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TRANSFER OF POLLUTION PREVENTION TECHNOLOGIES

Committee to Evaluate Transfer of Pollution Prevention Technology for the U.S. Army

Board on Manufacturing and Engineering Design

Division on Engineering and Physical Sciences

National Research Council

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PREFACE

In July 1999, in response to a request by the U.S. Army, the National Research Council (NRC) established the Committee to Evaluate Transfer of Pollution Prevention Technology for the U.S. Army under the direction of its Board on Manufacturing and Engineering Design. The specific organizations to be evaluated were the Industrial Ecology Center (IEC) and especially the National Defense Center for Environmental Excellence (NDCEE), Johnstown, Pennsylvania, for which the IEC had oversight responsibility from 1993 until 2000. The NDCEE was established by an act of Congress in 1990 for the purpose of demonstrating, applying, and disseminating advanced environmental technologies to the U.S. Department of Defense (DOD), as well as industry and other government agencies.

The overall objective of this study was to identify major barriers to, and approaches for, improving the transfer of pollution prevention technologies from the IEC to the U.S. Army, to other sectors of the Department of Defense, and to private industry, primarily defense contractors. After the initial scope of the project was defined and the committee was briefed on the overall IEC program, the sponsors and the committee realized both that the charge was very broad and that examination of representative projects as case studies would yield useful insights about major IEC and DOD-wide industrial pollution prevention programs. It was thought that the analysis of several technologies at the NDCEE would reflect a snapshot of barriers to technology transfer and implementation. Four such cases were identified, and the committee and sponsors agreed that recommendations based on what was learned in these cases could have a major impact on future technology transfer issues facing the Department of Defense. This report presents the results of the committee's consensus recommendations in response to the charge given.

This report has been reviewed 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 authors and the NRC in making the 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 participation in the review of this report:

Col. James A. Ball, retired, Strategic Defense Initiative Organization, Washington, D.C.,

Carl Handsy, Tank-automotive and Armaments Command - Armament Research, Development and Engineering Center, Department of the Army, Warren, Michigan,

James Holiday, Corpus Christi Depot, Department of the Army, Corpus Christi, Texas,

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John F. Rasmussen, Axsun Technologies, Billerica, Massachusetts,

Jerry Rogers, General Motors Research and Development Center, Warren, Michigan,

Donald Sekits, Boeing Defense and Space Group, Seattle, Washington, and

William Sharpe, Tank-automotive and Armaments Command - Armament Research, Development and Engineering Center, Department of the Army, Picatinny Arsenal, New Jersey.

Although the reviewers listed above 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. The review of this report was overseen by Richard A. Conway, retired, Union

Carbide Corporation. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

The chair also thanks the committee members for their participation in committee meetings and their effort and dedication in the preparation of this report; the sponsor, especially Robert Scola of the U.S. Army Industrial Ecology Center, speakers, and participants; and the staff of the Board on Manufacturing and Engineering Design, especially Patrick Doyle, who coordinated the meetings and provided substantial assistance in the preparation and publication of this report.

Sheila Kia, *Chair*
Committee to Evaluate Transfer of
Pollution Prevention Technology for the U.S. Army

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES AND TABLES

EXECUTIVE SUMMARY

The activities of the Department of Defense (DOD) and its contractors in manufacturing, testing, maintaining, and disposing of military equipment make up a significant portion of the industrial processes conducted in the United States. As is the case with the commercial industries, some of these activities, such as metal plating, have resulted in industrial pollution and environmental contamination. With increasing environmental regulation of such processes in recent decades, defense facilities have been faced with growing compliance issues. Department of Defense efforts to manage, correct, and prevent these problems have included the establishment of the National Defense Center for Environmental Excellence (NDCEE) under the management of the U.S. Army Industrial Ecology Center (IEC).

The National Research Council's Committee to Evaluate Transfer of Pollution Prevention Technology for the U.S. Army was formed to identify major barriers to the transfer of pollution prevention technologies and to recommend pathways to success. To address the study objectives, the committee (1) reviewed the NDCEE's technology transfer activities, (2) examined efforts to transfer technology in four areas, two of which were identified at the outset by the NDCEE as successful and two of which were identified as unsuccessful, and (3) identified opportunities for improving the transfer of pollution prevention technologies to maintenance and rework facilities in the Department of Defense and to industrial manufacturing facilities performing defense-related operations.

To facilitate the evaluation, four case studies of technology transfer were chosen that were representative of major industrial pollution programs in the Industrial Ecology Center and the Department of Defense. Two of these technologies, electrocoat and powder coating, are methods for applying coatings. The third technology, ion beam surface modification, is a method for improving coatings and surface condition, and the fourth, ultrahigh-pressure waterjet technology, is used for coatings removal and surface preparation. These technologies are within the purview of the NDCEE, which the Industrial Ecology Center managed from 1993 through 2000. The NDCEE's thrust areas are not limited to coatings, but these four areas were selected because they constitute a definitive and substantial part of the IEC's program. This report describes activities that occurred in the period from the NDCEE's inception until September 30, 2000.

APPROPRIATENESS OF TECHNOLOGIES

Military maintenance depots carry out a wide range of functions to refurbish and distribute materiel. Given this broad responsibility, certain technologies may be more appropriate than others in meeting an operation's needs. The complex requirements that coating technologies must satisfy encompass process reliability, throughput, and product performance as well as environmental impact.

One technology addressed early in the NDCEE program was electrocoat processing. For various reasons, electrocoat was not found by the committee to be appropriate for depot refinishing applications. It is a highly capital-intensive process and is suited almost exclusively to original equipment manufacturer, or OEM, applications. For the few specialized cases where electrocoat may be appropriate, commercial suppliers can readily fill the testing and demonstration needs.

> **Recommendation**. To better utilize technology transfer resources, the NDCEE should shut down its current electrocoat bath. In the event that any future demonstration of electrocoat technology is considered appropriate, the NDCEE should utilize the demonstration facilities of commercial suppliers of materials and process suppliers.

Also, ion beam technology, which has tremendous potential for application in surface modification, was not considered to be at an appropriate state of maturity for the investments made by the NDCEE. The NDCEE can maintain competency in the area in preparation for the future by establishing closer ties with research laboratories in the United States, both inside and outside the Department of Defense, and overseas that are actively and successfully engaged in ion beam surface modification research.

> **Recommendation**. No further effort or expenditure should be devoted to either utilizing or improving the existing ion beam equipment at the NDCEE, as this technology is still evolving. The

NDCEE's objective should be to develop and maintain an awareness of the potential for technology transfer to the U.S. military services, and to prepare to aid in implementation when the technology matures.

Transfer of powder coating technologies was similarly unsuccessful, and the NDCEE's documentation showed very limited evidence of implementation at Department of Defense facilities. While powder coating may result in improved performance and associated cost savings, the savings are unlikely to be large enough to offset the costs incurred by NDCEE for the overall development effort. Indirect costs, including those for permitting, monitoring, reporting, penalties, or damages, must be considered when evaluating the costs of implementing such new technologies.

Recommendation. The NDCEE should conduct a balanced assessment of alternative coating technologies to select the most appropriate approach for each defense application. The NDCEE must consider the trade-offs between direct environmental cost avoidance, indirect environmental improvements, and the cost of the technical effort needed to develop and implement powder coating technology or any pollution prevention technology.

Among the technologies examined, ultrahigh-pressure waterjet cleaning was the most appropriate for the NDCEE and offers numerous possibilities for pollution prevention across the services. Although the NDCEE has achieved some degree of success in transferring this technology, the limitations of the facility at the NDCEE must be overcome before the potential for this technology can be achieved.

Recommendation. The NCDEE should expand its efforts to transfer ultrahigh-pressure waterjet technology to additional types of applications. To support this effort, the NDCEE should configure the waterjet system at Johnstown for both in-house and field use to demonstrate technical applications. The NDCEE should also work more closely with commercial vendors of waterjet equipment and services and should purchase or lease field portable equipment as needed.

CRITERIA FOR SUCCESS IN TECHNOLOGY TRANSFER AT NDCEE

Successful technology transfer occurs when the organization receiving a technology assumes the cost of using the technology as part of its normal operating expenses. Successful technology transfer requires implementation of new technologies, not simply demonstration or implementation only after extremely long delays. Although technology awareness is raised by demonstrations, appropriate planning for technology transfer must identify the specific regulatory, organizational, and technical barriers to implementation from the beginning of the process.

The NDCEE's technology demonstration activities are substantial. However, results demonstrating cost-effective implementation of new processes have not been quantified. Planned program milestones could ensure visibility for the technologies across a broader array of potential users and help to establish government-industry implementation teams.

Implementing new technologies imposes costs on the user, on the organizations required to evaluate and approve the technology, and on the transferring organization. Consideration must be given to funding the efforts needed to test, approve, and implement the technologies demonstrated by the NDCEE at the Department of Defense system commands and the receiving depots. These depots are essential contributors to the success of any technology transfer.

Recommendation. The NDCEE should clarify in a mission statement the goals for all its programs along with stated interim and ending milestones. The NDCEE should provide this information and the background analysis to the potential recipient of a technology. Each program should set goals, for example, for the amount of pollution prevention to be achieved as a result of NDCEE efforts. These goals should be coordinated with NDCEE's technology partners, including original equipment manufacturers, DOD command organizations, DOD equipment depots, technology suppliers, technical consultants, and internal staff. An independent program oversight panel should regularly review and publish the NDCEE's quantifiable performance toward achieving these milestones.

Some specific coating technologies were selected for implementation at a very early stage in the NDCEE's operations. These coating technologies were identified as solutions to environmental problems at user facilities before the specifics of the situation were fully analyzed. For example, powder coat and electrocoat appear to have been applied where more in-depth consideration would have led instead to the use of high-solids or aqueous spray systems. These alternatives would offer improved environmental performance combined with easier implementation. Because the NDCEE chose the more complex technologies, power coat and electrocoat only reached the demonstration phase. As a result, pollution prevention technologies have not yet been implemented at many sites where they are needed.

Prior to accepting any projects, the NDCEE should perform a market survey of the site to assess the need to change or add technology. This assessment should include an economic analysis of any proposed process changes. The alternatives must be shown to offer improved environmental performance combined with easier implementation.

Recommendation. The NDCEE should perform system-level cost-benefit analyses for planned projects as well as for ongoing activities. These analyses should be conducted in light of NDCEE mission objectives and in close cooperation with all stakeholders and should include a market survey and a comparative assessment of all potentially useful technologies to determine the most appropriate approach to address user needs.

ORGANIZATIONAL FACTORS

Both the establishment of the NDCEE and the concept of providing technical and financial support during the later stages of technology transfer for pollution prevention are appropriate uses of government funding. An intermediary with the means to develop technological capabilities and the mandate to work through the organizational and technical barriers to adoption of pollution prevention technology has the potential to be a very effective agent for positive change.

Any intermediary such as the NDCEE that seeks to transfer technologies in a large, diverse organization such as the Department of Defense must bridge various organizational and cultural gaps. No matter what the environmental benefit, managers are understandably resistant to change in many defense systems, especially when lives depend on their successful operation. This cautious approach necessitates that the military system commands and the original equipment manufacturers be the primary arbiters of a technology transfer program's success.

The NDCEE appears to function at its best in support of organizations such as the Joint Group on Pollution Prevention and the Army’s Tank-automotive and Armaments Command. In these efforts, the NDCEE is integrated with the overall Department of Defense operation and has an organizational connection with the commands that can approve implementation of process changes.

Recommendation. The NDCEE should plan and operate programs with the goal of gaining the confidence and cooperation of the organizations responsible for approving new technologies for integration into the ongoing mission operations.

The complex organizational structure of environmental programs in the Department of Defense also plays a part in the difficulty of implementing new technologies. Because programs such as the Environmental Security Technology Certification Program and the NDCEE operate substantially in parallel, it is difficult to develop an overall picture of these programs in order to understand their effectiveness.

Another structural barrier involves management of equipment depots. Depot managers take a short-term approach to return on investment in commercial applications, yet their focus may not be to optimize payback. Although life-cycle costing for a piece of equipment may make sense from a total organizational standpoint, an individual depot manager may have different incentives and criteria for success. An organization like the NDCEE can be invaluable in demonstrating the overarching benefits of implementing a new technology.

A more pervasive structural barrier to implementation of new pollution prevention technologies is the use of military specifications or outdated procedures. Some specifications require processes and test procedures that may be inappropriate or outdated, and that can lead to false estimations of product life and life-cycle costs. Also, some may be written so as to give preference to the use of a specific technology, excluding other promising alternatives.

Recommendation. The NDCEE should integrate its activities more closely with the larger Department of Defense environmental and coatings programs and should cooperate with military specification developers, commercial industry, and coating materials suppliers in bringing all defense product finishing specifications up to date in the area of performance testing.

COLLABORATION AND OPENNESS

Information that would allow interested parties to learn about the activities of the NDCEE is currently limited. The NDCEE has not emphasized publishing its project results in either refereed literature or industry magazines, and data concerning NDCEE projects on its World Wide Web site generally consists of one- or two-page project descriptions. Greater access to more complete information would aid greatly in technology transfer efforts—both directly by attracting customers to the NDCEE and indirectly by contributing to general knowledge about the technologies under consideration.

Recommendation. The NDCEE should focus more effort on dissemination of its results, whether positive or negative. NDCEE staff should present and publish more technical and overview papers in military and technology-specific journals, should participate more fully in scientific and technical organizations, and should focus specifically on submitting papers to peer-reviewed journals and applying for patents where appropriate. Such participation will create a more visible presence for the NDCEE in the technical areas within its purview and will enable potential customers to more efficiently identify needed expertise and services. Publicly available Web pages should also be used to disseminate results.

A related issue is the lack of highly specialized subject-matter experts in the various technologies considered for implementation. Given the great breadth of activities the NDCEE has been tasked with over its history, the use of specialized experts from a broad range of institutions is essential to ensure program success. Such experts would cut down the learning period for new technologies, as well as help to gain the respect of organizations ultimately responsible for approving implementation of NDCEE programs.

Recommendation. The NDCEE should assemble a cadre of personnel who can provide the necessary continuing support to technology adopters, including training in technology and management. These experts should be capable of responding to the total breadth of DOD’s environmental concerns and provide technical advice or conduct case-specific experimental analyses. This service could be added either through direct staffing at NDCEE or through cooperative work with academic and government research centers in the appropriate fields, other mission organizations within the Department of Defense, or brokered relationships with industrial technology suppliers.

CONCLUDING REMARKS

Technology transfer is widely accepted as a difficult and costly challenge. The mission of the NDCEE toward this end is commendable, and the concept of establishing an intermediary organization to introduce and transfer new technologies for pollution prevention is certainly worthwhile. In practice at the NDCEE, unfortunately, this model has not been successfully demonstrated. The demonstration factory capabilities at the NDCEE investigated in this study are not a necessary or cost-effective means of demonstrating environmental technologies. Reliance on industrial facilities commonly used by the commercial users of coatings would be cost-effective and could lead to further collaboration with manufacturers.

Realization of several key elements of an effective intermediary strategy is necessary for success in transferring pollution prevention technology. These elements include (1) bridging the organizational gaps between the intermediary (the NDCEE), the technology users (the military system commands), and the technology suppliers (the original equipment manufacturers); (2) selecting and completing relevant projects with significant and quantifiable impacts; (3) supporting highly respected technical personnel both on staff and as external advisors; and (4) disseminating and publishing timely information on both successful and unsuccessful demonstrations.

1

INTRODUCTION

The Pollution Prevention Act of 1990 and the Clean Air Act Amendments of 1990 established a national environmental protection policy identifying pollution prevention as the preferred method of addressing problems created by industrial waste. Pollution prevention[1] is defined as ". . . any practice which reduces the amount of a hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and any practice which reduces the hazards to public health or the environment associated with the release of such substances, pollutants, or contaminants"[2]

Pursuant to the act, pollution prevention includes only those activities affecting the volume or the physical, chemical, or biological characteristics of substances in a way that is integral to a production process. Processes at the end of the production cycle, commonly called "end-of-pipe" processes, such as waste management, recycling, and waste treatment, are not included in the definition.

According to Executive Order 12088,[3] the head of each federal agency is responsible for ensuring that the agency's facilities, programs, and activities meet federal, state, and local environmental requirements. In response to increased interest in environmental issues during the late 1980s, along with requirements that the use of ozone-depleting chemicals in military systems be eliminated, the identification of hazardous waste sites on military installations, and rising costs of hazardous waste disposal, the U.S. Department of Defense (DOD) focused attention on pollution prevention. In Executive Order 12856,[4] the Pollution Prevention Act of 1990 and the 1990 Clean Air Act Amendments were declared applicable to federal facilities.[5]

As a result, the Department of Defense established pollution prevention programs and set a goal of reducing hazardous waste by 50 percent by 1999 based on a 1992 baseline.[6] In a recent National Research Council report,[7] environmentally compatible manufacturing technologies were identified as advances that could be leveraged to meet the needs of defense manufacturing. Coatings technologies were specifically identified as a target area.

In 1990, the Department of Defense established the U.S. Army Industrial Ecology Center, located at Picatinny Arsenal in New Jersey.[8] Picatinny Arsenal had been carrying out pollution prevention related functions since 1986. The Industrial Ecology Center was tasked to reduce the costs and risks of meeting the Army's long-range environmental goals for materials and processes used in the manufacture, overhauling, and maintenance of weapons systems. The three stated objectives of the Industrial Ecology Center are:

1) To provide technology and management tools to ensure compliance with environmental regulations and acquisition reform goals;
2) To coordinate, integrate, and transition environmental research and development related to pollution prevention and compliance; and

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[1] Section 6602(b) of the Pollution Prevention Act
[2] Pollution prevention can also be defined as the elimination of the waste stream. The term *pollution reduction* would then be used when the quantity or toxicity of waste is reduced but not eliminated.
[3] Executive Order 12088. Federal Compliance with Pollution Control Standards. Issued 1978. Available at <http://es.epa.gov/oeca/fedfac/cfa/eo12088.htm>. Accessed February 2002.
[4] Executive Order 12856. Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements. Issued 1993. Available at <http://es.epa.gov/program/exec/12856.html>. Accessed February 2002.
[5] Guide to Environmental Enforcement and Compliance at Federal Facilities. EPA 315-B-98-011. Available at <http://es.epa.gov/oeca/fedfac/yellowbk/yellowbk.pdf>. Accessed February 2002.
[6] Memorandum on Environmental Security Program Measures of Merit, Deputy Undersecretary of Defense (Environmental Security). Available at <https://www.denix.osd.mil/denix/Public/Policy/AF/Policy/note22.html>. Accessed February 2002.
[7] National Research Council. 1999. Defense Manufacturing in 2010 and Beyond. Washington D.C.: National Academy Press.
[8] Industrial Ecology Center. Available at <http://w3.pica.army.mil/iec>. Accessed July 2001.

3) To implement new environmental technologies via technology transfer to the U.S. Army, the Department of Defense, and industrial manufacturing facilities.[9]

NATIONAL DEFENSE CENTER FOR ENVIRONMENTAL EXCELLENCE

History

In direct response to projected requirements associated with environmental problems within the Department of Defense, Congress designated funds for the establishment of the National Defense Center for Environmental Excellence (NDCEE).[10] The NDCEE was established "as a national resource for demonstrating, applying, and disseminating advanced environmental technologies to the DOD, other government agencies, and industry."[11] Its stated mission is to:

1) Transfer environmentally acceptable materials and processes to defense industrial activities and private industry;
2) Provide training that supports the use of new environmentally acceptable technologies; and
3) Perform applied research and development, where appropriate, to accelerate the transfer of new technologies.[12]

The Industrial Ecology Center was the program management office that oversaw the NDCEE from January 1993 until September 2000. The Concurrent Technologies Corporation (CTC) has held the operating contract for managing the NDCEE facility and its programs since 1993. On April 30, 1998, the Army Materiel Command awarded a follow-on contract for $150 million to the Concurrent Technologies Corporation to operate the NDCEE for the next 5 years. The Concurrent Technologies Corporation, a professional services company with a staff of more than 1200, serves clients in the private sector, as well as state and federal government organizations.[13] This report describes activities that occurred in the period from the NDCEE's inception until September 30, 2000.

Organization

The NDCEE is organized to provide expert scientific, engineering, laboratory, and minifactory services to solve environmental problems for DOD organizations. Its task is to facilitate the transition of environmentally acceptable materials, engineering design tools, and manufacturing processes to defense industrial activities and to provide training to support their use. The NDCEE is meant to be uniquely capable of providing the Department of Defense with third-party, unbiased validation of environmental technologies. The center includes a 250,000-square-foot factory where technologies can be demonstrated, along with associated office space and laboratories for the testing and evaluation of materials and processes.

The projects undertaken by the NDCEE are divided into eight thrust areas:[14]

1) Cleaning/coating removal,
2) Inorganic coating,
3) Organic coating,
4) Recycle/recovery/reuse,
5) Environmental management,
6) Treatment and remediation,

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[9] See note 8 above.
[10] National Defense Center for Environmental Excellence home page. Available at <http://www.ndcee.ctc.com/>. Accessed February 2002.
[11] Funds provided pursuant to Public Law 101-302, May 25, 1990. Conference Report 101-493 directed that funds be provided to the University of Pittsburgh Trust to establish the NDCEE as a not-for-profit subsidiary of the university, May 22, 1990.
[12] See note 8 above.
[13] Concurrent Technologies Corporation. Available at <http://www.ctc.com>. Accessed February 2002.
[14] See note 10 above.

7) Technology transfer and insertion, and
8) Special projects.

A significant part of the NDCEE's mission is environmental cost analysis and health risk assessment for candidate technologies.

NDCEE Programs

The NDCEE has been tasked to work in a wide range of environmental fields. At its formation, the NDCEE was to address the initiatives listed below.[15] This extremely broad mandate was apparently recognized as such in the final item on the list.

1) Definition and staffing of a management, technical, and financial organization for the operation and administration of the NDCEE program;
2) Systematic assessment with DOD-designated organizations to determine and prioritize the nature, seriousness, and potential solutions in the following areas of environmental technology need:
    a) Hazardous waste remediation;
    b) Management of wastes falling under the Resource Conservation and Recovery Act (RCRA);
    c) Waste minimization;
    d) Municipal-type solid waste and incineration issues;
    e) Air pollution control;
    f) Medical waste disposal;
    g) Mixed waste disposal;
    h) Contaminated site remediation;
    i) Chemical weapons destruction;
    j) Recycling;
    k) Water pollution control and water usage;
    l) Underground storage tanks; and
    m) Nuclear waste disposal.
3) Identification and involvement of leading qualified academic, public, and private sector environmental technology resources to develop a broadly based NDCEE consortium capable of responding to the total breadth of Department of Defense environmental concerns.

In fiscal year 1993, the DOD Joint Environmental and Manufacturing Technology Policy Council approved eight initial demonstration tasks and the continuation of six technology assistance tasks. These tasks included subjects related to three of the four cases examined by the committee, specifically, powder coating, electrocoat, and ion beam surface modification. The remaining item, waterjet coating removal, was also pursued quite early in NDCEE's history through a number of published reports and a user conference held in 1995 in Johnstown, Pennsylvania.

Congress has mandated four additional tasks, which were as follows. These tasks add to the breadth of activities undertaken by the NDCEE.

1) Demonstration of automated plastic sorting at a DOD facility;
2) Demonstration of a liquid carbon dioxide pilot plant to evaluate effectiveness in reducing sulfur dioxide emission from boilers;
3) Medical waste tracking and management demonstration; and
4) Investigation of risks associated with use of toxic substances in the DOD manufacturing environment.

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[15] Scola, R. 1999. Pollution Prevention Program Overview. Background paper prepared for this study. Picatinny Arsenal, New Jersey: Industrial Ecology Center, U.S. Department of the Army.

Oversight

The U.S. Army Industrial Ecology Center acted as executive agent in the day-to day oversight and contract management of NDCEE from 1993 until 2000. This authority was delegated to the IEC by the Deputy Undersecretary of Defense for Environmental Security. In addition to the staff management personnel from NDCEE, the IEC assigned a technical monitor from its staff for each thrust area. Each task also had a DOD technical monitor, usually from an organization other than the IEC. Finally, four different advisory bodies support the activities of the NDCEE, as follows.[16]

The **DOD Working Group** consists of representatives from the Office of the Deputy Undersecretary of Defense for Environmental Security; the Army, Navy, Air Force, and Marine Corps; and the Defense Logistics Agency. The charter of this group is to oversee NDCEE projects. It functions as a clearinghouse of information and program results and provides integration with Service and DOD-wide programs. A major part of the government oversight of NDCEE is conducted through quarterly in-process reviews of its activities.

The **Strategic Oversight Committee** consists of individuals from academia and industry who review NDCEE strategic objectives and assist in peer review and in strategic and business planning.

The **Executive Advisory Council**, consisting of representatives from selected high-priority industries, meets three times a year primarily to identify and prioritize industry environmental problems. The council has had representatives from automotive, aerospace, and other defense manufacturing firms.

The **technical advisory groups** are made up of individuals supporting the NDCEE's technical thrust areas. Organic finishing and inorganic finishing are areas with active technical advisory groups.

In its operations, the NDCEE attempts to define user needs and select materials and processes to meet those needs through use of their facility in Johnstown, Pennsylvania, or site visits to depots or other user facilities. NDCEE's technology transfer process is summarized in six steps:[17]

1) Identify an enterprise representing a participator in need.
2) Survey the facility baseline to gather information on the technology need.
3) Test technology feasibility.
4) Test technology optimization.
5) Validate technology through demonstrations.
6) Complete technology transfer activities.

Sources of Funding

Funding for NDCEE is provided through three sources: direct Army support, congressional interest items, and cost-reimbursable programs supported by defense organizations and industry. The funding for NDCEE includes core funding for the operation of the facility and separate funding for specific projects. The direct Army support through the Industrial Ecology Center amounted to about $5 million per year. Target projects of congressional interest with separate line item budgets totaled approximately $99.7 million in fiscal years 1993 through 1999. Cost-reimbursable items from the Department of Defense, the Department of Energy, the Environmental Protection Agency (EPA), and industry clients totaled approximately $32 million over the same period.[18] EPA funding was provided through its Environmental Technology Verification program in the areas of coatings and coating equipment and metal finishing technologies.[19]

One of the NDCEE's projects is to provide engineering and technical services for DOD's Joint Group on Pollution Prevention, formerly known as the Joint Group on Acquisition Pollution Prevention.[20] The group, led by high-ranking officers of the Air Force, Army, Marine Corps, Navy, National Aeronautics and Space Administration (NASA), and the Defense Contract Management Command,

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[16] NDCEE. 1998. Five-Year Business Plan. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[17] NDCEE. 1997. Powder Coat Applications: Final Report and Project Summary. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[18] See note 15 above.
[19] Environmental Protection Agency. Environmental Verification Program. Available at <http://www.epa.gov/etv/>. Accessed February 2002.
[20] Joint Group on Pollution Prevention. Available at <http://www.jgpp.com/>. Accessed February 2002.

provides high-level policy guidance for defense pollution prevention activities. The Joint Acquisition Sustainment Pollution Prevention Activity, a working-level counterpart of the Joint Group on Pollution Prevention consisting of a group of managers from the member services and agencies, conducts various tasks at Department of Defense and contractor sites. Concurrent Technologies Corporation, the operating contractor for NDCEE, provides staff support to the Joint Group on Pollution Prevention through the NDCEE contract.

Relationship with Other Programs

A wide range of Department of Defense programs are working in the area of pollution prevention and their interrelationships are complex. Figure 1-1 shows a general framework of relationships among the major programs. The early stages of research, development, test, and evaluation are managed by the Office of the Director, Defense Research and Engineering (DDR&E). Field demonstration and validation are carried out under the Office of the Deputy Undersecretary of Defense (Environmental Security), or DUSD(ES). The day-to-day operations after implementation are carried out either by the Defense Environmental Restoration Program for environmental cleanup activities or with the regular operations and maintenance funds of the Department of Defense.

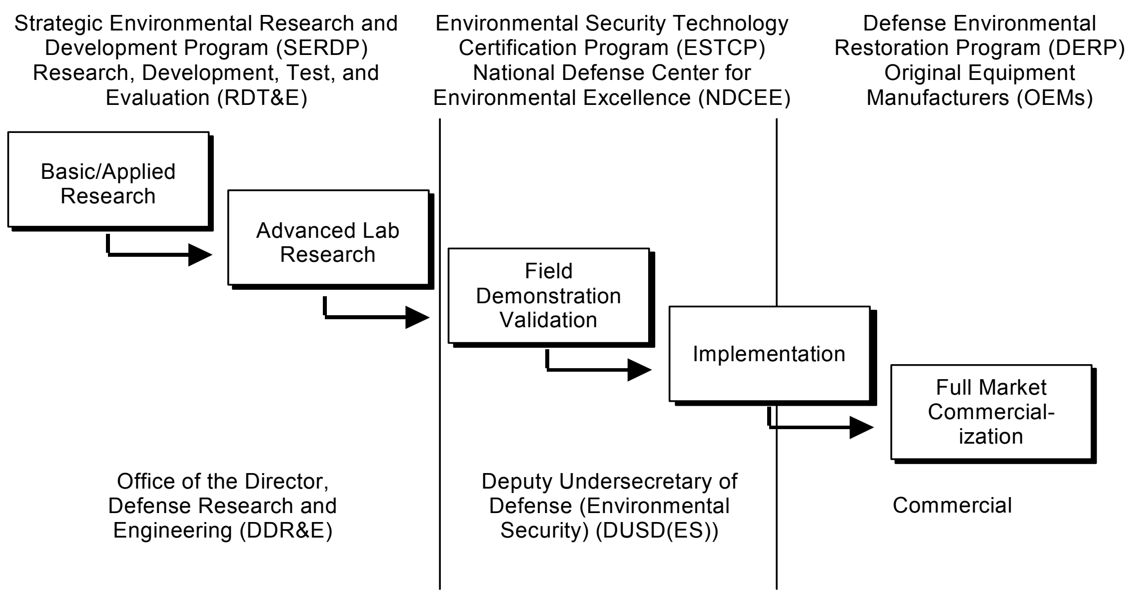

Figure 1-1 Department of Defense environmental technology programs.

The **Strategic Environmental Research and Development Program** (SERDP) is DOD's organizational research and development program for environmental matters.[21] Its principal participants are the Departments of Defense and Energy, and the Environmental Protection Agency. Other participants are NASA, the Department of the Interior, and the National Institute of Standards and Technology (NIST).

The four thrust areas of the Strategic Environmental Research and Development Program are cleanup, compliance, pollution prevention, and conservation. Funding for the program was approximately $45 million in fiscal year 1999, of which approximately $15.4 million was allocated to pollution prevention.[22] The pollution prevention program under SERDP is structured to address a wide variety of environmental problems associated with surface protection, energetics, advanced materials, and the elimination of ozone-depleting chemicals, and to provide life-cycle environmental tools to assist weapon systems designers. As one of many organizations funded for specific projects under SERDP, NDCEE has participated in several projects.

[21] Strategic Environmental Research and Development Program. Available at <http://www.serdp.org/>. Accessed February 2002.
[22] Environmental Security Program Budget Data. Available at <https://www.denix.osd.mil/denix/Public/ES-Programs/Program/Charts/FY99/updates.html>. Accessed February 2002.

Once the feasibility and utility of a new environmental technology concept have been proven, the next step in the Department of Defense research and development process is demonstration and validation, commonly called dem/val. This step validates technology prior to its transition to field use. The **Environmental Security Technology Certification Program** (ESTCP) and NDCEE are separate programs, both established to accomplish this objective.

The goal of the Environmental Security Technology Certification Program is to demonstrate and validate promising technologies to target DOD's most urgent environmental needs. These technologies are projected to pay back the investment through cost savings and improved efficiency. Current costs for environmental remediation and compliance in the Department of Defense are significant. Remediation totaled approximately $1.26 billion in fiscal year 1999; costs for compliance totaled approximately $1.89 billion in fiscal year 1999. Both figures have declined slowly since 1993, when they were $1.64 billion and $2.13 billion, respectively.[23] Based on the belief that innovative technologies can reduce both costs and environmental risks, this program's strategy is to select laboratory-proven technologies with broad defense applications and aggressively move them to the field for rigorous trials. The ESTCP then documents their costs, performance, and market potential. Successful demonstration of a technology leads to its acceptance by defense end users and the regulatory community. To ensure that the demonstrated technologies have real impact, the ESTCP includes these organizations in the development and execution of its programs.[24]

As indicated in Figure 1-1, the ESTCP and the NDCEE operate in parallel, although they cooperate on some projects. For example, the NDCEE participated in an ESTCP project on the use of powder coating for small arms bullet tip identification.[25]

The U.S. Air Force’s **Coatings Technology Integration Office** (CTIO), associated with the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio, has a number of projects to accomplish pollution prevention through the use of improved coatings.[26] The Coatings Technology Integration Office operates separately from the NDCEE. One project at CTIO is an assessment of the baseline performance of the Air Force’s existing aircraft coating systems. This characterization includes measurements of corrosion resistance, flexibility, adhesion, hydraulic fluid and jet-fuel resistance, and cleanability.

The intent of the assessment is to establish baseline levels of performance for current systems to compare with future changes to coatings systems, including those intended for pollution reduction. Other CTIO projects include optimizing paint removal processes for performance and pollution reduction with both dry particles and chemical systems and improving high-solids liquid paint systems.

The **Industrial Ecology Center** manages the Army's Environmental Quality Pollution Prevention Technology Program, which includes the Environmental Quality Basic Research and Development (EQBRD) Program, the Sustainable Green Manufacturing (SGM) Program, and the Corrosion Protection Control (CPC) Program. The responsibilities of the Industrial Ecology Center also include participation as the Army’s representative to the SERDP Pollution Prevention Technology Thrust Area Working Group and the Pollution Prevention Panel of the ESTCP.

The **Environmental Quality Basic Research and Development** Program emphasizes basic research to provide the fundamental scientific and technological building blocks to support the more mature, advanced development efforts. This $4 million per year Army program is focused primarily on evaluating the feasibility of early technology concepts for pollution prevention in the Army's industrial base. Its objective is to advance the state of the art in pollution prevention and the life-cycle management of hazardous materials and wastes. Its goal is to develop technologies to aid in maintaining readiness by reducing the costs and risks of meeting the Army's long-range environmental challenges.

The Environmental Quality Basic Research and Development Program's investment strategy is focused on identifying the waste streams associated with the manufacture, maintenance, and disposal of Army-unique products and conducting basic research to provide the maximum economic return. The program targets the critical areas of processing of energetics, metal finishing, cleaning/degreasing, and painting, which generate 85 percent of the Army Materiel Command’s wastes.[27]

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[23] See note 22 above.
[24] See note 22 above.
[25] Environmental Security Technology Certification Program. Available at <http://www.estcp.org/>. Accessed February 2002.
[26] Air Force Coatings Technology Integration Office . Available at <http://www.ml.wpafb.af.mil/facilities/ctio/>. Accessed February 2002.
[27] See note 15 above.

The **Sustainable Green Manufacturing** Program is an alliance with participation from the Armament Research, Development, and Engineering Center (ARDEC), NDCEE, and the New Jersey Institute of Technology. The program focuses on research in pollution prevention and life-cycle environmental issues with impacts on military systems.

The Sustainable Green Manufacturing Program has the following objectives:[28]

- Promoting reform of Army and DOD acquisition processes through sustainable green manufacturing,
- Improving environmental quality and increasing cost savings through efficient and effective life-cycle management, and
- Conducting research and development to address the needs of the Army that bridge environmental stewardship and the sustainability of the Army's armament mission.

The Industrial Ecology Center, which serves as a co-chair of the **Corrosion Protection Control** Program in the Army Materiel Command, is responsible for addressing the concerns about the corrosion of Army weapons systems, including cost control. The program objective is to reduce weapon system maintenance costs related to corrosion by 25 percent by the year 2005. The program's effectiveness is tracked by the Industrial Ecology Center using performance indicators including success in technology transfer, cost savings, extension of maintenance cycles, equipment design modifications, pounds of hazardous materials eliminated, and number of meetings, papers, and training events.

STUDY OBJECTIVES AND APPROACH

In January 1999, the Industrial Ecology Center asked the National Research Council (NRC) to evaluate the techniques being used to transfer pollution prevention technologies from the NDCEE to various Department of Defense operations. Under the direction of the NRC Board on Manufacturing and Engineering Design, the Committee to Evaluate Transfer of Pollution Prevention Technology for the U.S. Army was formed to perform the following three tasks:

1) Review the technology transfer activities of the Industrial Ecology Center, examine successful and unsuccessful technology transfer efforts, and identify lessons learned and opportunities for improvement;
2) Organize briefings by weapons systems program managers and facility operators to gather information on perceived barriers to implementing innovative technologies;
3) Recommend the opportunities for improved technology transfer processes for pollution-prevention-related technologies from the Industrial Ecology Center to maintenance and rework facilities in the U.S. Army and DOD and to industrial manufacturing facilities.

To facilitate the evaluation, the committee was asked to review four case studies of technology transfer that were representative of major industrial pollution prevention programs in the Industrial Ecology Center and the Department of Defense. These four areas were powder coating, electrocoat, ultrahigh-pressure waterjet coating removal, and ion beam coating deposition. These technologies are the purview of the NDCEE, which the Industrial Ecology Center managed from 1993 through 2000. The NDCEE's thrust areas are not limited to coatings, but these four areas were selected because they constitute a definitive and substantial part of the Industrial Ecology Center's pollution prevention program

[28] See note 15 above.

Chapter 2

TECHNOLOGY TRANSFER

Effective technology transfer is a difficult and complex process. Even the definition of *technology transfer* is complex. Numerous definitions can be found,[1] including one that concludes the term is too broad for a general definition to be useful! The National Technology Transfer Center defines technology transfer as "the process of utilizing technology, expertise, know-how, or facilities for a purpose not originally intended by the developing organization."[2] Because the NDCEE was established to transfer technologies developed for commercial applications to military uses, the NTTC definition was adopted for the purposes of this study.

CHARACTERISTICS OF SUCCESSFUL TECHNOLOGY TRANSFER

One important measure of success in technology transfer is the extent to which the receiving organization spends its own money to use and advance the technology. This measure implies that the technology is economically viable. If a technology is demonstrated at an enterprise through direct involvement with the transferring organization, but is ignored by that receiving enterprise once the transferring organization departs, the transfer cannot be considered successful.

The following are prerequisites for successful technology transfer:[3]

- The technology must be appropriate for the proposed application.
- The technology must be at an appropriate level of maturity.
- The recipient must be at an appropriate level to apply the technology.
- The technology must meet the organizational needs of the recipient.
- The technology must be economically viable.

The technology transfer process is widely accepted as a difficult one. It must be a process of cumulative learning, in the same manner as successful research and development.[4] The difficulties of transferring a new technology to the world or merely transferring one that is new to a particular organization or site are comparable. In either case, knowing why a particular technology works is often as important as knowing how to make it work. Because technology transfer depends on the transfer of knowledge in the specific context of the adopting location, understanding the reasons for a particular technological choice is essential for building on the transferred knowledge. Thus, the transferring organization must also have a complete understanding of the processes being transferred.

Technology transfer is a way of linking knowledge to need. Understanding the user's needs and their special circumstances and needs for products and processes are vital, as are continuing strong links between the users and the producers of the technology.

It is common practice to refer to technology transfer as a "contact sport." This is to say that extensive contact between individuals in the transferring and receiving organizations is essential for a successful transfer. This contact may be formal or informal. Formal technology transfer, as documented by the publication of papers either by the transferor or the receiver, or by installation of equipment at the receiving organization, is important. However, publications and reports are generally less effective than the movement of people for transferring a technology, because much technical know-how is typically unwritten. Therefore, a successful transfer of technology may require extensive person-to-person

[1] Washington, D.C., chapter of the Technology Transfer Society. Available at <http://millkern.com/washtts/docs/ttdefmec.html>. Accessed February 2002.

[2] National Technology Transfer Center. Available at <http://www.nttc.edu/aboutnttc/faq.asp>. Accessed February 2002 .

[3] Mansfield, E., A. Romeo, M. Schwartz, D. Teece, S. Wagner, and P. Brach. 1982. Technology Transfer, Productivity, and Economic Policy. New York: W.W. Norton. p. 29.

[4] Brooks, H. 1995. What we know and do not know about technology transfer: Linking knowledge to action. Published in Marshaling Technology for Development: Proceedings of a Symposium. Washington, D.C.: National Academy Press.

contact, and at times will even require a transfer of personnel for extended periods of time. Personal relationships and a degree of trust also help to bridge organizational and cultural differences that can delay technology implementation.

Although it is common knowledge that substantial resources are necessary to develop a new process or product, it is less well known that transferring technology, once it is developed, is an expensive, extended process. Sources of this cost include:[5]

- The cost of preengineering technological exchanges, during which the basic characteristics of the technology are discussed with the receiving organization;
- The engineering costs of transferring the process design and the associated production engineering;
- The costs of research and development personnel, ideally from both parties, throughout all phases of the transfer, including solving unexpected problems during the transfer and adapting or modifying the technology as needed; and
- Pre-startup training costs and the costs associated with reduced productivity during the changeover.

Many of the costs of technology transfer are typically borne by the recipient. Therefore, provisions must be made for meeting these costs, in terms of the specific technology and the specific conditions present. For a smooth transition, the parties must agree in advance on the equitable allocation of costs. Provisions for dealing with unexpected costs and conditions should also be written into the technology transfer agreement. The transferring organization's understanding of the technology is critical and can be gauged by the number of startups of the technology. The following are five characteristics of successful innovators:[6]

1) A thorough understanding of user needs;
2) Careful attention to marketing;
3) Efficient development work;
4) Effective use of outside technology and scientific advice; and
5) Senior staff responsible for innovation.

A critical point in materials development is the transition point between technology push from the research community and product pull from the users of technology. The development of a technology may be divided into the following five phases, where this critical point is listed as Phase 2.[7]

Phase 0 - Knowledge-Base Research

Phase 1 - Material Concept Development

Phase 2 - Material Process Development

Phase 3 - Transition to Production

Phase 4 - Product Integration.

Phase 2 has been called the "valley of death" in the materials science and engineering community because of the formidable barriers that must be overcome. These barriers begin with the perception that funding is variable and unstable, relative to the earlier and later stages of development. They also include the high costs and long time frames associated with certifying an innovation in materials or processes, especially in fields with high complexity and liability potential such as aerospace, and the difficulty of accurately estimating the costs, technical trade-offs, and demand for a

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[5] See note 3 above.
[6] Wang, Q., and N. Von Tunzelmann. 1998. A Study of the R&D/Marketing Interface Using SAPPHO Methodology. Brighton, United Kingdom: University of Sussex.
[7] National Research Council. 1999. Materials Science and Engineering: Forging Stronger Links to Users. Washington D.C.: National Academy Press.

material or process in order to quantify the potential of the innovation. The wide spectrum of expertise required to complete the development of materials or processes is also a barrier, which is generally beyond the ability of any one individual and may require multidisciplinary teams. In addition, the difficulty of mobilizing academic researchers to work in this phase of research is difficult because of the perception that this work is not as valuable as the earlier phases of research. Finally, differences in cycle times between academic research and industry make long-term collaboration difficult.

Technology transfer through a large corporation can be described as a form of Fibonacci series.[8] The basic Fibonacci series begins with 0, then 1, and each successive result is the sum of the previous two results. The series representing the number of organizations using a technology tends to be as follows: 0,1,1,2,3,5,8,13... indicating that a technology starts slowly but then catches on rapidly. When there are few users, resistance to adopting a new technology tends to be high, but once there are many users the technology is perceived as proven and tends to catch on rapidly, even if the supporting evidence is limited. This sequence reflects that few people are qualified to evaluate a technology on its own merits; so instead of evaluating the technology, they look around and see who else is using it.

The spread of a new technology from the early adopters, who are willing to work out the "bugs" inherent in a new technology, to the bulk of users is a difficult journey.[9] Most users of a technology wait until the technology is mature enough to be adopted easily. In the meantime, they observe the experience of early adopters to determine the usefulness and readiness of the technology for their needs. The mechanisms for communication of the technology from one location to another must be present for transfer to take place. The complexity of the process indicates that knowledge alone is not sufficient.

The barriers to successful technology transfer must all be addressed and overcome in an effort parallel to the development of the technology itself. These barriers are:[10]

1) Lack of awareness of available technologies and organizations available to assist;
2) Lack of the knowledge needed to use the technology;
3) Lack of funds; lack of common interests between the transferring and recipient organization;
4) Conflict of interest that would compromise the competitive position of the recipient organization;
5) Lack of trust between the transferring and receiving organization; poor communication; lack of resources, such as equipment; and
6) Lack of time to develop and implement a new process.

The following additional factors can prevent success:

1) Technical problems, which generally can be overcome, but can add time, cost and frustration;
2) Resource limitations, such as uncertainty about funding or poor budget control;
3) Changes in a project, such as withdrawal of a partner or the loss of key staff members; and
4) Organizational problems, such as a partner losing interest in the technological area.

TRANSFER OF POLLUTION PREVENTION TECHNOLOGIES

The successful transfer of a pollution prevention technology requires a detailed understanding of the needs and characteristics of the product to which it will be applied and the facility to which it is being transferred. Unfortunately, most technology transfer does not start with this level of understanding; in fact, "most of the process change literature is inadequately detailed and very few industrial operations are so generic as to allow direct implementation of waste reduction measures from published materials without significant in-house research and experimentation."[11] The challenge of achieving pollution

[8] Jones, C. 1995. Why is technology transfer so hard? IEEE Computer 28(6):86-87.
[9] Moore, G. 1995. Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers. New York: Harper Business.
[10] Cooke, I., and P. Mayes. 1996. Introduction to Innovation and Technology Transfer. Norwood, Massachusetts: Artech House Technology Management and Professional Development Library.
[11] U.S. Congress. 1986. Serious Reduction of Hazardous Waste: For Pollution Prevention and Industrial Efficiency, OTA-ITE-317. Washington, D.C.: Office of Technology Assessment, p. 99.

prevention goals in diverse, decentralized companies is very analogous to that in the government.[12] Despite the common assumption that the Department of Defense is a monolithic organization managed from the top down, the department's decentralized methods of manufacturing and maintaining weapons systems have much in common with those functions of a decentralized corporation.

Geographic proximity and direct communication, including informal interactions between employees, are critical for the transfer of a pollution prevention technology in such a decentralized organization. Utilizing process teams can enhance communication across traditional organization and job function lines in technology transfer, as well as many other fields.[13]

In addition, the Internet has provided new means of establishing communications between geographically distant locations. However, the formation and maintenance of long-distance relationships require the development of two other types of proximity—organizational proximity and cultural proximity. Organizational proximity can be promoted through membership in joint project teams or by the placement of employees in the facilities of a cooperating organization. Cultural proximity typically evolves over time but can be promoted through the adoption of common business practices, jargon, ethical standards, and language.[14]

Organizations that have extensive experience with change and product and process innovation are more likely to be successful in adopting a technology than are organizations with a history of resisting change. Often, opportunities to reduce emissions occur coincidentally with other process changes, and an innovative organization will be able to take advantage of those coincidences. It has been postulated that any change implemented in a product or process creates opportunities for implementing pollution-reducing technologies as well.[15]

The elements of economic pressures and competing interests, however, cannot be underestimated. Although a process change may make long-term economic sense, external business factors can prevent implementation. For example, even with a potential savings of more than $1 million per year, a major chemical facility did not implement identified pollution prevention strategies because of competing business and economic factors.[16] In both the military and the commercial arena, economic pressures are strong to continue using relatively mature processes rather than introducing change.

Carefully designed organizational relationships and agreements are essential to technology transfer.[17] Relationships between the transferring organization, the recipient, and any intermediaries, such as regulators, can be defined through a contract or contracts carefully structured to the mutual advantage of all parties. Contracts can also ensure the security of proprietary information and allow for change in the relationship over time. The owners of intellectual property naturally resist sharing their hard-earned knowledge, unless they are assured that the information will be secure.

Increasingly specific and restrictive emission regulations make it likely that pollution prevention technologies will be developed and transferred.[18] To a large degree, pollution prevention efforts have been driven by regulatory changes. In general, innovation occurs only when (1) stringent regulations are adopted and firms must innovate to comply, and (2) programs are developed specifically to encourage innovation.[19] If schedules for meeting regulations are too short, they may, in fact, limit innovation. The 1970 Clean Air Act is an example of stringent deadlines forcing the adoption of end-of-pipe compliance technologies, rather than process change.

For many technologies, the trade-off between direct environmental cost avoidance, indirect environmental improvements, and the cost of the technical effort to develop and implement technologies is subject to constant change. Indirect costs, including permitting, monitoring, reporting, penalties, or environmental damages must be considered when evaluating the implementation costs for such new technologies. As regulations are implemented and interpreted, organizations are driven toward new technologies, and indirect environmental costs and environmental cost avoidance can both gain in importance. For example, powder coatings have the potential to reduce volatile organic carbon (VOC) emissions to essentially zero, whereas the application of aqueous coatings or high-solids coatings

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[12] Rappaport, A. 1993. Development and Transfer of Pollution Prevention Technology. Westport, Connecticut: Quorum Books.
[13] See note 12 above.
[14] National Research Council. 2000. Surviving Supply Chain Integration: Strategies for Small Manufacturers. Washington, D.C.: National Academy Press.
[15] See note 12 above.
[16] Greer, L, and C. van Löben Sels. 1997. When pollution prevention meets the bottom line. Environmental Science and Technology 31(9):418A-422A.
[17] See note 14 above.
[18] See note 12 above.
[19] See note 12 above.

results in comparatively large VOC emissions. Direct environmental cost accounting may not recognize this difference, yet there is an environmental improvement to be made by going to powder coating technologies. Reduction in VOC emissions in urban areas has a positive impact on air quality and improved health for residents, but it is difficult to quantify with a dollar figure. Finally, the cost of implementing new technologies will decrease as more organizations adopt them.

International technology transfer may provide a convenient analogy for relationships between organizations involved in pollution-prevention efforts. In both cases, the recipient organization must work with an unfamiliar, and perhaps mistrusted, outside organization. In international situations, the recipient may fear becoming technologically dependent or that the transferring organization may not act in the interest of the recipient.[20] To allay these fears and emphasize the necessity of joint effort, transferring organizations often refer to the process of technology transfer as "technological cooperation." This change in terminology reflects a useful change in the mind-set at the corporate or organizational level and is not just a politically correct term.[21]

ROLE OF AN INTERMEDIARY IN TECHNOLOGY TRANSFER

The observations concerning the broad scope of knowledge and leadership qualities required for successful technology transfer support the view that an intermediary organization could greatly facilitate new technology adoption. A system for assessing the maturity and viability of a technology, with the full involvement of the developers, potential recipients, and other involved parties, is also necessary for success. An intermediary organization, which can facilitate but not control a transfer, must have excellent leadership skills, be able to develop person-to-person relationships, and must engender trust. The intermediary is primarily an integrator and should be perceived by the recipient organization as a part of a larger encompassing organization rather than an outsider.

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[20] See note 3 above.
[21] See note 16 above.

Chapter 3

NDCEE TECHNOLOGY TRANSFER: SELECTED CASES

Paint and coating materials are used extensively at DOD facilities. Vehicles, ships, and aircraft are coated at the time of initial manufacturing and are refinished during the life cycle as required. Coatings are used for a variety of purposes, including to protect exposed surfaces against corrosion and other forms of environmental deterioration; to add camouflage; to reduce radar signatures; or to facilitate removal of chemical and biological weapon residues. A variety of coatings are used across the military, but most involve standard liquid paint systems using spray or brush application. For example, the standard polyurethane coating system for Air Force equipment consists of high-solids epoxy primer, polyurethane primer, polysulfide primer, or water-reducible epoxy primer, topcoated with high-solids polyurethane.[1]

The Department of Defense has experienced environmental problems in its existing paint application facilities and has, in some cases, incurred violations for exceeding air emissions standards.[2] Consequently, various efforts within DOD have focused on investigating environmentally friendly coating materials as alternatives to those used currently. The NDCEE has worked with the U.S. Army, the Department of Defense, and defense contractor organizations to transfer various pollution prevention technologies. To identify lessons learned and opportunities for improvement in technology transfer activities, four of these technologies were selected as cases studies:

I. Electrocoat;
II. Powder coating;
III. Coating removal by ultrahigh-pressure waterjet; and
IV. Ion beam surface modification.

CASE I. ELECTROCOAT AND CASE II. POWDER COATING

Waterborne electrocoat technology—Case I—is widely used in automotive, appliance, and general industrial metal coating applications. In this process the pretreated object is immersed, usually by a conveyor system, in a bath containing a colloidal dispersion of an organic coating at 10 to 20 percent solids content. The coating is deposited by electrical transport (electrophoresis) at 200 to 400 volts, using a cathodic or anodic process as shown in Figure 3-1. Common industrial applications for electrocoat include clothes hangers, wire screens, metal air diffusers, automobile bodies, home appliances, office furniture, and lawn mowers**.** Electrocoat can provide excellent corrosion protection, especially for creviced configurations. The coating materials and solutions are relatively nonpolluting.

Powder coatings—Case II—are manufactured from ingredients such as polymeric binders, cross-linkers, pigments, and additives, most of which are solids at room temperature. The ingredients may also include liquid additives, such as flow agents, that are premixed with one of the solid components prior to the melt mixing. The ingredients are then mixed in an extruder at temperatures high enough to melt the polymeric binders, cooled, and then pulverized to form the powder, which is packaged for transportation to the application site. It is applied to the substrate, most often with an electrostatic spray gun or in a fluidized bed process, to deposit a uniform layer of charged powder particles onto the electrically grounded part. This layer is converted to a continuous film by baking, typically at temperatures ranging from 135 to 180 ^{o}C (275 to 356 ^{o}F).

Powder coating technology is relatively mature, having originated in the 1950s and 1960s, and is widely used in commercial original equipment manufacturing (OEM) applications, including automotive, appliance, and general metal finishing. Powder coatings are used primarily in high-volume applications for metal substrates at factories where the products are manufactured. Generally characterized by long runs of standard colors on relatively small metal objects requiring a rugged, durable finish, powder

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[1] NDCEE. 1995. Program Management Plan. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[2] See note 1 above.

coatings are also used in some refinishing operations, such as those for metal office furniture. Processing requirements for expensive equipment, high-temperature bake treatments, and frequent color changes generally make the technology unattractive for smaller-scale refinishing operations such as those at auto-body repair shops.

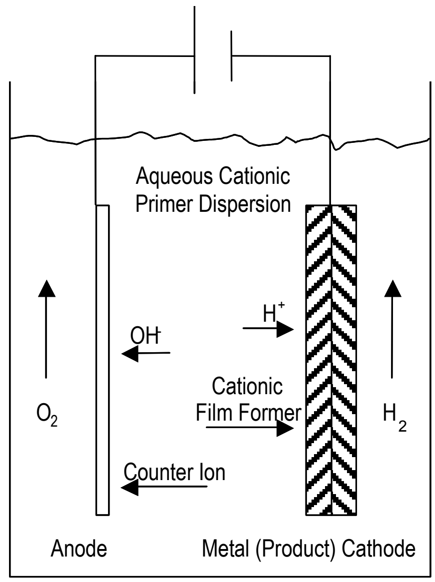

Figure 3-1 Schematic of electrodeposition process.

NDCEE Program Overview

In 1994, the NDCEE was tasked by the U.S. Army Tank-automotive and Armaments Command's Armament Research, Development and Engineering Center (TACOM-ARDEC) to facilitate the transition of electrocoat and powder coating technologies to both Department of Defense and defense industry applications.[3] These two technologies were among the original project areas identified at the establishment of the NDCEE.

The plan created by the NDCEE for transferring electrocoat and powder coating technology contained seven activities to meet the requirements of the statement of work:[4]

1) Establish baseline and identify requirements;
2) Develop electrocoat and powder coat technology benchmarks;
3) Establish a demonstration and training facility;
4) Perform applications engineering;
5) Conduct process validation;
6) Complete process verification; and
7) Complete technology transition.

[3] O'Connell, M.W. 1994. Transmittal letter from Michael W. O'Connell, Jr., Contracting Officer, U.S. Army Armament Research, Development and Engineering Center, to Herman Marine, Concurrent Technologies Corporation. August 19, 1994.
[4] NDCEE. 1995. Final System Design and Equipment Layout. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

One of the initial efforts undertaken by the NDCEE was a survey of commercial powder coating and electrocoat practices to establish a "state-of-the-market" baseline. Using a simplified costing program developed by PPG Industries, NDCEE also conducted an economic analysis of the two technologies.[5] The relationship between annual cost and cost per square foot was calculated for powder coat or electrocoat technologies for different production volumes used in the economic analysis (Figure 3-2).

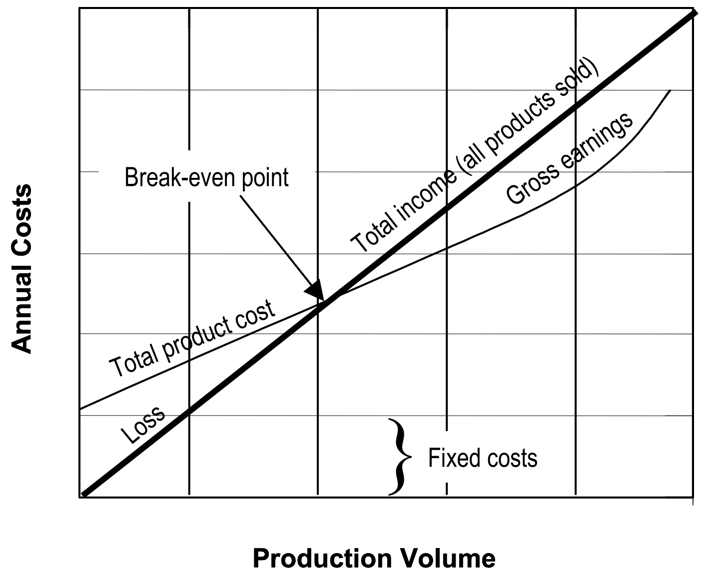

Figure 3-2 Annual cost of powder coating or electrocoating at various production volumes. Source: NDCEE. 1995. Report Comparing Industrial and Military Procedures in Cleaning, Preparation, and Coatings Application. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

Calculations based on this data show higher costs per part at low production volume, primarily because of the high capital cost of the equipment required (Figure 3-3). Most military applications would have production volumes well below 100,000 square feet per year, and the cost per square foot coated would be correspondingly high. This analysis confirmed the findings of numerous studies on the same topics over the past 30 years. The minimum economic volume for electrocoat has been characterized as at least 2 or 3 million square feet per year of painted surface, or a significant percentage of the overall painted surface market.[6]

Based on its review of military procedures, industrial practices, and the overall program plan, the NDCEE installed an electrocoat and powder coating demonstration facility at the NDCEE's Johnstown location. The rationale for an in-house facility was that it would provide an opportunity to independently validate materials and processes offered by commercial suppliers and to test and validate the coating technologies for specific Department of Defense applications prior to technology transfer.

The powder coat and electrocoat facility includes a seven-stage pretreatment/surface preparation unit; a cathodic five-stage electrocoat system; a powder application system with a booth; automatic and manual guns; two powder collection and reclamation modules; a wet spray system; ovens; material-handling systems; and system controls and data collection capabilities. The equipment purchase and installation cost of the facility was approximately $3 million, and the cost of operating the facility since its inception in 1994 is about $2.4 million.[7] The system allows for varying process parameters such as production volume and product size, weight, configuration, and residence time. It is capable of processing 60 parts per hour with a maximum part dimension of 1.22 m (4 feet) high by 1.22 m (4 feet) long by 0.91 m (3 feet) wide and a maximum weight of 113 kg (250 pounds).

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[5] NDCEE. 1995. Report Comparing Industrial and Military Procedures in Cleaning, Preparation, and Coatings Application. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[6] Triplett, T. 1997. The economics of electrocoat: Investing in electro-coating may not be as costly as you think. Industrial Paint and Powder. Available at <http://www.ippmagazine.com/articles/1997/997arc1.htm>. Accessed February 2002.
[7] See note 3 above.

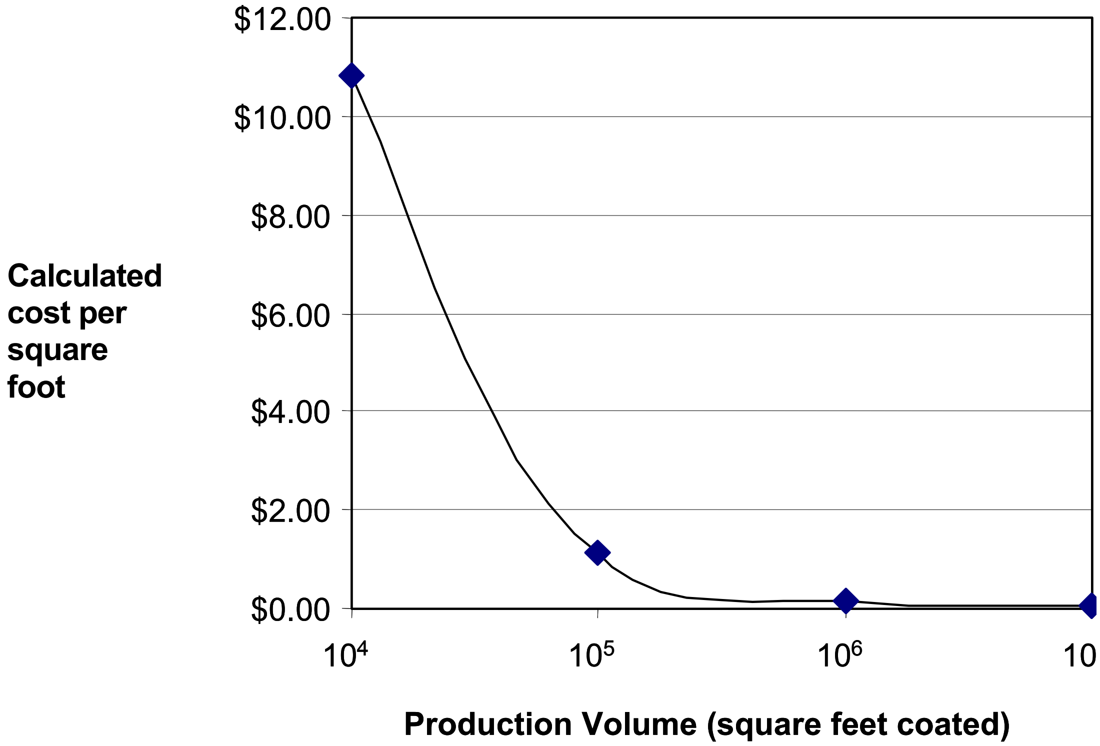

Figure 3-3 Calculated cost per square foot for electrocoat at various production volumes. The relationship shown is similar for powder coating. Data source: NDCEE. 1995. Report Comparing Industrial and Military Procedures in Cleaning, Preparation, and Coatings Application. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

To identify military coating applications for these technologies and to help the Department of Defense and government-owned, contractor-operated (GOCO) installations implement appropriate technologies, the NDCEE's technology transfer effort includes:

- Selection of coating materials, application techniques, and process parameters;
- Testing of powder coat and electrocoat materials to military specification requirements;
- Coating system design, configuration, and installation; and
- Training for personnel who will operate a system, as well as on-site start-up assistance.

Program Effectiveness

Both powder coatings and electrocoat are relatively mature technologies in commercial applications. Whereas commercial applications of these technologies focus on newly manufactured metal objects, the potential military applications for these coatings primarily involve refinishing of previously painted components.

Electrocoat

The electrocoat program at the NDCEE was initiated based on interest expressed by the U.S. Army Tank-automotive and Armaments Command (TACOM) and the Naval Air Systems Command (NAVAIR). The NDCEE has participated in evaluation of this technology for two sites, the Jacksonville Naval Air Depot (NADEP-JAX) and TACOM. For the Naval Air Depot, the NDCEE established preliminary operating parameters for powder coating or a powder coat/electrocoat system. Although the technology has not yet been implemented, a pilot electrocoat line is in operation for production testing.

Support provided by the NDCEE has included training and equipment design and installation.[8] For the Tank-automotive and Armaments Command, the NDCEE demonstrated a combination of electrocoat/powder coatings used as a primer to meet or exceed current performance requirements.[9]

Several reasons may account for this limited success in technology transfer. A primary reason is given in the initial assessment by NDCEE, which showed that an electrocoat system is cost-effective only if production exceeds a threshold volume, as shown in Figure 3-2 and Figure 3-3.[10] The technology is very costly at low production volumes primarily because of the various fixed costs associated with the process. Most of the applications for this technology at defense facilities are for refinishing rather than for production coating. Generally, the production volumes of refinishing applications are small, and the potential advantages of an electrocoat system are thus masked by high capital and maintenance costs.

In addition, the NDCEE was able to test only one electrocoat material at its facility in Johnstown.[11] Additional electrocoats could not be tested because of the difficulty of switching materials in the electrocoat tank, whose volume of more than 11,400 liters (3000 gallons) makes changing materials for the purpose of testing cost-prohibitive. This limitation clearly affects the transfer of electrocoat technology by the NDCEE.

Finally, an electrocoat bath is reliably stable only if it is used frequently. In industrial practice, 6 to 10 turnovers of the bath contents per year are typical. Currently the electrocoat bath at the Johnstown facility is used very infrequently. Considering its minimal use and large size, the present Johnstown bath must be monitored and its quality re-established each time the facility is used.

The electrocoat bath at the NDCEE Johnstown facility is maintained at an annual cost of approximately $50,000.[12] The need for this expenditure is unclear given the existence of several major electrocoat suppliers that have pilot facilities for their customers and that could perform the required tests with a variety of contemporary electrocoat materials, potentially at a far lower cost. Utilizing these facilities, the NDCEE could perform its intermediary function with greater flexibility and impact than with its current dedicated bath.

Powder Coat

Powder coating is cited by the NDCEE as an example of successful technology transfer.[13] The NDCEE has assisted several facilities in investigating powder-coating technology for specific applications, including the Jacksonville Naval Air Depot (NADEP-JAX), the Corpus Christi Army Depot (CCAD), the Army Tank-automotive and Armaments Command's Armament Research Development and Engineering Center (TACOM-ARDEC), and the Lake City Army Ammunition Plant (LCAAP).

Powder coat technology has been installed only at the Corpus Christi Army Depot; however, the line is used primarily for demonstration purposes.[14] The NDCEE provided training for its operators to become familiar with the operation and maintenance of the equipment, powder materials, pretreatment, racking, and cure. This training was designed to reduce the start-up time for implementation of powder coat.

Powder coating is used routinely at other military facilities. For example, at the Mayport, Florida, naval operations depot, powder coating is used to refinish metal doors removed from naval vessels that are in port for maintenance.[15]

In the powder coating program, the NDCEE acts as an intermediary between powder coating suppliers, powder coating equipment producers, and potential users in defense and contractor facilities rather than as a technology demonstrator. As an intermediary, the NDCEE gives presentations to point out needs and assess specifications, obtains suitable materials, coats test coupons or prototype objects at its Johnstown facility, tests the coupons for performance, develops and demonstrates application-specific processes, and helps to implement the technology at user sites. Although the NDCEE seeks off-the-shelf powder coatings that can be used without modification, it sometimes has to work with

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[8] NDCEE. 1997. Investigation of E-coat and PC Technology for NADEP-Jacksonville. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[9] NDCEE. 1997. Investigation of E-coat and Powder Paint Technology for TACOM. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[10] See note 5 above.
[11] See note 5 above.
[12] Scola, R. 1999. Pollution Prevention Program Overview. Background paper prepared for this study. Picatinny Arsenal, New Jersey: Industrial Ecology Center, U.S. Department of the Army.
[13] See note 12 above.
[14] NDCEE. 1997. Investigation of Powder Coat Technology for CCAD. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[15] See note 12 above.

commercial material suppliers to adjust formulations to meet special color or film property requirements for a given military application.

In commercial industries, intermediaries between suppliers and users are usually unnecessary. In the powder coating industry, for example, manufacturers and equipment suppliers work directly with prospective users to satisfy the user's requirements and can be expected to focus their resources on prospects likely to use substantial amounts of powder coating. However, most potential DOD applications are too small to attract the interest of material suppliers.

In this situation, the NDCEE could potentially act as an intermediary between military users and commercial suppliers interested in developing powder coating applications. In developing such an effort, however, several issues must be considered. First, the stated benefits of powder coating are pollution reduction, improved coating quality, and reduction of repainting costs—all clearly desirable and reasonable objectives. However, powder coating may be the preferred choice only if the ultimate objective is the total elimination of VOC emissions. If the objective is to meet the emissions requirements set by the regulatory agencies, then the more cost-effective choice may be low-VOC liquid coatings that are, in small runs, much less expensive than powder coatings when the system cost is considered.

A second issue is the limited potential applications for this technology. If the volumes of military applications are truly too small to warrant attention from the powder coat supplier community, the question can be raised as to the overall value of developing and applying the new technology. At some point, the NDCEE must consider the trade-off between saving environmental costs and the cost of the technical effort to develop and implement the new technology. Improved coating quality, if substantial and proven, undoubtedly results in cost savings, but these savings are unlikely to be large enough to offset the expense.

A third area of concern is the need to use balanced assessments of alternative coating technologies in selecting the most appropriate approach for each defense application. In the commercial sector, it is unusual to use powder coatings for repainting operations because of the need for extensive metal cleaning and the high-temperature bake. High-solids or two-component liquid coatings, such as polyurethanes, produce durable films and are generally preferred for repair.[16] They can be applied with relatively inexpensive equipment and usually cure at ambient or low bake temperatures. The concerns with conventional two-component liquid polyurethanes regarding worker safety and emissions are generally manageable through good industrial practices,[17] and they are routinely and safely used, for example, at auto body repair shops.[18] If very-low-VOC coatings are a primary objective, liquid polyurethane coatings can be formulated in solvents that meet regulations for VOC emissions in the United States. Very-low-VOC waterborne polyurethane and epoxy coatings are also available and may work very well in some applications.[19]

Certain potential applications, such as powder coating of small-caliber bullet tips, can both reduce emissions and enable easy identification by color coding them. In this case, the NDCEE was asked to investigate powder coatings specifically by the government contractor operating the ammunition production facility.[20] The contractor stated this preference because other alternatives, such as dip coating, would require major changes to the production line, while powder coating could be easily retrofitted.[21]

A fourth issue is the use of existing military specifications and test methods by the NDCEE to validate coating quality. Although current military specifications sometimes call for the use of, for example, static corrosion tests (such as salt spray, also known as salt fog) rather than cyclic corrosion tests, it is widely known that the results of static tests correlate poorly with the actual field performance of coated objects. Although these specified tests must still be used, it would be within the purview of the NDCEE to recommend changes to the specifications to allow for the use of more reliably predictive test methods or to enable supplementing the specified tests.

Finally, the NDCEE staff has demonstrated only limited involvement with national and international scientific, technical, and standards organizations in the area of powder coating. A notable exception is the Powder Coating Institute's endorsement of the NDCEE's 1997 Conference on

[16] Szycher M. 1999. Waterborne polyurethanes. Pp. 14.1–14.22 in Szycher's Handbook of Polyurethanes. Boca Raton, Florida: CRC Press.
[17] See note 16 above.
[18] See note 16 above.
[19] Wegmann, A. 1993. Novel waterborne epoxy-resin emulsion. Journal of Coatings Technology 65(827):27.
[20] Concurrent Technologies Corporation. 1997. Advanced Techniques for Painting DOD Weapons Systems. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[21] Docherty, M.J. 1999. Personal communication from Michael J. Docherty, Process Engineer, NDCEE, October 1999.

Advanced Techniques of Painting and Depainting DOD Weapons Systems.[22] In the 10 years since its inception and over 7 years of full-scale funding, NDCEE as a whole has produced only a handful of publications in peer-reviewed journals and has received no patents.[23] Peer-reviewed publications and patents are important to benchmark the capabilities of the research against contemporary standards and to validate the program's capacity to innovate.

Concluding Remarks

The NDCEE has identified no processes in the U.S. military services to date that would benefit from the use of electrocoat technology, and thus technology transfer has proven unsuccessful. The inclusion of electrocoat technology at the outset of the NDCEE program, including the heavy investment in facility construction, might have been avoided with more in-depth consultation with knowledgeable industry experts. Certainly, any future investments in new technologies should be thoroughly analyzed.

It is clear that the NDCEE should partner with industry to explore any product or process prior to embarking on implementation. With such an approach, it could have avoided spending time and money in building a pilot plant for the powder coating and the electrocoat line. The demonstrations could have been done in a number of existing commercial plants with quicker turnaround times.

Little data was available on the measured reduction of human exposures to toxic substances and the reduction of environmental pollution in using the powder coating process, which made the impacts of the NDCEE's powder coat program difficult to assess. The program appears to have one small-scale implementation, but adequate data to determine the cost-effectiveness of the program has not been assembled. It is difficult to determine the advantages and disadvantages of powder coat over other coating technologies for the applications selected.

CASE III: COATING REMOVAL BY ULTRAHIGH-PRESSURE WATERJET

Coating removal is an important activity of the DOD, because all vehicles, ships, and aircraft go through periodic maintenance during which coatings must be removed from most components in order to adequately inspect the parts. The removal and replacement of damaged or weathered coatings also provide substantial corrosion protection. Conventional methods of coatings removal include stripping with alkaline chemicals or solvents, or combinations of the two, and the use of abrasive blasting media including sand, glass beads, or aluminum oxide. Recent developments in abrasive blasting media include the use of plastic beads, sponges containing grit particles, and sodium bicarbonate.[24]

Innovative coating removal processes offer great potential benefit because current practices can have a significant impact on environmental air and water quality due to chemical outflows. The use of abrasive media may also generate nonrecoverable solid waste streams. For example, an abrasive whose purchase price is $40 to $60 a ton can cost up to $600 a ton for disposal once it has been contaminated by its use in cleaning.[25]

NDCEE Program Overview

Although not part of its original mandate, investigation of ultrahigh-pressure waterjet technology for coatings removal was among the initial project areas identified by the NDCEE. The topic was specifically requested by the Army and by the Naval Sea Systems Command (NAVSEA).

When this technology was selected for NDCEE support, high- and ultrahigh-pressure waterjets had been in commercial use for coatings removal for a number of years.[26] The companies advocating their use were, however, relatively small and the potential benefits of the process had not been widely promulgated. The economic and environmental benefits of changing to this new technology and its practicality for removing coatings from specific items had not been identified or documented.

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[22] NDCEE. 1997. Powder Coat Applications: Final Report and Project Summary. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

[23] Personal communication from Robert Scola, Director, U.S. Army Industrial Ecology Center, February 2000.

[24] NDCEE. 1995. Automated Ultrahigh-pressure Waterjet Technology Status Report. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

[25] See note 24 above.

[26] Ward, G.M. 1972. Safety considerations arising from operational experience with high pressure jet cleaning. Paper presented at First International Symposium on Jet Cutting Technology, BHRA Fluid Engineering, Coventry, United Kingdom, April 1972.

The NDCEE program was established to create a facility that could develop waterjet technology for specific applications by optimizing its performance, qualifying the system, and transferring the technology. It was anticipated that the technology would result in faster coatings removal, lower waste generation, and improved substrate surface quality. It would also reduce the health hazards to operators by reducing inhalation hazards for carcinogenic or otherwise toxic solvents, as well as silicosis hazards from sand blasting. By automating the process, a practical system for removing coatings compatible with the skills of the workforce could be developed.

The NDCEE system, installed at the Johnstown facility, includes an enclosed cleaning cell called the Automated Robotic Maintenance System (ARMS®), built by the Pratt & Whitney division of United Technologies Corporation. The system consists of the following components: a 379-MPa (55,000-psi), 11.4-liter-per-minute (3-gallon-per-minute) ultrahigh-pressure pump from Jet Edge Inc. of Minneapolis, a washout chamber with a cleaning head manipulator and a turntable, a water purification system, and a water chiller to reduce heat buildup in the recirculated water.

Parts or components to be cleaned are mounted on the turntable inside the cell, which has an 8-foot sliding access door and an overhead hoist for parts handling. During operation, a computer-controlled rotating multiorifice nozzle is moved around the part to remove any coatings present on the part. If necessary, the part can be repositioned during the procedure to allow complete coverage. The entire capital cost of the NDCEE waterjet system was $1.3 million, out of a total program budget of $2.378 million (see Figure 3-4).[27]

Since its installation in fiscal years 1995 and 1996, the system has been used to identify potential DOD applications for waterjet cleaning; to demonstrate waterjet cleaning; to assess the surface cleanliness of parts after stripping; to prepare acquisition and process documentation for user sites; and to develop manuals and training for site operators. Several clients have participated in this process, including the Corpus Christi Army Depot; the Naval Aviation Depot, Jacksonville; the Norfolk Naval Shipyard; the Puget Sound Naval Shipyard; and the Aberdeen Proving Ground.[28]

The NDCEE has also used the waterjet system to demonstrate the removal of coatings from jet engine parts, F-14 aircraft hook points, paint fixtures, artillery shells, military vehicles, and fragile surfaces used in submarine applications, as well as rubber removal from armored road wheels.[29]

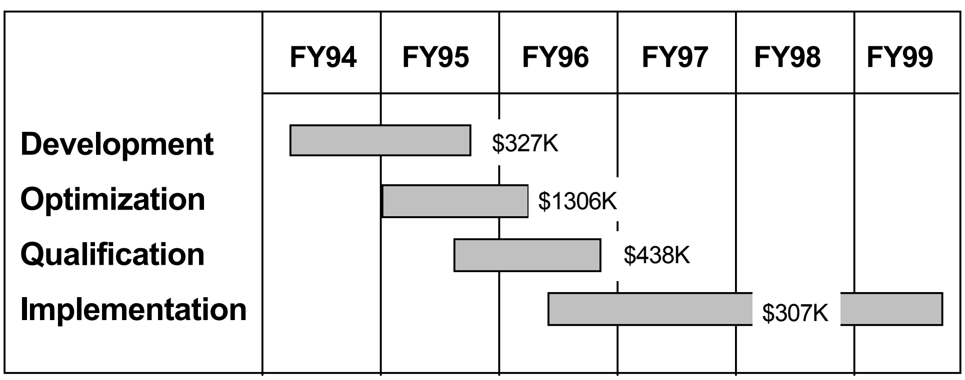

Figure 3-4 Program funding for NDCEE's waterjet effort. Source: NDCEE. 1995. Program Management Plan. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

Program Effectiveness

High- and ultrahigh-pressure systems have been used increasingly in cleaning chemical plants[30] and other industrial facilities.[31] Over the past decade, ultrahigh-pressure waterjet systems have

[27] See note 12 above.
[28] Lancaster, F.A., and R. Zanowicz. 1999. Review of NDCEE Automated Ultrahigh-Pressure Waterjet Projects. Presentation to this study committee, September 1999.
[29] Trunick, D., and D.R. Dagen. 1997. Innovations and emerging applications of ultrahigh-pressure waterjetting. Paper presented at Ultrahigh-Pressure Waterjet Users Conference, Lake Buena Vista, Florida, August 1997.
[30] Kupscznk,T. 1997. Water jetting applications in the petrochemical industries. Paper presented at Waterjet Technology Association's 19th American Waterjet Conference, Dearborn, Michigan, August 1997.

increasingly become the tool of choice for removing coatings from commercial ships[32,33] as well as engines.[34] By 1995, at the second NDCEE users' conference, Lufthansa reported that it had successfully implemented ultrahigh-pressure waterjet technology for repair of combustors in jet engines.[35] The advantages cited for the technique include a decrease in the total time for combustion chamber repair, a decrease in the amount of resizing work required to return combustors to service after stripping, the ability to strip and repair parts that were previously unworkable, a reduced number of high-value Inconel parts scrapped, and less damage to the parent material. The process was also reduced from 10 steps (disassembly, inspection, removal of top coat, cleaning of oxides, heat treatment, chemical stripping, grit blasting, inspection, repair, and reassembly) to 6 (disassembly, inspection, high-pressure waterjet stripping, inspection, repair, and reassembly).

Coating removal from engine parts was the original target market for the unit installed at NDCEE, and vendors have sold a significant number of units to this market.[36] More recently, it has been found that vending the service is a more profitable business than selling the equipment. In response, many system suppliers have established process centers to provide engine cleaning services.

As with any new technology recently introduced into the marketplace, the process has neither reached its optimal performance nor achieved universal acceptance. One reason is that waterjet cleaning is not the "silver bullet" that will resolve all surface cleaning issues. Some surfaces are at present—and perhaps always will be—more difficult to clean with a waterjet than with other technologies. For example, when removing paint from aluminum or composite material surfaces, the differential between the pressure required to remove the paint and the pressure that can damage the substrate can be small. Thus, removing paint may also lead to a loss in the surface of dimensionally critical parts,[37] and increasing production rates by using higher waterjet operating pressures can increase the risk of surface damage. Cost-benefit ratio calculations might, in these circumstances, argue for the use of alternate methods.

An additional concern is the appearance of the cleaned surface. For hard substrates, waterjet treatments can give a very clean surface, but without any deformation of the surface profile. This gives rise to surfaces that do not look as clean as those cleaned with abrasives but that may, in fact, be cleaner. Because of the thorough cleaning, the surface may almost immediately flash rust due to oxidation of the freshly stripped surface. While the flash corrosion can be overcome by adding an inhibitor to the cleaning water or heating the part to the point that water immediately evaporates from the surface, rust remains a concern.

For certain part configurations, it is difficult to reach all the surfaces that must be cleaned with a waterjet. While the waterjet can, to a limited degree, clean around small bends and into corners, it is largely a "line-of-sight" type of cleaning system. In the case of the wing fuel tanks of the KC-135, the mainstay of the Air Force tanker fleet, the varying surfaces of the tank limit such access. The Air Force has had little success in finding cleaning contractors that could meet time, cost, and performance guidelines for this task.[38]

Currently, contracting firms do much of the work on waterjet cleaning of surfaces. Due to the nature of government contracting, their capabilities for and interest in research to improve cleaning performance are somewhat limited. Optimizing performance or introducing new technology in this venue is difficult, thus giving the NDCEE a singular opportunity to fill a need in an area where there would be great demand for such efforts.

For the past 10 years, a committee of the Steel Structures Painting Council has worked to develop standards for the cleanliness of surfaces after waterjet cleaning.[39] Given the level of investment in this program and the participation of the Navy, it is surprising that the NDCEE has not been more

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[31] Schmid, R.F. 1999. Ultrahigh pressure waterjetting for coating removal. Paper presented at Waterjet Technology Association's 10th American Waterjet Conference, Houston Texas, August 1999.

[32] Williams, J., and R.M. Rice. 1995. Navy high-pressure waterjet closed loop paint stripping system. Paper presented at Society of Naval Architects and Marine Engineers, Ship Production Symposium, Seattle, Washington, January 1995.

[33] Carlos de Maia, M. 2000. Alternatives to conventional methods of surface preparation for ship repairs. Journal of Protective Coatings and Linings 17(5):31-39.

[34] Van Wonderen, M. 1995. 1.5 years practical experience using uhwp-stripping on aircraft engine parts. Paper presented at 2nd Annual Waterjet Users Conference, Johnstown, Pennsylvania, September 1995.

[35] Burmeister, H.H. 1995. High pressure waterjet stripping: Six months of experience at Lufthansa Technik AG. Paper presented at 2nd Annual Waterjet Users Conference, Johnstown, Pennsylvania, September 1995.

[36] Mitchell, C. 1999. Waterjet Case Study: Pratt & Whitney Water Jet Systems. Presentation to this study committee, November 1999.

[37] See note 24 above.

[38] Nieser, D.E. C/KC-135 Integral Wing Fuel Tank Topcoat Removal. Presentation to this study committee, November 1999.

[39] Frenzel, L. 1999. Use of Waterjet Technologies by the U.S. Navy. Presentation to this study committee, November 1999.

involved in this effort. The NDCEE did assist the Naval Surface Warfare Center, Carderock Division, in evaluating the use of ultrahigh-pressure waterjets for removing coatings from submarine panels,[40] but although the NDCEE provided the waterjet cleaning service, it was not involved in the subsequent evaluation or in the implementation of the technology.

The distinction between providing a service and evaluating it is important because a similar service might be obtained at no cost from one of the waterjet system vendors, given the potential for a sale. An active industry presence makes the role of the NDCEE particularly uncertain. Even if the NDCEE had a visible presence in helping to develop the market for waterjet use, the growth of vendors to supply that market would limit the life of that need. To sustain its relevance, it is especially critical for an organization like the NDCEE to ensure its visibility in the community through activities such as maintaining memberships in technical organizations and presenting technical papers at major meetings.

The NDCEE waterjet cleaning demonstration cell has limited flexibility for the many possible users of the technology. The cell is currently designed for automatic cleaning of engines and engine components. It is not set up for use in an assembly line type of installation where parts can be automatically fed into the bay, cleaned, and passed on. Nor is the unit, as assembled, capable of cleaning the relatively large surfaces of ships, tanks, and aircraft that must be stripped at regular intervals. These capabilities would greatly increase the potential usefulness of the unit. The component parts of the system can, to some degree, be reconfigured to allow some increase in flexibility. In addition, portable equipment may be purchased, borrowed, or leased if the need arises for a particular application.

Concluding Remarks

At the time the NDCEE work on waterjets was undertaken, their potential for application was considerable. Based on the growing acceptance of waterjet technology in industry, the selection of waterjet coating removal as a technology to be transferred by the NDCEE to military depots and defense industry was well timed. However, as with the transfer of any new technology, communication is key. To facilitate implementation, the NDCEE could survey the current perceptions of the role of ultrahigh-pressure waterjet coatings removal in defense applications among equipment manufacturers, potential users, and Department of Defense organizations that must approve new maintenance technologies. Ground vehicles, aircraft, and ships each have different coatings removal needs, and the perceived limitations of waterjet technology can be addressed only when these limitations are recognized. The NDCEE could develop, with the aid of consultants, a technical program to determine either the validity of or the practical problems in using the technology in additional applications.

CASE IV: ION BEAM SURFACE MODIFICATION

The two main technologies included in ion beam surface modification are ion implantation and ion beam assisted deposition. Ion implantation methods generally fall into three categories: mass analyzed ion implantation, direct ion implantation, and plasma source ion implantation. These methods are all performed in a high-vacuum chamber and involve the use of electrically accelerated positive ions generated within an ion source. They differ only in the way they form the plasma and in the methods used to make the implantation surfaces the negative electrode.[41]

The ions are extracted by means of electrodes positioned outside of the apertures in the ion source. Gaseous species such as nitrogen are easily ionized from the elemental feedstock, but other elements, such as metals, require the use of a volatile compound, often the chloride. The ions created when such compounds are used can be separated in terms of mass by passing the ion beam between the poles of an electromagnet.

Ion beam assisted deposition uses a similar setup, but the deposited species is not the charged ion, but rather an atom suspended in surrounding plasma. The process results in an improved coating compared to that obtained with regular physical vapor deposition. Both ion implantation and ion beam assisted deposition result in hard and very tenacious coatings that protect the surface of the coated material from wear and abrasion without adversely affecting the properties of the substrate. The thickness of the coating is only that of a few atoms and is far thinner than that achieved by

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[40] See note 28 above.
[41] Wegmann, A. 1993. Novel waterborne epoxy-resin emulsion. Journal of Coatings Technology 65(827):27-42.

electroplating, powder coating, or even electrocoat. Little, if any, waste is generated in the coating process, resulting in a tremendous potential for pollution prevention.

NDCEE Program Overview

Commencing in 1975, broad-ranging research programs on ion implantation were carried out at the Naval Research Laboratory and subsequently at the Army Research Laboratory. As a result of this work, the Army Materiel Command became aware of the potential of these new technologies, which have no toxic by-products, to improve the performance of defense systems and to reduce dependence on coatings that contain hazardous materials such as chromium, cadmium, and nickel.[42]

The Department of Defense recognized that ion beam processing technologies offered much promise for improving the performance of currently used coatings and materials. The NDCEE began work on the task to evaluate the potential for ion beam processing for environmentally acceptable coatings in March 1994. Technical monitors were appointed from the Army and Navy research laboratories. The scope of this task was to:

1) Characterize present electroplating practices;
2) Identify user or niche applications of ion implantation and ion beam assisted deposition;
3) Validate processes;
4) Establish a production prototype ion beam demonstration facility; and
5) Compile cost/benefit and specification data.

Establishing the production prototype ion beam demonstration system was a daunting task.[43] The system design specification was developed based on the choice of candidate components and treatment categories. The selections called for a large work chamber capable of treating parts up to 1.8m (6 ft) long by 0.3 m (1 ft) in diameter, and weighing up to 900 kg (2000 lb), and also parts as small as 0.64 cm (0.25 in.) in diameter and 6.4 cm (2.5 in.) long. A load-lock system was incorporated to increase system throughput. The following processing capabilities were specified:

- High-energy (up to 100 keV) ion implantation of gaseous species;
- Two low-energy ion sources, operating at 1 keV and at 100 eV for ion beam assisted deposition in conjunction with a 4-hearth electron-beam evaporator;
- Plasma source ion implantation system (option 1); and
- High-energy metal ion implantation system (option 2).

As designed, the facility was to be the most complex, multifunctional ion beam processing unit in the world. The original quotation for the design and construction of the ion beam systems without the two optional features was $1,344,796. The work began in July 1995 and the unit was delivered in January 1997, 10 months behind schedule, at a final cost of $1,932,598. Major modifications to the system due to cost overruns included elimination of the barrel coater, the planetary fixture, the operation and maintenance manual, and the integrated automated control. In addition, the unit was shipped with some subsystems below specifications.

As a consequence of the heavy equipment cost overrun, which can be attributed to the complexity of the system design, changes were made to the scope of work with government approval. Some requirements were also eliminated, including validation of ion beam processes by laboratory and field service testing, compilation of an operation and maintenance manual, compilation of cost/benefit data using life-cycle cost estimation, and definition of military and commercial standards and specifications.

A number of additional problems with the facility were discovered after installation. For example, the electron beam high-voltage power supplies needed new transformers before they could attain the

[42] NCDEE. 1996. Ion Beam Process for Environmentally Acceptable Coatings, Component Treatment, Final Report. Johnstown, Pennsylvania: Concurrent Technologies Corporation.
[43] NDCEE. 1999. Ion Beam Processing for Environmentally Acceptable Coatings, Final Report. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

rated power, insufficient grounding of the high-energy ion source resulted in internal electrical discharges, and the workpiece trolley air and water hoses leaked during motion.

The desired equipment changes have now been compiled, most with several subsidiary items, and work is in progress on many of these.[44] A set of operating procedures has been established for the ion beam facility, which has been sufficiently modified since its installation and is now working well. Funding for ongoing activities in ion-beam technology has been provided under the U.S. Army's Sustainable Green Manufacturing Initiative, which has technology transfer as one of its objectives.[45]

Program Effectiveness

The NDCEE is currently engaged in several technology transfer activities for ion beam technology. Several extensive paper surveys and process considerations were carried out as part of the NDCEE ion beam program, resulting in a short list of coatings that may serve to replace chromium and cadmium. Treatment of some of the selected components has now begun under the Department of Defense's Sustainable Green Manufacturing Initiative. Although the study of possible alternatives to cadmium for fasteners has been terminated because none were economically viable, work continues on ion beam alternatives to chromium electrodeposition.

To promote technology transfer, the NDCEE conducted an "Industry Day" meeting for the military vehicle, propulsion, and munitions user community. This meeting was aimed at identifying parts that are suitable candidates for ion beam technology. The NDCEE has agreed to provide ion beam treatments with the understanding that the clients will carry out performance testing of the processed parts under conditions of actual use and will supply the resulting information to NDCEE.

There have also been some activities in support of the Propulsion Environmental Working Group in which the industry members and equipment manufacturers have identified appropriate parts and the NDCEE has devised suitable ion beam treatments for them. The overall objective is to improve the service life of parts such that components will require refurbishment only once during the life of the equipment. The effort focuses on the total cost of ownership, including the entire life-cycle cost of a system and extending to eventual disposal of the equipment. Ion beam treatments have a tremendous potential for success when life-cycle costs are considered.[46]

Concluding Remarks

The definition phase of the NDCEE's ion beam surface modification program resulted in a very ambitious and complex design for the ion beam processing equipment. Indeed, with the two additional options of metal ion implantation and plasma source implantation, it would have been almost an order of magnitude more complex and multifunctional than any other such facility in the world. The vendor certainly underestimated the difficulties of meeting this specification on time and within budget. As a consequence, most of the available funding and effort have been consumed in the attempt to complete a working facility, albeit with reduced specifications. As a result of these setbacks, the program's intent to demonstrate the effectiveness of ion beam processing and to transfer this technology has not yet been realized.

The NDCEE staff working in this area provide a good example of a systemic condition at the NDCEE, and that is the lack of adequate networking in the technology community. Real-time communication, both on a formal and an informal level, is critical to achieving the technology development and the technology transfer goals of the NDCEE.

It is clear that ion beam technology, appropriately applied, can bring significant benefits to the Department of Defense. The field is still developing and standardized equipment is not yet commercially available. It is, however, not too early to begin to identify the most appropriate areas of application and to spread awareness of the technology among the Army depots, military equipment manufacturers, and other suppliers.

[44] NDCEE. 1999. CTC/CDRL No. MP013 issued May 21, 1999.
[45] Klingenberg, M. 2000. Ion Beam Processing. Presentation to this study committee, January 2000.
[46] See note 45 above.

Chapter 4

BARRIERS TO TECHNOLOGY TRANSFER

The NDCEE's primary customers for the technologies examined in this study are military depots performing maintenance on a wide range of military equipment, including transport and combat aircraft as well as trucks and mobile artillery. To a lesser extent, the original manufacturers of military equipment are also customers for specific products of NDCEE programs, such as powder coating of the tips of small-caliber ammunition.

DEPOT MAINTENANCE

Depot maintenance is defined by the Department of Defense as

> that maintenance performed on materiel requiring major overhaul or a complete rebuild of parts, assemblies, subassemblies, and end-items, including the manufacture of parts, modifications, testing, and reclamation as required. Depot maintenance also serves to support lower categories of maintenance by providing technical assistance and performing that maintenance beyond their responsibility. Depot maintenance provides stocks of serviceable equipment by using more extensive facilities for repair than are available in lower level maintenance activities.[1]

Military depots performing this work face such pressures as reduced budgets, declining workload, and privatization. The number of depots declined from 39 in 1988 to 19 in 2001. The privatization of Air Force depot maintenance was planned to exceed 50 percent in fiscal year 2000, but this requirement has been waived temporarily because of national security concerns.[2]

Reduced budgets in real terms and the declining workforce in the defense industry make it difficult for depot personnel to travel to gain knowledge of new technology. The relatively static processes used by depots can tend to limit opportunities to adopt new technologies in maintenance. However, the more entrepreneurial approach required from depots in response to the defense downsizing and privatization of functions described above may also create such opportunities.

In general, new technology is most easily introduced in new systems. The stakeholders, funding, and methods of application differ for new weapon system acquisitions and for defense maintenance installations, and the Department of Defense has therefore developed separate pollution prevention strategies for each.[3]

Because military systems are remaining in service far longer than envisioned by their designers, continued maintenance of some systems may be impractical without new maintenance technologies. For example, the coating removal and resealing of wing fuel tanks on KC-135 tanker aircraft that have been in service since the 1950s is unprecedented in either military or commercial aviation. This additional maintenance was necessitated by delamination of the topcoat inside the fuel tanks that resulted in clogged fuel filters.[4] The pressure from environmental regulations may provide additional incentive to drive the use of new technologies for maintaining existing weapons and equipment in service for long periods of time.

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[1] Defense Technical Information Center. Undated. DOD Dictionary of Military Terms. Available online at <http://www.dtic.mil/doctrine/jel/doddict/data/d/01905.html>. Accessed January 2002.
[2] Government Executive Magazine. 2001. GovExec.com Daily Fed, DOD Depots, Buyouts on Agenda, September 26, 1997. Available at <http://www.govexec.com/features/0601/0601s2.htm>. Accessed December 2001.
[3] Office of Deputy Undersecretary of Defense (Environmental Security). 1997. Environmental Quality Annual Report to Congress. Available at <http://www.denix.osd.mil/denix/Public/News/OSD/EQ97/toc.html>. Accessed January 2002.
[4] Nieser, D.E. C/KC-135 Integral Wing Fuel Tank Topcoat Removal. Presentation to this study committee, November 1999.

ADDITIONAL FACTORS

Before a new technology can be implemented by a depot or other military facility, a clear definition is needed of the technology's role, including it's suitability for meeting the customer's needs, its impact on current and future regulatory compliance, and its impact on labor and other operating costs, as well as the cost, schedule, and requirements for training associated with its implementation. Because the systems in place are complex—including equipment, facilities, specifications, existing technology, the knowledge base, and so on—it is often a challenging task to implement a new technology, whether the changes in existing operations are minor or major. A clear understanding of a maintenance depot's needs, both with regard to the specific problem at hand and how the proposed solutions would support the depot's ability to meet its overall mission, is essential.[5]

Some of the major considerations that determine the success or failure of technology transfer are as follows:

Maturity. The technology must be at the appropriate level of maturity. A technology ready for transfer has already been implemented in a similar facility or a similar product, either in an industrial or academic setting.

Organization. Both the transferring and receiving organizations must be well prepared for the technology implementation process, which is guaranteed to consume additional time and funds in the short term. When a technology is owned by a supplier with few employees to aid in implementation, or a depot is unable to allocate adequate personnel to the project, the budgets, time lines, goals, and objectives must reflect this shortcoming.[6] Identification of champions on both sides of technology transfer is especially critical when validating and accepting a new process or material for defense applications, for which the technical complexity, environmental demands, and system considerations are generally high when compared to many commercial activities. For example, implementing a new coating for aircraft that meets VOC compliance regulations typically requires new surface preparation, new application methods, new specifications, and new maintenance procedures, as well as training of depot facility operators.

Design Control. It is important to understand which organization controls the design of the product and the process. In general, the designs are controlled by the original equipment manufacturers of the weapons or by the research laboratories in the military services. Therefore, for example, the implementation of vapor-deposited coatings on a part for an Army helicopter would require the approval of both the Army Aviation Systems Command and the helicopter manufacturer—perhaps with no input from a major technology user, the equipment depot. In addition, the design may or may not follow military specifications. This complex interdependence requires a technology intermediary like the NDCEE to be able to convince all stakeholders that new technologies proposed are safe and effective for all stages in equipment lifetime. The ability to sell new technologies to external organizations as well as cooperating with the user depots requires a high degree of communication and trust.

Time line. The time line for use of a new technology requires careful consideration, because the time for maturation and implementation may exceed budgetary, environmental, or other constraints. Plans for alternative capabilities must be assessed, as well as the possibility that a technology may become obsolete by the time it is put in place. Life-cycle costing should always be considered, and cost models must relate future benefit to present cost and risk.

System Considerations. The system drivers for technology implementation must be well defined. Due to the substantial effort needed to implement process changes, processes without an immediate regulatory or specification driver tend to remain unchanged even if less-polluting processes are available. A system-level understanding of logistics and of depot operation is required in order to select appropriate technologies for transfer. Details such as equipment

[5] Asiello, David. 2000. Navy Program Experience. Presentation to this study committee, January 11, 2000.
[6] NDCEE. 1999. Ion Beam Processing for Environmentally Acceptable Coatings Final Report. Johnstown, Pennsylvania: Concurrent Technologies Corporation.

capabilities and parts requirements including size, accessibility, and throughput should be clearly defined when scaling a technology from demonstration to regular use.

Communication. The decentralized nature of depot maintenance and the limited opportunities for interaction between locations due to time and budgetary constraints tend to prevent the transfer of expertise. Decentralization can, however, provide the freedom to implement innovations in trial operations. Purveyors of new technologies and expertise in technology transfer need to understand this potential as well as general business practices among military suppliers and maintenance depots. Technology champions are key in this communication process.

Life-Cycle Accounting. A combination of past practice and current incentives can cause depot managers to maintain a short-term view of cost and operational effectiveness versus the long-term goals of pollution prevention and reduced life-cycle costs. Base command staff are typically rotated within 2 to 4 years, and investing in technology may result in negative budget impacts during their terms and savings that accrue to future commanders. Program managers face similar difficulties. Some means of extending the life-cycle benefits to all parties or of adjusting the life-cycle accounting is needed to ensure adoption of appropriate new technologies.

Ownership. Implementation of a new technology will generally result in a short-term increase in workload for depot personnel. To justify this sacrifice, depot managers should be willing to assume some ownership of the new technology. They must also clearly understand the goals and objectives, along with budgets and time lines, prior to technology implementation so that the cost of successful transfer can be defined.

A more nebulous barrier to technology transfer is the inability of those working to implement a new process to overcome the inertia inherent in years of use of an existing technology. Families of technologies that become integral to the workings of societies tend to remain dominant for many decades.[7] The technologies proposed for replacement by the NDCEE's efforts, such as chemical paint stripping and cadmium plating, have become integral to the functioning and maintenance of military and similar commercial equipment.

In essence, the issues determining success in technology transfer can be categorized as money, people, and logistics. The need for adequate funding is the barrier cited most often. Most people are aware that funds must be available to implement a change and pay for the equipment, time, and training needed, but the role of personnel, which may be even more critical, is often overlooked. Not only must adequate personnel be allocated to implement a change, but they must also be properly trained. Moreover, everyone, from the commander to the technician, must buy in to the need for and the process of change. Finally, the logistics of change is a less well recognized barrier. Logistics ranges from communicating a change to external support organizations to revising in detail such control documents as specifications, technical orders, drawings, or maintenance cards.

The role of the implementing organization is one of the most critical factors in achieving success in technology transfer. The implementing organization needs to:

- Concur with the NDCEE's statement of the organization's needs;
- Identify a champion who has the authority to make the business decisions and to commit the resources needed to make the implementation succeed;
- Approve the proposed demonstration and participate in the testing and evaluation;
- Send personnel to the demonstration for training;
- Cooperate during the facilitation and implementation; and
- Communicate issues and problems as they occur.

[7] Weinberg, M., E. Eyring, J. Raguso, and D. Jensen. 1994. Industrial ecology: The role of government. Chapter 8 in The Greening of Industrial Ecosystems. Washington D.C.: National Academy Press.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Adapting to technological change, whether evolutionary or occasionally revolutionary, is an integral part of a successful industry. However, it is difficult for day-to-day operating units to be aware of the existence and relative merits of new technologies entering the marketplace. An intermediary organization can, with appropriate management, skills, and the respect of its customer community, play a worthwhile role in overcoming the barriers to technology transfer. The NDCEE aspires to this role in its mission that centers on the identification, investigation, and introduction of technologies, either existing or evolving, to solve problems for its customer community.

GENERAL CASE STUDY CONCLUSIONS

The NDCEE was created to respond to a nationally important set of goals. One specific goal was to replace current methods of applying and removing coatings on surfaces with more effective and less environmentally damaging technologies. As it has evolved, the NDCEE has examined a number of problems that exist in defense facilities and has evaluated potential solutions to the identified problems. For the purpose of this evaluation, the studies that the NDCEE made of four potential technical changes were reviewed. Two of these technologies, electrocoat and powder coating, are related to methods for applying coatings, the third, ion beam surface modification, is a method for improving coatings and surface condition, and the fourth, ultrahigh-pressure waterjets, is used for coatings removal and surface preparation.

In each case, the technologies were sufficiently advanced that the NDCEE could obtain, from an outside vendor, equipment at an operational scale. This equipment allowed NDCEE personnel to become familiar with the technology, evaluate its use and benefits in different applications, and help with transitioning technology where appropriate. Three of the systems obtained were commercially available, while the fourth, ion beam, was intended to go beyond the existing state of the art. In each case, the purchase cost of the equipment was significant and made up a major part of the overall cost of the project.

In addition to the direct production value from transferring technology to end users, the value to the Department of Defense comes in the knowledge base that is created with use of the equipment. Sometimes the knowledge gained is negative and the technology is of little or no immediate use.

> **Recommendation.** The NDCEE should focus more effort on dissemination of its results, whether positive or negative. NDCEE staff should present and publish more technical and overview papers in military and technology-specific journals, should participate more fully in scientific and technical organizations, and should focus specifically on submitting papers to peer-reviewed journals and applying for patents where appropriate. Such participation will create a more visible presence for the NDCEE in the technical areas within its purview and will enable potential customers to more efficiently identify needed expertise and services. Publicly available Web pages should also be used to disseminate results.

Some of the technologies investigated by the NDCEE have demonstrated a level of potential use in the commercial sector. The potential for successful application in military depots has been shown for powder coating and for waterjet cleaning. Full realization of this potential will certainly demand that NDCEE personnel increase the depth and breadth of their knowledge. If the NDCEE is to be of value, it must be able to provide its clientele with expert knowledge of the subject technology. To be most useful, this expertise should be generated through the use of a technology over a substantial period under a wide range of operating conditions. From that knowledge base, NDCEE can recommend to its customer whether a new technology should be introduced, how to use it, and how to modify it for use in other applications.

APPROPRIATENESS OF TECHNOLOGIES

During the NDCEE's formation, projects were selected and work begun without well-developed experience, which is a natural consequence of the need to begin work at a high level of effort. The initial assessments of new technologies illustrated the potential benefit NDCEE can provide to the community in the future. The coatings industry is large, and that part of it that deals with corrosion and recoating of surfaces is, in itself, a multibillion-dollar-a-year segment. However, the research and industrial communities attached to the development of new technologies for the recoating industry generally consist of a relatively few individuals. Often these individuals have limited access to the personnel operating military depots, and limited knowledge of the potential applications of the technology in the military. The converse also holds true.

> **Recommendation.** The NDCEE should conduct a balanced assessment of alternative coating technologies to select the most appropriate approach for each defense application. The NDCEE must consider the trade-offs between direct environmental cost avoidance, indirect environmental improvements, and the cost of the technical effort needed to develop and implement powder coating technology or any pollution prevention technology.

The NDCEE was created to directly address these weaknesses in communication. However, at the inception of the program, certain decisions were made before adequate internal analysis capabilities were developed. For example, given the maturity of electrocoat technology and the availability of technical experts familiar with the technology's high fixed costs and minimum economic production volumes, it is likely that timely input of this expertise would have led to the decision that the NDCEE not invest heavily in this process.

The electrocoat equipment installed had a high initial cost and considerable operational maintenance costs, and so a steady throughput and continued use of the system were required for it to be cost-effective. Because the minimum usage level to make electrocoat economical exceeds the maximum requirements at most DOD depots where it was expected to be used, this technology proved to be of limited value.

> **Recommendation.** To better utilize technology transfer resources, the NDCEE should shut down its current electrocoat bath. In the event that any future demonstration of electrocoat technology is considered appropriate, the NDCEE should utilize the demonstration facilities of commercial suppliers of materials and process suppliers.

A somewhat similar situation exists in the case of the NDCEE’s waterjet installation. As purchased, this facility has limited flexibility, potentially restricting the studies that can be made and the knowledge base that can be developed. This limitation may create a hurdle to the introduction of novel technology, rather than aid its implementation. With greater input from the existing experts in this field at the time, a different equipment setup may well have been selected.

> **Recommendation.** The NCDEE should expand its efforts to transfer ultrahigh-pressure waterjet technology to additional types of applications. To support this effort, the NDCEE should configure the waterjet system at Johnstown for both in-house and field use to demonstrate technical applications. The NDCEE should also work more closely with commercial vendors of waterjet equipment and services and should purchase or lease field portable equipment as needed.

Ion beam surface modification technology was appropriate to NDCEE's mission, given the technology's great potential for cost-effective pollution prevention. However, the technology had not reached a level of maturity commensurate with the level and type of effort at the NDCEE.

> **Recommendation.** No further effort or expenditure should be devoted to either utilizing or improving the existing ion beam equipment at the NDCEE, as this technology is still evolving. The NDCEE’s objective should be to develop and maintain an awareness of the potential for technology transfer to the U.S. military services, and to prepare to aid in implementation when the technology matures.

In all cases, the NDCEE needs to have a more strategic view of the potential for pollution prevention along with a thorough understanding of individual technologies.

> **Recommendation.** The NDCEE should clarify in a mission statement the goals for all its programs along with stated interim and ending milestones. The NDCEE should provide this

information and the background analysis to the potential recipient of a technology. Each program should set goals, for example, for the amount of pollution prevention to be achieved as a result of NDCEE efforts. These goals should be coordinated with NDCEE's technology partners, including original equipment manufacturers, DOD command organizations, DOD equipment depots, technology suppliers, technical consultants, and internal staff. An independent program oversight panel should regularly review and publish the NDCEE's quantifiable performance toward achieving these milestones.

ORGANIZATION AND TASKS

To successfully transfer a new technology and to accomplish the intended goals of cost reduction, compliance with regulations on VOC emissions, and improved performance, technical champions are needed on both sides of the technology transfer process. The technology transfer expert at the NDCEE can recruit and educate these champions and can also act as a champion for the process. Such champions need to maintain visibility through the approval and implementation process and help support and manage the process. To be effective, a champion must have technical credibility that is evident internally as well as externally. Among the required capabilities are excellent oral and written communication skills, knowledge of depot needs and capabilities, and knowledge of the industry. The NDCEE can serve this role in several ways. For example, it can:

1) Develop technology contacts at various depots and within the supplier base;
2) Consult with industry and academic experts;
3) Anticipate future regulations in response to environmental issues that may impact processes domestically as well as internationally, and increase awareness of European regulations that may already exist as a source of information on alternative technologies to meet changing environmental regulations;
4) Train depot staff in areas of the technologies to be transferred;
5) Attend domestic and international conferences on the targeted technologies;
6) Present technical papers at conferences and publish results, especially in peer-reviewed journals; and
7) Write internal reports that can be circulated throughout various depots.

Given time and appropriate access to existing expertise, the NDCEE can develop its own internal experts in fields critical to its mission. However, such an effort requires long-term commitments to areas of interest and cannot be guaranteed for every potentially beneficial technology. Development of the NDCEE's expertise in carefully selected fields would help the depots and the community that NDCEE is set up to serve because even after a new technology arrives at a plant door, the problems of technology transfer remain complex. Training, development of operating procedures, and modifications of equipment to solve problems with new applications, or similar work to optimize existing methods, require ongoing interaction. Further, the ability to bring together the civilian and military users of technology to discuss new approaches is an ever-present need.

Making information available on technology through the NDCEE's World Wide Web site or by other means would help the military bases. Public dissemination of the NDCEE's work and goals would also provide information on needs that industry suppliers may be able to address.

Certain military applications, however, represent markets that are too small for industry to address. It is appropriate that the NDCEE focus on such applications that have significant environmental impacts and/or have met cost-benefit criteria by carrying out research to maintain and expand the knowledge base in these areas. Given the expense of developing and maintaining experts at the forefront of knowledge in their fields, it may be more effective, however, if the knowledge base involves outside experts in the relevant technologies, brought in as necessary to supplement in-house personnel.

To identify, investigate, and transfer technologies to its customers, the NDCEE should develop a strategic approach. Before a candidate technology is adopted, a select panel should review the current state of the technology, both in industrial applications and as it is being developed in research, for its potential uses in different areas of the Department of Defense. Once a technology appears to be a credible candidate, a program of development and demonstration can be designed to determine the validity and limitations of the technology with the aid of DOD experts or consultants widely recognized as experts in the specific technology. As part of this evaluation, the most flexible and practical equipment can be identified for evaluating the technology and building a knowledge and experience base.

Recommendation. The NDCEE should perform system-level cost-benefit analyses for planned projects as well as for ongoing activities. These analyses should be conducted in light of NDCEE mission objectives and in close cooperation with all stakeholders and should include a market survey and a comparative assessment of all potentially useful technologies to determine the most appropriate approach to address user needs.

All interested parties should be involved in this analysis, including original equipment manufacturers, depot plant operators, military researchers and other experts, technical consultants, and NDCEE staff, as part of a clearly defined program of presentations, demonstrations, and evaluations. Their purpose should be to develop a well-defined plan to determine the practicality of the technology in meeting required, and previously defined, objectives. The plan should establish milestones, and specific tasks to ensure broad visibility of the technology and should provide for close involvement of the industry that would ultimately service the Department of Defense. Involvement of the full range of stakeholders in program development provides contacts and champions within the organizations that control designs to help overcome the real and complex hurdles in implementing technology in military applications.

In the case of technology transfer to maintenance depots, the need for multiple organizations to cooperate in implementing new maintenance technology makes operating as a complete team as early as possible in the process essential to successful implementation. This teamwork requires that the NDCEE be able to convince all stakeholders that any new technologies proposed are safe and effective at all stages in the equipment lifetime.

PLANNING FOR APPROVAL PROCESSES

Overcoming administrative and approval barriers in transitioning technology has been identified repeatedly as a major factor in the successful implementation of new technologies in military systems. Long-term success in using existing technologies is difficult to achieve, and understandable resistance exists to changing processes in systems where failure is likely to cause loss of life. Appropriate identification of these barriers and approaches to overcoming them are thus essential.

Requirements for approval of new technologies by organizations, such as military system commands and original equipment manufacturers (OEMs), before implementation by users must be explicitly identified in the NDCEE's program planning, milestone charts, statements of task, and similar documents to ensure consideration of such requirements at all stages of the technology transfer process. Further integration of NDCEE programs with defense-wide formal review processes would ensure the full involvement of stakeholders in project selection and a formal process for assessing the relevance of the selected projects.

Recommendation. The NDCEE should plan and operate programs with the goal of gaining the confidence and cooperation of the organizations responsible for approving new technologies for integration into the ongoing mission operations.

The NDCEE is a conduit between the ultimate parties to successful technology implementation—the vendors of commercial equipment and materials and the installation where those items will be used. Maintenance of impartial and objective working relationships both with suppliers of material and equipment and with the ultimate customer is critical to success.

Technology transfer is not an easily defined, one-time event. If it is to be completely effective, the recipient must have access to expert knowledge from the source, often for a period of years after inception of the transfer. Thus a body of expertise must be built for those technologies that the NDCEE seeks to transfer. Although such expertise need not exist within the NDCEE, the NDCEE must nevertheless have a broad range of knowledge of its chosen subject areas and must have access, when necessary, to more focused expertise. The current level of expertise within the NDCEE varies from program to program, and for certain technologies may reside in a single individual. Reliance on a single point of knowledge can threaten a program's long-term effectiveness, especially when a rapidly developing technology creates a strong market for knowledgeable personnel. The establishment of an external supporting technical panel of experts in certain areas would be a step toward overcoming this risk.

Recommendation. The NDCEE should assemble a cadre of personnel who can provide the necessary continuing support to technology adopters, including training in technology and management. These experts should be capable of responding to the total breadth of DOD's environmental concerns and provide technical advice or conduct case-specific experimental analyses. This service could be added either through direct staffing at NDCEE or through cooperative work with academic and government research centers in the appropriate fields, other mission organizations within the Department of Defense, or brokered relationships with industrial technology suppliers.

It is also not necessary that NDCEE build extensive laboratories or facilities, especially in the early stages of investigating a technology. Commercial concerns will often cooperate in running small experiments, and specialized laboratories at commercial or university facilities may also be available. Reliance on in-house capital equipment may also unnecessarily limit the involvement of coating suppliers. It is tremendously important to establish strong working relationships with the coatings industry.

Recommendation. The NDCEE should integrate its activities more closely with the larger Department of Defense environmental and coatings programs and should cooperate with military specification developers, commercial industry, and coating materials suppliers in bringing all defense product finishing specifications up to date in the area of performance testing.

Government funds should be spent on the development of new coating technologies only when commercial off-the-shelf (COTS) technologies and capabilities are not adequate to meet DOD requirements.

Increased communication with commercial suppliers and technologies, and increased knowledge of their abilities and facilities, may give depots under pressure some additional options. Depots could reduce their VOC emissions or reduce other objectionable material processes at their sites by shipping parts to local custom finishers for cleaning and coating. This approach would reduce the depot's involvement in small-scale coating operations and would also permit the demonstration and use of new coating technologies, especially those that require a higher critical mass of work than most depots possess. With good knowledge of supplier capabilities, an organization like the NDCEE could facilitate these partnerships.

FINAL THOUGHTS

The NDCEE is clearly active in technology transfer related to pollution prevention. However, evidence of its success is difficult to quantify, primarily because measures of success were never established. Specific evidence of quantifiable successes in pollution prevention was not made available to the committee during this study. The need for independent and objective measurement of the environmental effectiveness of industry-initiated approaches is well documented.[1]

Analyzing risk and examining business case information from the start is critical to technology transfer, as well as follow-through of projects until the implementation of the new technology is accomplished in the normal course of business. Only then can a measure of success truly be calculated in terms of pollutants minimized, the number of users of new technology, or dollars saved in reducing pollutants. Strategic alliances within DOD are critical to the success of this effort.

The NDCEE has demonstrated theoretical understanding of the technology transfer process but is limited by a number of stakeholder constraints. The full participation of the NDCEE in both the Department of Defense technology community and the larger scientific and engineering community will be essential to ensure the effectiveness of the NDCEE's work.

Technology transfer is widely accepted as a difficult and costly challenge. The mission of the NDCEE toward this end is commendable, and the concept of establishing an intermediary organization

[1] National Research Council. 1997. Fostering Industry-Initiated Environmental Protection Efforts. Washington, D.C.: National Academy Press.

to introduce and transfer new technologies for pollution prevention is certainly worthwhile. In practice at the NDCEE, unfortunately, this model has not been successfully demonstrated. The demonstration factory capabilities at the NDCEE investigated in this study are not a necessary or cost-effective means of demonstrating environmentally useful technologies. Reliance on industrial facilities commonly used by the commercial users of coatings would be cost-effective and would lead to further collaboration with manufacturers.

Appendices

Appendix
A

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

Sheila F. Kia is the engineering group manager at General Motors Manufacturing Engineering. Dr. Kia's research interests include finishing, materials interfaces and surface characteristics, lightweight materials, casting processes, and the environmental impact of manufacturing operations. Dr. Kia was the 1996 and 1997 recipient of the GM R&D McCuen Awards and is listed in *Who's Who in Science and Engineering* (2nd Ed.). She is an editorial review board member of the *Journal of Coating Technology*, subcommittee chair for the USCAR Low Emission Paint Consortium, and a board member of the MSU-Manufacturing Research Consortium. In addition, she is currently serving as a member of the National Materials Advisory Board.

Earl W. Briesch has been a consultant for Dayton Aerospace, Inc., since retiring as deputy director for requirements at the U.S. Air Force Materiel Command Headquarters at Wright Patterson Air Force Base. He served in senior management positions at Warner-Robins Air Logistics Center, where he was responsible for major system modifications and for depot-level maintenance programs for the F-15, C-141, and C-130. Overall, he has 35 years of experience in logistics management, program management, and engineering and is an expert on the technology of major Air Force weapons systems. He previously served on the NRC's Committee on Aging of U.S. Air Force Aircraft.

Geoffrey Dearnaley retired as vice president of the Materials and Structures Division of Southwest Research Institute. Dr. Dearnaley was a pioneer in the development of ion implantation and in the development of the semiconductor nuclear radiation detector for charged particles and gamma rays. His research interests have also included the combination of vacuum coating technology with ion implantation for ion-beam-assisted deposition. Dr. Dearnaley is the author of 300 published papers and two books. He has been the editor of several technical journals and has organized and chaired an international conference on ion implantation. He is a member of the Institute of Physics (London) and a fellow of the Royal Society (London).

John L. Gardon is a graduate of McGill University and the Swiss Federal Institute of Technology. He started his industrial career with the International Paper Company, held various senior positions with the Rohm and Haas Company, was director of research of the M&T Chemical Subsidiary of the American Can Company, and was vice president, R&D, of the Sherwin Williams Company. In the last 10 years before his retirement, he was vice president, R&D, of the Akzo Nobel Coatings, Inc. He is currently adjunct professor at Eastern Michigan University and a consultant. Dr. Gordon authored 45 refereed papers and 6 textbook chapters, received 16 U.S. patents, and edited 2 textbooks. His research interests include nonpolluting coatings; textile, leather, and paper finishing; polymer synthesis; thermodynamics of polymers; and adhesion. He has held leadership positions at the American Chemical Society, Federation of Societies for Coatings Technology, Gordon Research Conferences, National Paint and Coatings Association, and Industrial Research Institute. He was a recipient of the Tess Award of the American Chemical Society and was a Mattiello lecturer for the Federation of Societies for Coatings Technology.

Frank N. Jones is director of the National Science Foundation Industry/University Cooperative Research Center at Eastern Michigan University. Dr. Jones's areas of expertise are polymer synthesis, materials, and coatings. Dr. Jones is the author of numerous publications, including a text and reference entitled *Organic Coatings: Science and Technology.* He is a recipient of the 1986, 1987, and 1991 Roon Foundation Award. In 1995 he was named Joseph P. Matiello Memorial Lecturer of the Federation of Societies for Coatings Technology, and in 2001 Dr. Jones received the Tess Award in Coatings from the American Chemical Society.

Joseph H. Osborne is a principal engineer with the Boeing Company, where he has worked for 13 years. His expertise includes environmentally compatible finishing processes, materials and process specifications, and the transfer of new chemical reduction technologies to production shops. He is the principal investigator for two coatings development contracts with the Air Force Research Laboratory (advanced corrosion-resistant aircraft coatings and environmentally benign sol-gel surface treatments for aluminum bonding applications). Dr. Osborne is Boeing's representative to the Aerospace Chromium Elimination Team and the JG-PP cadmium elimination project. He holds eight patents and patents-pending for sol-gel based coatings technology and is a member of the Materials Research Society, the Electrochemical Society, and the American Chemical Society.

Rose A. Ryntz is staff technical specialist at Visteon Automotive Systems, an enterprise of the Ford Company venture. Dr. Ryntz is also an adjunct professor for the University of Detroit. Dr. Ryntz's areas of expertise include plastics, paint, coatings, interpenetrating polymer networks, silicone modification of resins, and adhesion. She has been in the coatings industry for over 15 years, has received 13 patents, and is the author of numerous publications, a book on painting and molding of plastics, and two book chapters. She is the recipient of the 1992 Women in Coatings Management Award and is a member of the Society of Automotive Engineers, the Federation of Societies for Coatings Technology, and the American Chemical Society. She is chair of the NIST Review Board on Material Assessment, an ex-officio member of the NRC's Board on Assessment of National Institute of Standards and Technology Programs, and chair of its Panel for Building and Fire Research.

David A. Summers is Curators' Professor of Mining Engineering and director of the High Pressure Waterjet Laboratory and the Rock Mechanics and Explosives Research Center at the University of Missouri-Rolla. His research activities have included the development of high- and ultrahigh-pressure waterjet equipment for mining, munitions demilitarization, drilling, cleaning, and radioactive waste removal. He is the author of numerous articles, holds four U.S. patents, and received the Pioneer Award from the Waterjet Technology Association in 1997. A fellow of the Institution of Mining and Metallurgy, he became a Distinguished Member of the Society for Mining, Metallurgy and Exploration in 1999. Elected to the Russian Academy of Mining Science in 1996, he is a past president of the Waterjet Technology Association and serves as president of the International Water Jet Society.

Michael Van de Mark is the director of the Coatings Institute and an associate professor of chemistry at the University of Missouri-Rolla. His research interests include flash rust inhibition, hydrogel synthesis and modification, phthalocyanine pigment research, low VOC and water-borne coatings formulation, and organic photo- and electro-chemistry. He is the author of numerous papers, has developed several protocols for industry, and holds four patents. He is a member of the American Chemical Society, the Electrochemical Society, and the Federation of Societies for Coatings Technology, and is a member of the board of directors of the Missouri Enterprise Business Assistance Center. Dr. Van de Mark was the recipient of the First Place Service Booth Award at the national meeting of the Federation of Societies for Coatings Technology in 1992.

Appendix B

INVITED SPEAKERS

Review of National Defense Center for Environmental Excellence (NDCEE) Ion Beam Technology Projects
Eric Boomis
Concurrent Technologies Corporation

Review of NDCEE Powder Coating Projects
Michael J. Docherty
Concurrent Technologies Corporation

Review of NDCEE Ultrahigh-Pressure Water Jet Projects
Frederick Lancaster
Concurrent Technologies Corporation

NDCEE/Army Research Laboratory Ion Beam Work
Melissa Klingenberg
Concurrent Technologies Corporation
Jim Hirvonen
Army Research Laboratory

Powder Coat Technology
Peter Gribble
Seibert Corporation

Overview of Pollution Prevention Programs in the U.S. Army, the Industrial Ecology Center, and the National Defense Center for Environmental Excellence
Robert Scola
U.S. Army Industrial Ecology Center

Pratt and Whitney Waterjet Systems
Clifford Mitchell
Pratt and Whitney Waterjet Systems

C/KC-135 Integral Wing Fuel Tank Topcoat Removal
Donald Neiser
Oklahoma City Air Logistics Center, United States Air Force

Use of Waterjet Technologies by the U.S. Navy
Lydia M. Frenzel
Advisory Council, San Marcos, Texas

Ion Beam Case Study: NDCEE and Industry
James Treglio
IMS Corporation

Navy Program Experience
Dave Asiello
Office of the Chief of Naval Operations, U.S. Navy

Appendix C

REVIEW OF ORGANIC COATING TECHNOLOGY

Military equipment, vehicles, ships, and aircraft generally require coatings that are both hard and flexible, with high requirements for outdoor durability, corrosion protection, adhesion, and resistance to chemicals. This combination of properties is best achieved if there is a chemical reaction during and/or after film formation to "cure" the coatings. This chemical reaction provides connections between the polymer molecules, leading to formation of cross-links in the binder. This class of coatings is generally referred to as thermoset, as compared to thermoplastic coatings, which are not cross-linked. Thermoplastic paints such as architectural latexes, industrial plastisols, and nitrocellulose lacquers are used in some industries; the Navy uses modified rosin gum-based antifoulant paints. Several good references are available on the complex and sophisticated chemistry of organic coatings and on their applications.[1,2,3]

Thermoset coatings are used in several demanding civilian applications and have military uses as well. In the civilian economy, such coatings are generally classified as *special-purpose* or *original equipment manufacture (OEM)* coatings. Thermoplastic marine antifoulant paints are an exception.

Special-purpose coatings include paints for automotive refinishing and for aircraft and marine applications; these meet technical requirements broadly similar to the requirements for coatings for military needs. Other significant specialty coatings are for industrial maintenance, roof coatings, and traffic striping. A salient feature of specialty coatings is that they are cured at or close to ambient temperature, as are most depot and field-applied military coatings.

Most coatings applied during original manufacturing are cured at elevated temperatures. Application in factories requires fast throughput, which can be best achieved with coatings cured at temperatures higher than 110 °C (230 °F) for metal substrates and around 82 °C (180 °F) for plastics and wood. Important OEM markets include automobiles, appliances, furniture, containers, machinery, small implements, and flat stock. Chemical coating sales in the United States in 2000 were $17 billion at a volume of 5.24 billion liters (1 billion gallons).[4] The market mix is shown in Table C-1.

Table C-1 Market Share of Coating Sales in the United States in 2000

	Percentage of Dollar Value (2000 total: $17 billion)	Percentage of Gallon Volume (2000 total: 1.3 billion gallons)
Original equipment	40	36
Special purpose	22	14
Architectural	38	50

Source: Chemical Week. November 7, 2001. Available at <http://www.chemweek.com>. Accessed January 2002.

Five of the largest paint suppliers in the United States are Sherwin Williams, PPG, DuPont, BASF, and Akzo Nobel. These highly diversified global companies have significant sales in the automotive and refinish markets. Other major paint suppliers include Valspar and Benjamin Moore. The industry is consolidating, but about 450 paint manufacturers remain active in the United States and more than 17,000 remain active globally.

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[1] Wicks, Z.W., Jr., F.N. Jones, and S.P. Pappas. 1999. Organic Coatings. 2nd edition. New York: Wiley-Interscience.

[2] National Research Council. 1994. Coatings, subsection in Polymer Science and Engineering: The Shifting Research Frontier. Washington, D.C.: National Academy Press, pp. 98-100.

[3] Koleske, J.V. 2000. A century of paint. Paint & Coatings Industry Magazine 1:54-114.

[4] Chemical Week. November 7, 2001. Available at <http://www.chemweek.com>. Accessed January 2002.

The major driving force for technology change in the past 30 years has been reduction of emission of volatile organic compounds (VOCs) in compliance with the Clean Air Act of 1970 and the successive federal and state regulations. Compliance was accomplished primarily by reducing the solvent content in paints and secondarily by improving the deposition efficiency.

Elimination of toxic ingredients is another major issue for the paint industry. Today's paints contain no heavy-metal-based pigments, with the exception of lead in some electrocoats and chromates. Lead is gradually being eliminated from electrocoat. Strontium chromate is still a key ingredient for improving the corrosion resistance of primers for aircraft and coil coatings, and no satisfactory replacement has yet been found. Chromates are also part of many inorganic conversion coatings for aluminum, steel, and galvanized steel. Such conversion coatings are applied before metal substrates are painted with organic coatings. New chromate-free conversion coatings are now being market tested.

Formulation of paints without hazardous air pollutants (HAPs) is a high priority. Toxic aromatic solvents and ethylene-oxide-based oxygenated solvents are being increasingly replaced by more benign ingredients. There is also much research to reduce formaldehyde emissions from heat-cured coatings that contain amino resin crosslinkers. Amino resins are condensation products of formaldehyde with certain nitrogenous compounds.

In recent years, the Environmental Protection Agency has exempted a few solvents, including acetone, methyl acetate, and 4-(trifluoromethyl)chlorobenzene from VOC regulations on the grounds that their potential for generating ozone is very low. When used in coatings, these exempt solvents do not count as VOCs. While exempt solvents are expensive and/or very volatile, they can be blended with other solvents to enable formulators to meet stringent VOC limits.

HIGH-TEMPERATURE-CURE COATINGS

The cross-linking reaction in a thermoset material is heat induced in most industrially applied coatings. Many cars, trucks, small implements, appliances, metal containers, metal furniture, and other industrial products are covered by heat-cured paints when originally manufactured.

Most often, acrylic and polyester resins are used in topcoats. The topcoat resins contain pendant hydroxyl (-OH) groups, which are reactive toward cross-linkers. The most widely used crosslinkers are the amino resins. Other cross-linkers such as blocked isocyanates also find considerable use. The design of resins and cross-linkers is continuously improved. Such binder systems provide excellent performance at relatively low cost. The long durability and high esthetic value of modern automotive paints illustrate this benefit. Also, modern washing machines, dryers, and dishwashers break down mechanically long before their paint fails.

Special property requirements for automotive topcoats such as acid rain resistance require various functional resins and cross-linkers. These include cross-linking of hydroxyl functional resins with blocked isocyanates, carbamate functional resins with amino resins, and carboxyl functional resins with epoxies, to name a few examples.

Corrosion protection is an essential requirement for most coating systems for metal. Topcoats provide modest protection and can be used without primer for some indoor applications, such as metal file cabinets and shelving. In applications requiring rigorous corrosion protection, primers, usually based at least partly on epoxy resins, are used. Where corrosion protection in recesses and crevices is important, as for autos, trucks, farm implements, or appliances, electrodeposited coatings based on modified epoxy resins and cross-linked with blocked isocyanates are almost universal. Such primers require high baking temperatures, generally in the range of 160 to 190 °C (320 to 374 ^{o}F).

Heat-induced cross-linking reactions often involve the evolution of volatile by-products. This happens even in the cure of solventless powder coatings, which consequently cannot be designated as "zero VOC."

Ambient-temperature-cure coatings, generally referred to as special-purpose coatings, are particularly important for the refinishing of large objects such as airplanes, naval vessels, and cars and trucks. Also, because heat curing of large objects is not practical, airplanes, naval vessels, combat vehicles, large implements, bridges, and industrial machinery are painted with ambient-temperature-curing paints both in original manufacture and in refinishing.

The most commonly used high-performance ambient-curing paints are two-component urethanes for topcoats and two-component epoxies for primers. Most urethane binders are hydroxyl functional acrylics or polyesters cross-linked with trifunctional isocyanates. Amine functional compounds are used for cross-linking epoxy resins. It is one of the major achievements of modern coating technology that ambient-curing automotive refinishing systems based on two-component urethane topcoats and two-component epoxy primers now provide properties matching those of heat-cured coating systems. Fundamentally similar two-component coatings are used for painting aircraft, both in original manufacturing and in refinishing, and for above-water-line paints for commercial ships.

Alternate two-component technologies for topcoats have been developed and have the advantage that they do not involve the use of isocyanates, which are highly allergenic. They are important in a few markets. Such systems include the cross-linking of glycidyl, carbonyl, or activated methylene or acryloyl functional binders with polyamines generated by the reaction of ketimines with moisture.

A special two-component solventless system is a blend of unsaturated polyester and styrene. Such gel coats are cured by incorporation of peroxides. Boat and yacht coatings, particularly for fiberglass hulls, and some "wet look" wood furniture coatings are based on gel coats.

A single-component and ambient-temperature cross-linking is achieved by air oxidation of alkyd resin binders. Though alkyd paints are generally inferior to isocyanate-cured paints in outdoor durability and chemical resistance, they are used extensively in high-gloss architectural paints. Modification with silicones, acrylics, or urethanes improves performance, though not enough to match that of two-component systems. The Navy aims to avoid the use of isocyanates. Instead of two-component urethanes, the Navy uses silicone-modified alkyds for topcoats. These are applied over two-component epoxy primers in above-water-line paints.

ORGANIC COATINGS WITH REDUCED SOLVENT CONTENTS

Before the 1970s most industrial and specialty paints were applied from organic solvents at relatively low solids contents, causing significant emission of ozone-depleting chemicals. In the past 30 years, the solvent content of paints has been drastically reduced by the means outlined below.

High-Solids Coatings

High-solids paints are one of two dominant nonpolluting paint technologies in the United States. New binders were developed that allowed convenient paint application at 50 to 80 weight percent solids content, or 1000 to 250 grams of solvent per kilogram of paint solids (1 to 0.25 pounds of solvent per pound of paint solids). In contrast, a typical old-style solvent-borne paint contained about 20 to 40 weight percent solids, or 4000 to 1500 grams of solvent per kilogram of paint solids (4 to 1.5 pounds of solvent per pound of paint solids). According to these examples, the change to high-solids paints often reduced solvent emissions 4-fold, and in some instances even 16-fold.

The current high-solids technology for heat-cured coatings has been evolving since about 1970. Of the many technical expedients involved, the most critical is the reduction in the molecular weight of the binder resins without compromising the physical properties of the final coating film. This was accomplished using modern polymer chemistry so that the new high-solids paints generally perform better than their low-solids counterparts. High-solids automotive and appliance coatings have been particularly successful in the past 25 years.

The Clean Air Act of 1970 initially regulated only high-temperature-curing paints. The requirements to reduce the VOC content of ambient-temperature-curing paints originated in the early 1980s. High-solids, two-component urethane topcoats and epoxy primers are now routinely used in car refinishes, aircraft manufacture and refinish coatings, primers for above- and below-waterline marine paints, heavy-duty industrial maintenance paints, and many other applications. The alkyd, silicone-modified alkyd, and thermoplastic antifoulant technologies have also been adapted for high-solids coatings. High-solids ambient-curing organic coatings dominate military painting operations.

Recently, the formulation of high-solids coatings has been greatly facilitated by the use of the exempt solvents listed above. While these solvents are unsuitable to serve as the total solvent of most paints, they can be blended with nonexempt solvents to reduce the total VOC content.

Waterborne Coatings

Waterborne coatings are the second dominant nonpolluting paint technology. Two waterborne organic coatings were widely used even before environmental concerns became important. These are architectural latex paints and electrocoat. Latexes provide the best available binder technology for low- to medium-gloss architectural paints.

Electrocoat is a high-temperature-cured system. The articles are dipped into the coating bath and electric current deposits the coating. The main merit of electrocoat is that it provides the best corrosion protection for articles with complex shapes by uniform coating deposition onto exposed surfaces and into crevices. VOC emission by electrocoat processes is negligibly small.

Aqueous binder resins may be grouped into three classes: latexes, polyurethane dispersions, and water reducibles. For specialty and OEM coatings acrylic latexes are used; vinyl-acetate-based latexes are limited to architectural coatings. Latexes and polyurethane dispersions have high molecular weights and form good films without cross-linking. However, cross-linking improves their toughness and chemical resistance. Polyurethane dispersions provide particularly high quality coatings but are expensive.

Water-reducible resins have relatively low molecular weights and can be considered as water-dispersed analogues of high-solids resins. For good film formation such resins must be cross-linked. Electrocoat technology is based on water-reducible resins. Waterborne organic coatings contain some solvents for enhancing substrate wetting and film formation. However, the solvent content of aqueous coatings per pound of solids is often, but not always, lower than that for high-solids paints. In many applications aqueous coatings provide an option for reducing VOC emissions beyond what can be achieved by high-solids coatings. High-solids coatings formulated partly with exempt solvents can, in some circumstances, provide equal or lower VOC emissions than those typical for waterborne coatings.

Spraying is the most common method of applying paint. High-temperature-cure aqueous spray paints are widely used for automotive base coats, can coatings, business machines, furniture, shelving, and many other applications.

In the past 5 years the technology of two-component, aqueous urethanes and epoxies has been greatly improved; such paints match the performance of their high-solids counterparts in several, though not all, applications. These novel paints and the more traditional latexes cross-linked through carbonyl or carboxyl groups are now widely used for painting plastics, composition boards, and wood furniture.

Powder Coatings

Powder coatings are almost completely solventless. The powder is applied by electrostatic means. The object with its layer of powder is then heated; the powder liquefies and flows out and then cross-links. In addition to providing very low VOC emissions, powder coatings can, in favorable circumstances, offer advantages such as low energy consumption and excellent film mechanical properties. However, they are best suited to high-volume applications of a single color, or a limited range of colors. High-solids, waterborne, and powder coatings are competitive high-temperature-cure technologies.

Radiation-Cured Coatings

Radiation cure provides a method for applying solventless paints and curing them at ambient temperature. The precursor of the binder is in a liquid state and polymerizes under ultraviolet or electron beam radiation. Major end uses include can varnishes and coatings for sports equipment, wood furniture and paneling, optical fibers, plastics, and wheels. Radiation curing is now also used for cross-linking solid binders. Aqueous or powder paints are allowed to form continuous uncross-linked films first and are subsequently cross-linked by UV irradiation.

Radiation cure provides coatings with excellent chemical resistance. In favorable circumstances, the relatively high raw material costs are offset by savings due to very fast throughput without the use of expensive heat-curing ovens.

APPLYING ORGANIC COATINGS

Reduced solvent content in paints is complemented by novel technologies allowing improved efficiency of paint application. In conventional spray applications 30 to 80 percent of the paint does not hit the target surface. This overspray is generally wasted, but its solvent content contributes to VOC emissions. The percentage of paint hitting the surface, known as the transfer efficiency, is improved by the technologies described below.

1) Electrostatic spaying of liquid paints greatly improves the wrap of paint particles around the targets, and therefore the transfer efficiency. This technology is very sophisticated and includes air-assisted and airless guns, as well as rotating disks and bells used to atomize paint. Novel equipment design even allows electrostatic application of aqueous paints.

2) Supercritical carbon dioxide partly replaces organic solvents in some high-solids paints. It is particularly effective in improving atomization so that particle size distribution in the paint aerosol becomes uniform and the efficiency of electrostatic spray is enhanced.

3) Robotic applications are now widespread in the automotive industry. The robots follow the shape of the target very closely and thus minimize overspray.

4) New low-pressure/high-volume guns improve the transfer efficiency of liquid paints even without robotics or electrostatics.

5) Overspray is recycled in the application of powder coatings, leading to better than 99 percent effective paint utilization. There are now experimental systems available for recycling the overspray originating from liquid coatings.

6) Electrocoat provides an application method that also allows complete paint utilization.

7) Application of paints by rollers over flat surfaces for coil coating or radiation-curable coatings is accomplished with almost 100 percent transfer efficiency. Coil coating provides prefinished steel or aluminum sheets, which are later stamped and formed to shape by the OEM end user. This technology is widely used for building siding, roof coatings, and appliances. Much development activity in the automotive industry is aimed at manufacturing automotive components from prefinished steel to eliminate electrocoat primers, as well as at powder- or high-solids-based primer-surfacer coatings.

Reducing the solvent content of paints, reusing emitted solvents, and improving transfer efficiency not only yield environmental benefits but also often provide considerable cost savings. Reducing the costs of waste disposal provides additional economies.

Appendix D

ACRONYMS AND ABBREVIATIONS

ARDEC	Armament Research, Development and Engineering Center
ARMS	Automated Robotic Maintenance System
BMAED	Board on Manufacturing and Engineering Design
CCAD	Corpus Christi Army Depot
COTS	commercial off the shelf
CPC	Corrosion Prevention and Control Program
CTC	Concurrent Technologies Corporation
CTIO	Coatings Technology Integration Office
DDR&E	Director, Defense Research and Engineering
DERP	Defense Environmental Restoration Program
DLA	Defense Logistics Agency
DOD	Department of Defense
DUSD(ES)	Deputy Undersecretary of Defense (Environmental Security)
EPA	Environmental Protection Agency
EQBRD	Environmental Quality Basic Research and Development Program
ESTCP	Environmental Security Technology Certification Program
GOCO	government-owned, contractor-operated
IEC	U.S. Army Industrial Ecology Center
JG-PP	Joint Group on Pollution Prevention
LCAAP	Lake City Army Ammunition Plant
NADEP	Naval Aviation Depot
NADEP-JAX	Naval Aviation Depot Jacksonville
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NDCEE	National Defense Center for Environmental Excellence

NIST	National Institute of Standards and Technology
NRC	National Research Council
NTTC	National Technology Transfer Center
O&M	Operations and Maintenance
OEM	original equipment manufacturer
RDT&E	Research, Development, Test and Evaluation
SERDP	Strategic Environmental Research and Development Program
SGM	Sustainable Green Manufacturing Program
SSPC	Steel Structures Painting Council
TACOM	Tank-automotive and Armaments Command
VOC	volatile organic compound