and technology, including mitigation and control measures. The core faculty who are capable of providing those educational resources must be regenerated, and the only way to accomplish this is through the support of graduate education.

MARK R. PLICHTA
MICHIGAN TECHNOLOGICAL UNIVERSITY

Michigan Tech has managed to keep corrosion education as an element of the materials science and engineering curriculum, although not at the same level as was once possible. There are several reasons for this, including (1) a general university-wide reduction in credits (that is, courses available), as mandated by the university leadership; (2) fewer courses, required or elective, as a consequence of the academic calendar changing from quarters to semesters; and (3) less faculty expertise in the area of corrosion and corrosion engineering.

At present the topic of corrosion is included in at least three required undergraduate courses, but there is no single required course devoted to the topic. Basic concepts of corrosion are introduced in the second semester of the chemistry curriculum and also near the end of the introductory course on materials science and engineering. Subsequently, the junior-level course on thermodynamics has a 2- or 3-week segment devoted to corrosion concepts. Finally, there is a senior-level elective course, "Corrosion and Environmental Effects on Materials Performance," which is presently attended by approximately half of the graduating bachelor-level students. At present, there are no plans to strengthen the offerings on this topic. One reason is a shortage of the resources needed to support strong research and instruction on corrosion.

Consider the first limitation, that is, reduced availability of credits. As part of the curricular revisions needed to convert the former quarters system to a semester system, the Provost at that time mandated that no degree would require more than 128 student credit hours. At that time (AY2000) this upper credit limit translated into a ~7 percent decrease in credits required under the quarter system. Although the impact is small, it does limit the range of technical topics that can be offered in support of the bachelor's degree.

The second limitation is related to the first. In general, curricula designed for the semester system have fewer courses than curricula for the quarter system. The advantage of semester courses is that the material can be covered in much more depth and students have a longer time to digest and hopefully master the topics covered in the class. That being said, a natural consequence of this benefit is the forced reduction in the number of courses that students take to complete the degree.

The final limitation, faculty expertise, is probably the most critical and is being faced by most, if not all, materials-related programs in the nation. Faculty are hired so that strong research programs can be established. A consequence of this is that faculty expertise tends to follow those areas of research that attract the most funding. Research achievements, graduate studies, and scholarly activities are the main criteria in promotion and tenure. This, of course, has a snowball effect, since fewer faculty working in corrosion will produce fewer Ph.D.s in the discipline. In the worst case, and if no corrective action is taken, the nation would have no significant experience in this field. As a department chair, I believe this is the most critical issue. The first two limitations could probably be offset by designing the curriculum in clever ways. However, not having faculty expertise in the area of corrosion will have a more devastating and longer-lasting impact. At the moment, Michigan Tech has an advocate for corrosion education and we can keep the topic alive for awhile. With the right support from university leaders, perhaps we could even rejuvenate the program.

LEE SAPERSTEIN
UNIVERSITY OF MISSOURI–ROLLA (RETIRED)

In the past several decades, ABET's approach to accrediting university programs has evolved.[2] It once focused on minimum standards and judged programs by a set of primarily process criteria. It now encourages a continuous assessment of and improvement in a program's objectives. It looks at how well a program meets or exceeds its programmatic objectives by assessing the outcomes the program has set for the program's graduates to achieve. ABET also asks to see the process by which these objectives and desired outcomes are renewed. It is now much more performance based. With this in mind, this workshop should go beyond the question of whether or not corrosion education is needed, to ask what elements of understanding and practice should be expected of a graduate who is deemed to be knowledgeable in corrosion science and engineering.

Accreditation is based on a disinterested review and comparison of educational offerings—in this case, engineering degree programs—against a set of published criteria. ABET, Inc. (www.abet.org), the agency enabled by the professional societies to perform specialized accreditation of engineering programs, has a published set of general criteria that are applied to all engineering programs and separate sets of individual program criteria that are applied to programs bearing a specific identifier or designation. The seven categories in the general criteria are students, program educational objectives, program outcomes and assessment, the professional component, faculty, facilities, and institutional support and financial resources. The second and third criteria require input from external advisory groups, with the objectives meant to define a program's individual characteristics and reflect the character of graduates some years after graduation and the outcomes meant to relate more to the abilities of a graduate upon graduation. The outcomes must include 11 traits defined in the general criteria but may include additional traits defined by an individual program and imposed on all graduates in a specific discipline.

To assist programs in their quest for accreditation of corrosion engineering offerings, ABET may choose to provide them with desired subject-matter or even set trial program criteria that will allow each program to decide if it wants (1) an introduction to corrosion in existing courses and curricula, (2) an emphasis within a set sequence of courses, (3) a corrosion engineering option, or (4) a corrosion engineering degree. The first two can be done without requesting accreditation, but the second two will require, eventually, an accreditation review. The choice should be that of the program and its various advisory boards or groups, consistent with its stated programmatic objectives. If corrosion educational programs desire accreditation, the involved community can draft program criteria specific to corrosion education, along with learning objectives for individual courses. It is my intent to help the workshop participants and the members of the Committee on Assessing Corrosion Education flesh out these choices.

[2]ABET is the accreditor for college and university programs in applied science, computing, engineering, and technology. It is a federation of 28 professional and technical societies representing these fields. Lee Saperstein is a past president of ABET.

MARK D. SOUCEK
UNIVERSITY OF AKRON

In response to demands from industry and DoD, the University of Akron is undertaking an initiative to establish the first comprehensive educational program in the field of corrosion engineering and science. Our innovative approach seeks to develop a corrosion engineering degree and goes beyond the piecemeal approach of integrating corrosion topics into a pre-existing engineering discipline. The goal is to train an engineer to incorporate corrosion as a key criterion from the initial structural design, through the material selection process to, ultimately, the entire life-cycle of the structure or product. This project aims to create corrosion-specific, ABET-accredited engineering degrees at the associate and baccalaureate levels as well as to offer the workforce industry-accredited certification courses. While the certification courses and the associate degree program will be delivered from the University of Akron's new Medina County University Center, the B.Sc. will be housed on the Akron campus. It is our plan to have an ISO-certified laboratory that will not only support laboratory-based courses for the degree programs but will also be made available to industry partners for carrying out their R&D activities.

Appendix A
Corrosion Education Workshop Statement of Task

A Type 4 workshop will be convened to consider scientific and technical issues pertinent to the development of effective corrosion education of engineering students.

The Corrosion Education Workshop will be organized by an appointed planning group that will develop an agenda with the goal of discussing fundamental questions that will need to be addressed in any future assessment of the capability of U.S. engineering curricula to educate undergraduate students in corrosion identification and abatement.

The Corrosion Education Workshop will bring together corrosion specialists with materials and mechanical engineering educational leaders. The workshop participants will feature invited presentations and discussion to provide perspectives on whether corrosion abatement is adequately addressed in our nation's engineering curricula and, if not, what needs to be added to develop a comprehensive corrosion curriculum in undergraduate engineering.

The workshop activity will result in a proceedings, which will consist solely of the individually authored extended abstracts from the workshop's speakers.

Appendix B
Agenda for the Materials Forum 2007

SESSION I: MOTIVATION		
	Moderator, Ralph Adler, Army Research Laboratory	
8:00 am	Welcome and setting the scene	Fiona Doyle, Forum Chair
8:10 am	Introduction of Session I participants	Gary Fischman, NMAB
8:15 am	Cost of corrosion	Neil Thompson, CC Technologies
8:40 am	DoD's mandate on corrosion	Daniel Dunmire, DoD-OSD
	DoD's corrosion and national security needs	Lewis Sloter, DoD-OSD
9:05 am	The need for corrosion engineering curriculum	Aziz I. Asphahani and Helena Seelinger, NACE Foundation
9:45 am	*COFFEE BREAK*	
SESSION II: CURRENT PRACTICE		
	Moderator, John Scully, University of Virginia	
10:10 am	Introduction of Session II participants	Michael Moloney, NMAB
10:15 am	AMPTIAC ad hoc study on corrosion education	David Rose, Quanterion Solutions, Inc.
10:30 am	Corrosion education: materials science	Gerald Frankel, Ohio State University
10:45 am	Corrosion education: mechanical engineering	Matthew Begley, University of Virginia
11:00 am	Corrosion education: industry needs and response	Robert Schafrik, GE Aviation
11:15 am	Corrosion education: industry needs and response	Ramesh Sharma, Raytheon
11:30 am	Panel Discussion	
WORKING LUNCH WITH TALK		
12:00 pm	The Challenge of Change in a Change-Resistant Environment	Luis M. Proenza, University of Akron
SESSION III:IMPLEMENTATION		
	Moderator, Ron Latanision, Exponent Inc.	
1:15 pm	Introduction of Session III participants	Gary Fischman, NMAB
1:20 pm	Perspectives on implementation	Ron Latanision, Exponent Inc.
1:30 pm	Response from panel members (2 minutes each) followed by panel discussion with audience participation	George Dieter, University of Maryland Robert Dodds, University of Illinois, Urbana-Champaign David Duquette, Rensselaer Polytechnic Institute Mark Plichta, Michigan Technical University Lee Saperstein, University of Missouri–Rolla Mark Soucek, University of Akron
2:45 pm	*COFFEE BREAK*	
SESSION IV: NEXT STEPS		
	Moderator, Fiona Doyle, University of California, Berkeley	
3:00 pm	Overview of workshop	Fiona Doyle, Forum Chair
3:15 pm	Looking forward to the follow-on study	Wesley Harris, ACE Chair
3:15 pm	Discussion of NRC's corrosion education study	Workshop attendees
4:00 pm	*ADJOURN*	

Appendix C
Speaker and Panelist Biographies

Ralph Adler is a research metallurgist on the coatings and corrosion team in the Materials Applications Branch of the Army Research Laboratory (ARL). He works in the Weapons and Materials Research Directorate of ARL at Aberdeen Proving Ground, Maryland, and has been a federal employee working for the Army since 1985, when he joined the Army Materials Technology Laboratory. Dr. Adler is a research scientist and is not involved in the formulation or implementation of Department of Defense policy. His research interests include science education and awareness for all levels of our society. He has taught graduate-level courses in x-ray diffraction at Northeastern University. To encourage technical collaboration between ARL and universities, Dr. Adler has worked with university faculty in an advisory capacity to provide project oversight and to share resources and materials as well as collaboratively by co-authoring joint publications. He has served as a science fair judge at both local and national levels and organized the initial student poster session at the 2005 Tri-Service Corrosion Conference. To improve the science awareness of public school students and the quality of science education in his hometown, he was a member of the Committee on Science Education of the Citizens for Wellesley Public Education; its charter was to enhance and enrich science education of public school students through strong support of Wellesley public schools' science faculty and by obtaining donations of scientific equipment. Dr. Adler has represented the Army on several high-level DoD panels, currently serving as an ARL member of the Corrosion Forum, where he is chair of the Corrosion Education Consortium; was chair of Subpanel 8 (materials processing/manufacturing research) for the Project RELIANCE technical panel for advanced materials; was a member of OSD's Laboratory Infrastructures Consolidation Study, the JDL-TPAM Manufacturing Sciences Working Group and two sessions of the Technical Managers Acquisition Workshop; and was secretary for the metals panel, TP-1, of the Materials Technology and Performance of the MAT group of TTCP. He is/or has been a member of many professional committees: as service liaison on two NRC panels, as a member of ASM's Advisory Technical Awareness Council; on thesis review panels for Worcester Polytechnic Institute (WPI) and Northwestern University; and as chair and Executive Committee member of the Boston section of the Metallurgical Society/AIME. He has also participated in many Army/DoD/NSF source selection panels and has been an invited member of the ARL/ARO and IRAD technical review boards. Dr. Adler earned a D.Eng. degree in metallurgy from Yale University and has over 40 years of experience in leading and conducting sponsored or in-house research for a variety of materials science and engineering programs in both industrial and Army organizations. With his expertise in synthesis/metals processing and materials characterization, he has authored publications and holds U.S. patents in a variety of technical areas with commercial and military applications.

Aziz I. Asphahani is a retired executive of Carus Chemical Company, Peru, Illinois. He completed mathématiques spéciales at the Lycée Janson Sailly in Paris in 1967 and received a diplôme ingénieur-physique from the Ecole Centrale de Paris in 1970. He earned his Ph.D. in materials science at the Massachusetts Institute of Technology in 1975. Dr. Asphahani joined Carus Chemical Company in 1995 as president and CEO after spending more than 19 years in the specialty metal industry with Haynes International, Inc. (formerly a division of Cabot Corporation) and Cabval, its joint venture with Vallourec Industries. He served as president of Cabval and as vice president of Haynes, general manager of corrosion alloys, director of R&D, group leader, and corrosion engineer (1975-1994). Dr. Asphahani served on the board of directors of Haynes International, Inc., and Cabval. He is presently serving on the board of directors of Carus Corporation.

Dr. Asphahani holds eight patents, authored 61 papers on high alloys and corrosion control, and contributed to over 300 technical presentations at major conferences and special symposia. Two products of his patents won the 1984 Vaaler award and the 1991 R&D 100 award. Dr. Asphahani is a fellow of the American Society for Materials (ASM) and of the National Association of Corrosion Engineers (NACE). He is a member of the Minerals, Metals, and Materials Society (TMS), the Electrochemical Society, and the American Water Works Association. He is an ASM past president and past chair of the Technical Awareness Council. He served as the chairman of the Corrosion Committee of MPC (Materials Properties Council) and on the ASTM-G1 Corrosion Committee. He has also served on the board of directors of NACE International, the board of trustees of the Chemical Educational Foundation, and the board of directors of the American Chemistry Council. Dr. Asphahani is presently serving on the board of directors of the ASM Materials Education Foundation (of which he was past chairman) and the NACE Foundation.

Matthew R. Begley earned his B.S. and M.S. in mechanical engineering from Penn State University and graduated with a Ph.D. in mechanical engineering from the University of California, Santa Barbara, in 1995. He was a Gordon McKay postdoctoral fellow at Harvard University from 1995 to 1997 and a visiting assistant professor at Harvard in the fall of 1998. Dr. Begley is currently an associate professor in mechanical and aerospace engineering, with appointments in materials science and engineering and electrical and computer engineering. Dr. Begley's research and teaching interests are focused on the development of handheld devices for molecular diagnostics, with an emphasis on the implications of nanoscale material behavior for device performance.

George E. Dieter is the emeritus professor of mechanical engineering and the Glenn L. Martin Institute professor of engineering at the University of Maryland, having retired as dean of the College of Engineering in 1994. Prior to this, Dr. Dieter was professor of engineering and director of the Processing Research Institute at Carnegie Mellon, as well as the chair of metallurgical engineering at Drexel University. He started his career at the Engineering Research Laboratory of the DuPont Company. His teaching and research interests are engineering design, materials processing, and quality engineering. Dr. Dieter is a member of the National Academy of Engineering and a fellow of the AAAS, ASM International, TMS, and the American Society for Engineering Education (ASEE). He was national president of ASEE and received the Lamme Medal, its highest honor. His book *Mechanical Metallurgy* has been in print since 1961 in various editions, while his book *Engineering Design: A Materials and Processing Approach* is in its third edition (2000). He was the editor of Volume 20 of the *ASM Handbook* "Materials Selection and Design," published in 1997. He has been active on many National Research Council committees, including the National Materials Advisory Board. Dr. Dieter received a bachelor's degree in metallurgical engineering from the Drexel Institute of Technology and a Sc.D. from the Carnegie Institute of Technology (Carnegie Mellon).

Robert H. Dodds earned a Ph.D. in civil engineering from the University of Illinois at Urbana-Champaign (UIUC) in 1978. Before returning to UIUC in 1987, he served on the faculty at the University of Kansas for 9 years. He has been an active researcher in the field of nonlinear fracture mechanics and computational methods for the past 25 years. His current research enjoys support from external sponsors including the U.S. Navy, the U.S. Nuclear Regulatory Commission, the U.S. Air Force, and NASA (Ames, Marshall). Dr. Dodds has published more than 100 journal papers in the areas of fracture mechanics, computational methods, and software engineering. From 1996 through 2005, he served as co-editor of *Engineering Fracture Mechanics*, a leading international journal on fracture mechanics for the past 30 years. He is an associate editor for three other international journals on these topics and actively participates in related technical societies, including the American Society for Testing and Materials (E-8). He recently served on a technical advisory panel for the national research project on performance of steel buildings during strong earthquakes, which was sponsored by the Federal Emergency Management Agency (FEMA). Professor Dodds's research awards include the American Society of Civil Engineers' Walter L. Huber Research Prize (1992) and its Nathan M. Newmark Medal (2001); the George R. Irwin Medal from ASTM (2000) and the 2001 Award of Merit with fellow status from ASTM; the 2000 Munro Prize for best paper published in the *International Journal of Engineering Structures*; the 2002 speaker for the Southwest Mechanics Tour; and honorary fellow of the International Congress on Fracture in 2005. He has delivered more than 30 invited keynote and plenary lectures at international conferences. In 1997, Dr. Dodds was named the inaugural holder of the Nathan and Anne M. Newmark Professorship in Civil Engineering at the University of Illinois. In 2000, he became the first holder of the M.T. Geoffrey Endowed Yeh Chair in Civil Engineering, and in 2004 he became the 13th head of the Department of Civil and Environmental Engineering.

Fiona M. Doyle is a professor in the Department of Materials Science and Engineering at the University of California, Berkeley (UCB). She is also the executive associate dean and associate dean for academic affairs in the UCB College of Engineering. She obtained her bachelor's degree in metallurgy and materials science from the University of Cambridge, England, and an M.Sc. in extractive metallurgy and a Ph.D. in hydrometallurgy from Imperial College, University of London. Dr. Doyle's main area of research is the solution processing of minerals and materials. She studies processes such as the leaching and transformation of minerals, solvent extraction, organic-phase reactions, hydrolysis, precipitation, crystallization, and electrochemical reactions from a fundamental thermodynamic and kinetic perspective. Much of her work aims to adapt the techniques used in the primary production of commodity minerals and metals for the commercial-scale processing of value-added advanced materials. She also has ongoing research into improving the environmental impact and energy utilization associated with the production of minerals and materials. Dr. Doyle has served the state of California in assessing the environmental impact of mining and mineral processing operations and developing policies for addressing the environmental damage due to historic mining activities. Dr. Doyle is a member of the National Materials Advisory Board and is currently serving as the chair of this panel, the Corrosion Education Workshop Organizing Panel.

Daniel J. Dunmire is the special assistant, DoD Corrosion Policy and Oversight in the Office of the Under Secretary (Acquisition, Technology and Logistics). He started his federal career in the Office of the Secretary of Defense in 1984 through the Presidential Management Internship (now fellowship) program. From 1987 through 2002, Mr. Dunmire worked in program and policy acquisition oversight. He received a B.A. in communications from Kent State in 1974 and an M.P.A. from the University of Alabama in Birmingham in 1984, and is currently a Ph.D. candidate at Virginia Tech.

Mr. Dunmire received the Office of the Secretary of Defense Medal for Exceptional Civilian Service twice and was a team recipient of the Vice President's Hammer Award for Acquisition Policy and Deskbook Design. He is a member of the Department of Defense Acquisition Corps, Level III, Program Manager, and is a retired Army Corps of Engineers reservist.

David J. Duquette received his Ph.D. in materials science from the Massachusetts Institute of Technology in 1968. Following his postgraduate work, he performed research on elevated temperature materials, joining the Rensselaer faculty in 1970. He is the author or co-author of more than 160 scientific publications, primarily in the areas of environmental degradation of materials and electrochemical processing of semiconductor interconnects. He is a recipient of the Whitney Award of the National Association of Corrosion Engineers for his contributions to corrosion science and of an Alexander von Humboldt Senior Scientist Award. He is a fellow of ASM International and of NACE International.

Dr. Duquette's research interests include the physical, chemical, and mechanical properties of metals and alloys, with special reference to their environmental interactions. Current projects include studies of aqueous and elevated-temperature corrosion phenomena, the effects of corrosive environments on fatigue behavior, the environmental cracking of alloys, the role of corrosion science in understanding the planarization of metal interconnects on semiconductor devices, and the electrodeposition of semiconductor interconnects. A fundamental understanding of material–environment interactions is critical to engineering application of metallic materials.

Gerald S. Frankel is the DNV Chair professor of materials science and engineering at Ohio State University (OSU) and director of the Fontana Corrosion Center. He earned an Sc.B. in materials science engineering from Brown University in 1978 and an Sc.D. in materials science and engineering from the Massachusetts Institute of Technology in 1985. Prior to joining OSU in 1995, he was a postdoctoral researcher at the Swiss Federal Technical Institute in Zurich, Switzerland, and then a research staff member at the IBM Watson Research Center in Yorktown Heights, New York. He has more than 180 publications, and his primary research interests are in the passivation and localized corrosion of metals and alloys, corrosion inhibition, and protective coatings. He is past chairman of the Corrosion Division of the Electrochemical Society, past chairman of the Research Committee of NACE, and a member of the editorial board of the journal *Corrosion*. Dr. Frankel is a fellow of NACE International, the Electrochemical Society, and ASM International. He has received the Alexander von Humboldt Foundation Research Award for Senior U.S. Scientists, the H.H. Uhlig Educators' Award from NACE, and the Harrison Faculty Award and Lumley Research Award from the OSU College of Engineering. In 2005 he was on sabbatical at the Max Planck Institut fuer Eisenforschung (Institute for Iron Research) in Düsseldorf, Germany. Dr. Frankel is a member of the NRC's Corrosion Education Workshop Organizing Panel.

Ronald M. Latanision is professor emeritus of materials science and engineering and nuclear engineering at the Massachusetts Institute of Technology and a principal and practice director of mechanics and materials/metallurgy at Exponent. He is the author or co-author of more than 200 scientific publications, and is founder and cochairman of the New England Science Teachers and a member of the National Academy of Engineering and the American Academy of Arts and Sciences. Dr. Latanision has been a consultant to industry and government and has been active in organizing international conferences. He was appointed to the Nuclear Waste Technical Review Board on June 26, 2002, by President George W. Bush. Dr. Latanision received a B.S. in metallurgy from Pennsylvania State University and a Ph.D. in metallurgical engineering from Ohio State University. During a sabbatical in 1982-1983, he served as a science advisor to the U.S. House of Representatives' Committee on Science and Technology. Dr. Latanision has served as a member of a number of committees at the National Academies, including several committees on science education, and he also served on the Center for Education advisory board. He is a member of NRC's Corrosion Education Workshop Organizing Panel and the Committee on Teacher Preparation Programs in the United States. He was a member of the now inactive Committee on Undergraduate Science Education.

Mark R. Plichta graduated with high honors from Michigan Technological University with a bachelor's degree in metallurgical engineering in 1974. He completed his M.S. and Ph.D. degrees in metallurgical engineering in 1977 and 1979, respectively, also at Michigan Technological University. Research conducted in fulfillment of the graduate degrees dealt with the thermodynamics, kinetics, and crystallography of solid-state phase transformations in metallic materials.

Upon completion of his graduate degrees, Dr. Plichta joined the faculty in the Department of Materials Science and Engineering at the University of Utah. While at Utah he developed many courses in the areas of phase transformations, kinetics, materials science, and electron microscopy. His research efforts grew to include the microstructural development and stability of metal and ceramic materials. In 1983 Dr. Plichta received the Ralph R.Teetor Educational Award from the Society of Automotive Engineers.

In 1984, Dr. Plichta returned to Michigan Technological University as associate professor of metallurgical and materials engineering. In addition to continuing his work on research interests in microstructural evolution in materials, he began to pursue educational and curricular interests. Within the department he served as chair of the undergraduate program committee and the curriculum change committee, which was responsible for the development and implementation of a massive curriculum revision in 1993. He was awarded the State of Michigan Teaching Excellence Award and the Michigan Technological University Distinguished Teaching Award, both in 1990.

In the summer of 1997, Dr. Plichta was appointed associate dean for academic programs in the College of Engineering. His responsibilities in this position included curricular reform, issues for women and underrepresented groups, ABET and NCA accreditations, international engineering experiences, and distance learning activities. In 1998, he was the principal investigator on a large NSF grant for systemic engineering education reformation. Under this award, Michigan Tech developed a unique educational experience called the Enterprise Program, within which students operate their own on-campus companies as part of the engineering degree requirements. In October 2002, Dr. Plichta was named chair of the Department of Materials Science and Engineering. In the summer of 2003, he was appointed Foundry Education Foundation key professor at Michigan Tech. Dr. Plichta maintains membership in the American Society for Engineering Education, ASM International, the Metallurgical Society of AIME, the American Ceramic Society, and the Materials Research Society.

Luis M. Proenza is the president of the University of Akron, the public research university for northern Ohio. He provides overall leadership to more than 4,500 faculty and staff and oversees an annual budget of $350 million, serving more than 24,000 students in 350 academic programs, including a consortium medical school and three branch campuses.

Under Dr. Proenza's leadership, the University has undertaken several major initiatives, including a $300 million New Landscape for Learning campus enhancement program with 9 new buildings and major additions or renovations of 14 other facilities, a University Park Alliance project supported by the Knight Foundation to revitalize a 40-block neighborhood and commercial area surrounding the campus, and information technology (IT) investments that have established the University of Akron as a national leader in IT and made it one of the most "wired for wireless" universities in the country.

Dr. Proenza has brought private donations to an all-time record and garnered two of the largest gifts ever made to the university. He also has expanded its outreach with the creation of two new regional branch campuses, and he has spearheaded an innovative enrollment management program that has generated significant increases in new and transfer students.

Dr. Proenza's marketing and leadership initiatives earned him the 2005 Chief Executive Leadership Award from the Council for Advancement and Support of Education District V and the 2006 Northeast Ohio Regional Vision Award from the Northeast Ohio Regional Leadership Taskforce. He also was recipient of the 2001 Executive of the Year Award by the Sales and Marketing Executives Association of Akron; along with recognition from *Crain's Cleveland Business*, which named him to its Power Pack, the list of the 50 most influential people in Northeast Ohio, and from *Inside Business*, which listed him among the Power 100.

In 2001, President George W. Bush appointed Dr. Proenza to serve on the President's Council of Advisors on Science and Technology (PCAST), the nation's highest-level policy advisory group for science and technology. The group advises the president and assists the Office of Science and Technology Policy and the National Science and Technology Council in securing private-sector involvement in their activities. Dr. Proenza has served on PCAST panels on U.S. research and development investments, technology transfer, energy efficiency and advanced manufacturing, and also serves on panels addressing nanotechnology, alternative energy, and IT.

Dr. Proenza is a member of the Council on Competitiveness, where he serves on the executive committee, and on the National Innovation Initiative Leadership Council. In addition, he sits on the advisory board of the U.S. Secretary of Energy and chairs the Science and Mathematics Education Task Force. He also is a member of the Council on Foreign Relations. Dr. Proenza chairs the Ohio Supercomputer Center and serves on the boards of the State Science and Technology Institute, the Great Lakes Science Center, the Ohio Chamber of Commerce, and OneCommunity. In 2003, he was appointed by Governor Robert Taft to Ohio's Third Frontier Advisory Board.

He previously served on the NAS-NRC Committee on Vision, the National Biotechnology Policy Board, the U.S. Arctic Research Commission (appointed by former President George H.W. Bush), and as advisor for science and technology policy to Alaska governor Walter J. Hickel.

Before coming to the University of Akron, Dr. Proenza was vice president for research and dean of the Graduate School at Purdue University. He previously served as vice president for academic affairs and research and as vice chancellor for research and dean of the graduate school at the University of Alaska.

Dr. Proenza holds a bachelor's degree from Emory University (1965), a master's degree from the Ohio State University (1966), and a doctorate from the University of Minnesota (1971).

He joined the faculty of the University of Georgia in 1971, where his research was continuously supported by grants from the National Eye Institute, including a Research Career Development Award, and where he also served as assistant to the university's president and university liaison for science and technology policy.

In Ohio, he is past president of the Inter-University Council and serves on the Northeast Ohio Council on Higher Education, on the Executive Council of the Northeast Ohio Technology Coalition (NorTech), and on the Executive Committee of the Greater Akron Chamber of Commerce. He also serves on the Board of the Akron Roundtable.

Dr. Proenza is a member of many professional, scholarly, and honorary organizations; is the recipient of several awards and honors; and has published numerous articles in nationally and internationally recognized journals. In addition, he edited and co-edited two books. He is invited frequently to speak throughout the country and abroad, and his presentations have appeared in *Vital Speeches of the Day* and *The Executive Speaker*. He is often quoted on issues affecting higher education, research, and economic development.

David H. Rose is the Manager of Advanced Programs for Quanterion Solutions, Inc., a small business in Utica, New York. His responsibilities include directing a variety of technical projects for both commercial and government customers. He also supports the Reliability Information Analysis Center (RIAC), a DoD-sponsored information analysis center (IAC) operated by Quanterion as part of a team lead by Wyle Laboratories.

From June 1998 through November 2006, Mr. Rose was the director of the Advanced Materials, Manufacturing, and Testing Information Analysis Center (AMMTIAC) and its predecessor, the Advanced Materials and Processes Technology Information Analysis Center (AMPTIAC). Like RIAC and seven other-DoD sponsored IACs, these centers were chartered to improve the productivity of researchers, engineers, and program managers in the defense research, development, and acquisition communities by collecting, analyzing, synthesizing, and disseminating worldwide scientific and technical information in clearly defined, specialized fields or subject areas. While at AMMTIAC and AMPTIAC, he supported both government organizations and industrial base contractors involved with materials selection efforts. This experience provided him with insight into how materials selection is accomplished, which subsequently led to his questioning whether existing undergraduate engineering curricula, and the knowledge they provide, result in adequate consideration of corrosion during product design.

Mr. Rose is a retired U.S. Air Force officer. He holds a bachelor's degree in mechanical engineering from the University of Washington, a master's degree in mechanical engineering from the University of Dayton, and completed his Ph.D. course work and candidacy examinations in materials engineering, also at the University of Dayton. His Air Force assignments included a tour to the Air Force

Plant Representative's Office at the Boeing Company in Seattle. He also spent two tours at the Air Force Research Laboratory (AFRL), including 5 years at the Materials and Manufacturing Directorate, where he conducted research on composite materials, and 2 years at the Electromagnetics and Reliability Directorate, where he conducted research on material failure modes and the impact they have on the reliability of plastic encapsulated microcircuits. He holds a U.S. patent for developing a process to reduce residual stresses by prestressing fibers in composite materials.

Lee W. Saperstein is dean emeritus of the School of Mines and Metallurgy and professor emeritus of Mining Engineering at the University of Missouri–Rolla (UMR); he served as dean from July 1993 to June 2004; he retired from UMR at the end of December 2006. He has a B.S. in mining engineering from the Montana School of Mines (1964), now Montana Tech of the University of Montana, and a D.Phil. in engineering science from Oxford University (1967), which he attended as a Rhodes Scholar. He was a faculty member in mining engineering at Penn State from 1967 to 1987 and for the following 6 years at the University of Kentucky, where he was also chair of the Department of Mining Engineering. While at Kentucky, he participated in an interim management team for the University of Kentucky Center for Applied Energy Research, where he was assistant director for clean coal fuels.

His research specialization has been in the environmental engineering of mines. He has published papers, proceeding articles, book chapters, and informal articles on this subject. He created Penn State's first surface mining design course and he has taught courses in senior design, explosives engineering, erosion and sediment control, and reclamation engineering. He also has supervised training programs for miners, including health and safety training and job-skills training. In addition to his activities at ABET, he is chair of the Missouri Society of Professional Engineers' educational advisory board, member of the American Society for Engineering Education's engineering deans council (and former member of its public policy committee), former chair of the Mineral and Energy Resources Section, and one-time chair of the Board on Natural Resources of the National Association of State Universities and Land-Grant Colleges. He is a distinguished member of the Society for Mining, Metallurgy and Exploration (SME-AIME), which also gave him the Ivan B. Rahn Award for Education. He also received the SME President's Citation for services to education. He has chaired SME's education board, its research council, and the Erskine Ramsay Medal award committee. Montana Tech of the University of Montana granted him the distinguished alumni award. He is listed in *Who's Who in America*. He is licensed as a professional engineer in three states. Dr. Saperstein has served on four state committees of selection for the Rhodes Scholarship.

Within ABET, he served as president in 1999-2000 and is completing 23 years of service to ABET. He has been representative director for SME-AIME as well as secretary, president, and past president of its board of directors. He served as chair, 1989-1990, of the Engineering Accreditation Commission (EAC). As an EAC commissioner, he led evaluation teams to 13 universities, and as an officer, he edited the reports of 75 more. As chair, he dealt with 96 institutions. Prior to being EAC chair, he chaired the Criteria Committee when it devised the concept of "engineering topics" and wrote the first references to "program objectives" and "outcome assessments." A member of ABET's Strategic Planning Committee, he was named a fellow of ABET and most recently served as chair of the ad hoc Task Force on Governance, which has delivered a new constitution, bylaws, and rules of procedure to ABET. He is a holder of its Linton E. Grinter Distinguished Service Award.

Robert E. Schafrik is currently the general manager of the Materials and Process Engineering Department at GE Aviation. He is responsible for developing the advanced materials and processes used in GE's aeronautical turbine engines and their marine and industrial derivatives. He oversees the materials application engineering activities supporting GE Aviation's global design engineering, manufacturing, and field support activities. He also operates a state-of-the-art in-house laboratory for advanced materials development, characterization, and failure analysis. He heads the GE Infrastructure Materials Council, which includes GE Energy, GE Transportation, and GE Water. Prior to joining GE in November 1997, he served in two concurrent positions within the National Research Council, which he joined in 1991: director, National Materials Advisory Board, and director, Board on Manufacturing and Engineering Design. Under his direction, 33 final reports for studies were issued that addressed significant national issues in materials and manufacturing. Dr. Schafrik also served in the U.S. Air Force in a variety of R&D and system acquisition capacities; he retired as a lieutenant colonel. He has a Ph.D. in metallurgical engineering from Ohio State University, an M.S. in information systems from George Mason University, an M.S. in aerospace engineering from the Air Force Institute of Technology, and a B.S. in metallurgy from Case Western Reserve University.

John R. Scully is professor and co-director of the Center for Electrochemical Science and Engineering at the University of Virginia, which he joined in 1990. Before that, Dr. Scully served as the senior member of the technical staff in the metallurgy department of Sandia National Laboratories. His research interests focus on the relationships between material structure and composition and properties related to environmental degradation, including hydrogen embrittlement, stress corrosion cracking, localized corrosion, and passivity of materials. His research also includes advanced aluminum-, magnesium-, titanium-, ferrous-, and nickel-based alloys, stainless steels, and aluminum-based intermetallic compounds, as well as development of methodologies for predicting the lifetime of engineering materials used in corrosive environments. A recent interest has been nano-engineered materials, including multifunctional metallic glasses that deliver novel barrier, sacrificial anode, and chemical inhibition properties. Dr. Scully received his bachelor of environmental science and his M.S. from The Johns Hopkins University. He served as a technical consultant to the space shuttle's Columbia Accident Investigation Board in 2003, was a member of the Defense Science Board Task Force on Corrosion Control in 2004, and was the chair and organizer of the 2004 Gordon Conference on Aqueous Corrosion. He is a member of the Corrosion Education Workshop Organizing Panel.

Helena Seelinger graduated from Michigan State University with a degree in international relations and a minor in journalism, received her M.B.A. from the University of Houston, and earned ASAE Certified Association Executive status in 2007. She joined NACE in 1986 as a technical editor in the standards division and since has served as director of technical activities, director of education, and interim executive director. Ms. Seelinger now serves as Director of the NACE Foundation and senior director of new business and program development at NACE International.

As staff director of the NACE Foundation, Ms. Seelinger works with the foundation's board to implement programs, primarily at the high school and undergraduate levels, to inspire students to pursue a career in the field of corrosion science or technologies. This involves the implementation of industry internships for undergraduates, scholarship and award programs, travel assistance for college students to attend NACE meetings, a partnership with the ASM Foundation to fund high school teacher camps that provide resources and exciting ideas to make the teaching of corrosion interesting and inspiring, and working with universities to establish degree programs in the area of corrosion control. She also oversees fundraising events and corporate campaigns to secure funding for the student and teacher programs.

Ramesh Sharma is a senior engineering fellow at Raytheon Missile Systems in Tucson. He is also an adjunct professor at the University of Arizona in Tucson, where he teaches practical materials engineering and cost-effective design. As a visiting professor at the Naval Postgraduate School he teaches the fundamentals of tactical missiles. His main emphasis is on practical, reliable, and affordable engineering.

He obtained a B.Tech. (Hons) in metallurgical engineering from the Indian Institute of Technology, Kharagpur, India, a master of metallurgy in iron and steel technology from the University of Sheffield, United Kingdom, and a D.Phil. in physical metallurgy from the University of Oxford, United Kingdom. He has about 40 years of experience in industry and university teaching. He has experience in a wide range of fields such as corrosion management, tribology, alloy development, strengthening mechanisms, materials for high-strength and high-temperature applications, extraction metallurgy, rolling, casting, forging, extrusion, powder metallurgy, welding, and electronic packaging. His main efforts have been in optimum selection of materials and manufacturing processes, cost reduction, and producibility. He supports all programs at Raytheon. Several of his ideas offering annual savings worth millions of dollars have been successfully implemented. He is a pioneer in the development of surface mount technology and has written several papers.

Lewis E. Sloter, II, is the DoD associate director for materials and structures within the Office of the Director, Defense Research and Engineering. As a senior materials technologist he is responsible for the technical oversight of DoD science and technology activities in materials, processes, and structures associated with current and future defense systems and for technical assessments associated with materials, processes, materials manufacturing, and engineering applications.

Prior to joining the Office of the Secretary of Defense, Dr. Sloter was a program officer in the Office of Naval Research in Washington, D.C.; materials technology manager and propulsion technology manager, and metals section head at the Naval Air Systems Command, also in Washington, D.C.; and lead materials engineer and senior specialist for Vought Corporation in Dallas, Texas.

Dr. Sloter is a recipient of the DoD Exceptional Civilian Service Award and a member of several professional societies and honor societies, including Alpha Sigma Mu, Phi Kappa Phi, and Sigma Xi. He holds a B.S. in metallurgy and materials science and history and a Ph.D. in metallurgy and materials science and engineering and public policy from Carnegie Mellon University and an M.S. in materials engineering from Drexel University. When he did research, his primary academic interests were in welding metallurgy, corrosion fatigue, biomaterials, and forensic engineering. He has published and lectured on biomedical materials, welding metallurgy, armor, military aircraft, forensic engineering, and materials policy and is a registered professional engineer.

Mark D. Soucek obtained a B.S. in chemistry from Eastern Illinois University and an M.S. from Illinois State University with a thesis project in physical organic photochemistry. In 1990, he obtained his Ph.D. from the University of Texas at Austin in inorganic chemistry with an emphasis on stabilization of metal clusters for catalysis. From 1990 to 1993, he was an NRC postdoctoral fellow at the NASA-Langley Research Center working on the metal catalysis of high-performance polymers. From 1993 through 2001, Dr. Soucek was an assistant and then associate professor at North Dakota State University in the Department of Polymers and Coatings, focusing his research on coatings science. In 1999, Dr. Soucek won a Roon Award for his work in thermosetting latexes, and in 2000 he won the first Gordon Award for his work on nanocomposite polyurethane coatings as chromate replacements coatings for aircraft. In 2001, Dr. Soucek moved to the Department of Polymer Engineering at the University of Akron, where he is an associate professor. In 2003, Dr. Soucek was selected as a Gordon Award finalist for his work in UV-curable bio-based polymers. In 2004, he was awarded the Radtech Innovation Award for his work in UV-curable coatings. In 2004 and 2005, Dr. Soucek won an honorable mention Gordon Award for core-shell latex work and UV-curing of unsaturated polyesters. He has written more than 100 research papers, all in coating science.

Neil G. Thompson is founder and chairman of CC Technologies, an international engineering and research firm located in Ohio and Alberta and established in 1985. CC Technologies specializes in materials evaluation, pipeline and facilities integrity, corrosion control, and fitness for service. In 2005, CC Technologies joined the Norwegian DNV group of companies, where Dr. Thompson is currently interim director of a new corporate research group, DNV Research & Innovation, which is the first activity of its kind operating outside Norway for DNV.

Dr. Thompson has a B.S. and an M.S in materials science engineering from the University of Alabama, Birmingham, and a Ph.D. in materials science engineering from Vanderbilt University. He has worked in corrosion science for the past 30 years. Since 1982, he has performed numerous projects on underground corrosion and cathodic protection. He has published over 60 technical papers and a book on electrochemical testing and has authored or co-authored six patents in corrosion monitoring.

Dr. Thompson was the 2005-2006 president of NACE International, the world's leading professional association of corrosion specialists, and has been a NACE member for 29 years. He served on DoD's Defense Science Board and is a member of Alabama's Engineering Hall of Fame. Dr. Thompson was co-author of a congressional study on the economic impact of corrosion to the U.S. economy.

Dr. Thompson has grown CC Technologies-DNV from a 2-person company to 175 and employs the largest number of corrosion scientists in North America. CC Technologies operates worldwide on an array of difficult corrosion-related issues facing some of the world's largest companies.