



## Memorandum

Date: January 20, 2004

From: Michael J. Galvin, Ph.D., Program Official   
Office of Extramural Programs, NIOSH, E-74

Subject: Final Report Submitted for Entry into NTIS for Grant 5R03OH004155-02.

To: William D. Bennett  
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

#### Attachment

cc: Sherri Diana, EID, P03/C13

#### List of Publications

Roelofs CR, Moure-Eraso R, Ellenbecker MJ: Pollution Prevention and the Work Environment: The Massachusetts Experience. *Applied Occupational and Environmental Hygiene* 15(11):843-850, 2000

Roelofs, C.R., R. Moure-Eraso, and M.j. Ellenbecker, Pollution Prevention and the Work Environment: The Massachusetts Experience. *App Occup Environ Hyg*, 2000.15(11): p. 843-850.

Roelofs, C.R., et al., Prevention Strategies in Industrial Hygiene: A Critical Literature Review. *Am.Ind. Hyg. Assoc. I*, 2003.64(1): p. 62-67.

Roelofs, C.R. and M.J. Ellenbecker, Results of the Massachusetts Methylene Chloride End-Users Survey. *App. Occup. Environ. Hyg.*, 2003.18(2): p. 132-137.

Roelofs, C.R. and M.J. Ellenbecker, Source reduction for prevention of methylene chloride hazards: cases from four industrial sectors. *Environ Health*, 2003.2:9.

The principal investigator's doctoral dissertation was also supported by this grant:

Roelofs CR: *Losing Controls: The Case for a Preventive Industrial Hygiene*, ScD Thesis, University of Massachusetts Lowell, 2001.

**Title:** Intervention Effectiveness Of Process Change Techniques  
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**Final Report Abstract:**

Abstract

This report describes case studies of source reduction process changes undertaken in four Massachusetts firms in order to reduce hazards associated with exposure to methylene chloride. Source reduction strategies aim to intervene in the industrial process itself to eliminate or reduce hazards through the use of chemical substitution, process modification, and/or substitute technologies. While common in environmental protection, source reduction strategies have not had broad acceptance in the industrial hygiene field and industrial hygienists have relied upon local exhaust ventilation and other control strategies that specifically do not change industrial processes. Such "interference" in industrial processes may have been deemed "infeasible," thus this study sought to report on the feasibility and effectiveness of source reduction strategies for the purposes of prevention of worker health hazards.

The four firms profiled here had used methylene chloride, a high-volume chlorinated aliphatic hydrocarbon solvent, suspect occupational carcinogen and hazardous air pollutant, for cleaning and adhesive thinning operations. Three of the firms, a rubber products maker, an electrical equipment manufacturer, and an industrial vessel cleaning service, had eliminated use of methylene chloride at the time of the study. The fourth, a metal finishing company, was assisted by the investigator in reducing methylene chloride use. The case studies document the industrial process prior to and after the source reduction process, the steps each company took to accomplish the change, the company's motivations for the change, how the company evaluated the project, assessments of worker exposures before and after the change, costs, benefits and problems resulting from the change, and key lessons from each case. Data for the cases were collected via in-depth interviews, site visits including industrial hygiene walk-throughs, and document review.

The key findings of this study include that 1) companies will undertake source reduction as a preferred strategy for regulatory compliance; 2) technical performance is companies', principal evaluation criterion; 3) source reduction efforts, while motivated by environmental and occupational health concerns, often have the benefit of improving production processes and saving companies money; 4) because exposure to methylene chloride is a significant worker health hazard, the elimination and reduction of its use resulted in improvement in the work environment. However, company review of the

potential health and safety and environmental impact of "un-listed" or chemical supplier-recommended alternatives was limited and some new hazards, including ergonomic and noise, were introduced. Recommendations of this report include a new focus on technical assistance that can help companies identify optimal source reduction strategies and anticipate and minimize new occupational and environmental health and safety hazards is necessary to maximize the benefits of this approach.

**Publications:**

Riordan CM, Vandenberg RJ: Employee Involvement and Organizational Effectiveness: An Organizational System Perspective. *Journal of Management*, in press, 2001

DeJoy, D.M., Wilson, M.G., & Griffin-Blake, C.S. (2000). Healthy work organization. In: W. Karwowski (Ed. ), *International encyclopedia of ergonomics and human factors*. London: Taylor- Francis.

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DeJoy, D.M., & Wilson, M.G. (2003). Organizational health promotion: Broadening the horizon of workplace health promotion. *American Journal of Health Promotion*. 17. 337-341.

DeJoy, D.M., Gershon, R.M.M., & Schaffer, B.S. (2003, March). Management/organizational influences on human error, safety performance, and program effectiveness. *Proceedings of the Human Error and Occupational Safety Symposium* (pp. 15- 32). Des Plaines, IL: American Society of Safety Engineers.

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Wilson, M.G., DeJoy, D.M., Vandenberg, R.J., Richardson, H., & McGrath, A.L. Work characteristics and employee health and well-being: Test of a model of healthy work organization. Accepted pending revision: *Journal of Organizational and Occupational Psychology*.

DeJoy, D.M., Gershon, R.M.M., & Schaffer, B.S. Management and organizational influences on safety: Effects of safety climate. Accepted pending revision, *Professional Safety*.

Lance CE, Vandenberg RJ: Confirmatory Factor Analysis. In: *Frontiers of Industrial and Organizational Psychology: Advances in Measurement and Data Analysis*, (eds. F Drasgov, N Schmitt), San Francisco: Josey-Bass, Vol. 1

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- Riordan CM, Richardson HA, Schaffer B, Vandenberg RJ: Alpha, Beta, and Gamma Change: A Review of Past Research with Recommendations for New Directions. In: Trends in Organizational Research, (eds. C Schriesheim, L Neider), Menlo Park, CA: Sage, in press, 2001
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- DeJoy DM, Wilson MG, Griffin-Blake CS: Healthy Work Organization. In: International Encyclopedia of Ergonomics and Human Factors, (ed. W Karwowski), London: Taylor and Francis, in press, 2001
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- Roelofs CR, Moure-Eraso R, Ellenbecker MJ: Pollution Prevention and the Work Environment: The Massachusetts Experience. *Applied Occupational and Environmental Hygiene* 15(11):843-850, 2000
- Roelofs, C.R., R. Moure-Eraso, and M.J. Ellenbecker, Pollution Prevention and the Work Environment: The Massachusetts Experience. *App Occup Environ Hyg*, 2000.15(11): p. 843- 850.
- Roelofs, C.R., et al., Prevention Strategies in Industrial Hygiene: A Critical Literature Review. *Am.Ind. Hyg. Assoc. I*, 2003.64(1): p. 62-67.
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**RESEARCH FOUNDATION**

December 5, 2003

Cynthia Mitchell  
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Subject: Final Report. "Intervention Effectiveness of Process Change Techniques"  
UM project # 05-08681-1  
Cora Roelofs, Principal Investigator

Dear Ms. Mitchell:

Enclosed are 2 copies of the Final Report, one copy on CD and 3 copies of the publications for the above referenced project sent on behalf of Dr. Cora Roelofs from the University of Massachusetts Lowell.

Sincerely,

A handwritten signature in blue ink that reads 'Linda Concino'.

Linda Concino  
Grants & Contracts Administrator

LC/sr

Enclosures

Dr. Cora Roelofs, Principal Investigator

**REPORT TO THE NATIONAL INSTITUTE FOR  
OCCUPATIONAL SAFETY AND HEALTH:**

**CASE STUDIES OF THE FEASIBILITY AND  
EFFECTIVENESS OF DICHLOROMETHANE  
SOURCE REDUCTION FOR HAZARD  
PREVENTION**

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**Grant Number: 1 R03 OH04155-01**

**“Intervention Effectiveness of Process Change Techniques”**

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## List of Abbreviations

cfm	cubic feet per minute
DBE	dibasic esters
DCM	dichloromethane, or methylene chloride
EHS	environmental health and safety
EPA	U.S. Environmental Protection Agency
HAP	Hazardous Air Pollutant
L/min	liters per minute
LEV	local exhaust ventilation
MACT	Maximum Available Control Technology
MSDS	Material Safety Data Sheet
NIOSH	National Institute for Occupational Safety and Health
NMP	n-methyl pyrrolidone
OSHA	U.S. Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
Perc	perchloroethylene
ppm	parts per million
psi	pounds per square inch
STEL	short-term exposure limit
TCA	1,1,1-trichloroethane
TCE	trichloroethylene
TRI	Toxics Release Inventory
TUR	toxics use reduction
TURA	Massachusetts Toxics Use Reduction Act
TURI	Massachusetts Toxics Use Reduction Institute
TWA	time weighted average
VOC	volatile organic compound

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## Abstract

This report describes case studies of source reduction process changes undertaken in four Massachusetts firms in order to reduce hazards associated with exposure to methylene chloride. Source reduction strategies aim to intervene in the industrial process itself to eliminate or reduce hazards through the use of chemical substitution, process modification, and/or substitute technologies. While common in environmental protection, source reduction strategies have not had broad acceptance in the industrial hygiene field and industrial hygienists have relied upon local exhaust ventilation and other control strategies that specifically do not change industrial processes. Such “interference” in industrial processes may have been deemed “infeasible,” thus this study sought to report on the feasibility and effectiveness of source reduction strategies for the purposes of prevention of worker health hazards.

The four firms profiled here had used methylene chloride, a high-volume chlorinated aliphatic hydrocarbon solvent, suspect occupational carcinogen and hazardous air pollutant, for cleaning and adhesive thinning operations. Three of the firms, a rubber products maker, an electrical equipment manufacturer, and an industrial vessel cleaning service, had eliminated use of methylene chloride at the time of the study. The fourth, a metal finishing company, was assisted by the investigator in reducing methylene chloride use. The case studies document the industrial process prior to and after the source reduction process, the steps each company took to accomplish the change, the company’s motivations for the change, how the company evaluated the project, assessments of worker exposures before and after the change, costs, benefits and problems resulting from the change, and key lessons from each case. Data for the cases were collected via in-depth interviews, site visits including industrial hygiene walk-throughs, and document review.

The key findings of this study include that 1) companies will undertake source reduction as a preferred strategy for regulatory compliance; 2) technical performance is companies’ principal evaluation criterion; 3) source reduction efforts, while motivated by environmental and occupational health concerns, often have the benefit of improving production processes and saving companies money; 4) because exposure to methylene chloride is a significant worker health hazard, the elimination and reduction of its use resulted in improvement in the work environment. However, company review of the potential health and safety and environmental impact of “un-listed” or chemical supplier-recommended alternatives was limited and some new hazards, including ergonomic and noise, were introduced. Recommendations of this report include a new focus on technical assistance that can help companies identify optimal source reduction strategies and anticipate and minimize new occupational and environmental health and safety hazards is necessary to maximize the benefits of this approach.

## Significant Findings

These case studies can help occupational health and safety professionals understand the feasibility and effectiveness of source reduction process change for hazard prevention and bring to light some of the characteristics and impacts of the approach as practiced in the “real world.” In 1997 OSHA lowered the methylene chloride Permissible Exposure Limit (8hr-TWA) from 500 ppm to 25 ppm. For the companies profiled here, complying with the new standard with engineering controls would have been difficult and expensive. The alternative route they took appeared to gain them the benefits of both regulatory compliance, and in most cases, process improvements. New processes and chemicals sometimes introduce new hazards, however, and these were, in general, not adequately anticipated or addressed in companies conducting process changes on their own without trained assistance. This study found that effective, feasible and safer alternatives to the use of methylene chloride exist in a variety of industrial sectors, processes and facility sizes. Key lessons from these cases include the following:

1. Source reduction strategies can be a feasible and effective approach to compliance with standards and reduction of worker health hazards. In its methylene chloride standard, OSHA had concluded that engineering controls were not feasible for vessel cleaning and this industry would rely on air-line respirators for exposure control. This study found that for this sector (and others), source reduction process changes that eliminated methylene chloride use were not only feasible, but beneficial to production and environmental protection goals.
2. Technical assistance is key to facilitating process change. Companies may make sub-optimal choices, from an occupational health and safety or environmental standpoint, with inadequate information about alternatives. Typically, technical concerns are top-priority and many companies trust that “unlisted” products are “safe.” Thus, technical assistance sensitive to both technical and occupational and environmental health concerns could help maximize the benefits of the process.
3. Source reduction strategies can result in financial gains, without even considering the benefits from improved regulatory compliance. When companies look at processes, they often try to improve them overall, by reducing the problems they cause (environmental contamination and worker exposure) and innovating production improvements. Financial concerns of change, other than significant capital investments, do not appear to be a major barrier to the utilization of source reduction strategies, especially when the changes are motivated by regulatory compliance.
4. This research suggests that source reduction strategies motivated by strict regulation have the potential to drive significant industrial innovation and reduction of worker health hazards, but should be accompanied by technical assistance sensitive to technical performance and worker and environmental health concerns.

## Usefulness of Findings

The major finding of this report—that source reduction process change strategies are feasible and effective for the reduction of methylene chloride hazards—can be immediately applied in applicable industrial processes. The report provides examples of source reduction strategies for the major uses of the chemical (Table 2.4) and resources for further information and technical assistance (Appendix). The four cases studies of source reduction process change presented here detail the processes, tools, concerns, benefits and problems associated with process change for hazard prevention and can guide similar efforts. In these cases, “off the shelf” less hazardous substitutes and processes including aqueous cleaning chemistry, dibasic esters, and baking soda and water mechanical cleaning, were able to take over the jobs performed by methylene chloride and the companies were able to eliminate (three cases) or significantly reduce (one case) their use of the chemical.

In addition to eliminating or reducing occupational health hazards, the advantages of source reduction include process improvements resulting in cost savings and lack of conflict with environmental regulations—a potential consequence of compliance strategies involving local exhaust ventilation. Disadvantages include the burden of considering the impact of the source reduction strategy including on technical performance and environmental and occupational health and safety. In one of the cases described here, sub-optimal substitutions were made in two different processes: in one, an ozone-depleting chemical was substituted for methylene chloride, and in the other, n-methyl pyrrolidone, an “un-listed” but potential reproductive hazard, was introduced. Because technical concerns will dominate companies’ source reduction strategies, occupational health and safety professional must become familiar with the technical, financial, environmental and health and safety resources and tools that available in order to maximize the benefits and minimize the potential negative impacts of source reduction process changes. They can do so by studying the cases in this report and by consulting the numerous resources cited in an appendix to this report.

# Scientific Report

## 1 Introduction

This report describes four case studies of source reduction process change for hazard prevention. "Process changes" include chemical substitution, process modification, and substitute technologies that intervene in the industrial process itself to eliminate or reduce hazards.<sup>(1)</sup> This study specifies that the process changes undertaken are source reduction, that is, they change the process to reduce or eliminate the source of the hazard, instead of changes that may alter the process and/or the exposure without reducing the source. In the environmental field, such strategies have also been called "pollution prevention" or "toxics use reduction".

The promise of source reduction is that it can effectively and reliably prevent chemical exposure hazards by reducing the quantity and/or toxicity of the hazard at every stage of production without shifting risks to other workers or the environment. However, application of these techniques to the problem of worker exposure to hazardous chemicals is still somewhat new. Although source reduction strategies have been used successfully for protection of the environment, there have been few documented cases of their feasibility and effectiveness for protecting workers. Of course, there are not hard and fast definitions of the terms "feasible" and "effective," but we may define them as follows: feasible means meeting the minimum technical, financial, environmental and occupational health standards set by the company themselves within the context of regulatory compliance. It does not mean that the new strategy must not require the company to change its operations, products and processes. "Effective" is defined as an evaluated and assessed finding of feasibility and implies sustainability, albeit in a context of continuous improvement. While source reduction alternatives may introduce new hazards, a comprehensive effectiveness evaluation should identify these problems and either develop strategies of avoiding or minimizing them, or challenge the change-makers to go back to the drawing board.

The cases presented below are intended to give a comprehensive picture of process changes in real world settings, so that government agencies, companies and public interest groups may gain a footing from which to jump off to address their particular concerns in this area. Of course, we cannot generalize based on a few cases, but the key lessons and conclusions of this study can point toward important areas for further exploration and instill a measure of confidence in the approach.

The cases we investigated focused on strategies to reduce the use of methylene chloride, also known as dichloromethane (DCM), a suspect occupational carcinogen and hazardous air pollutant that is widely used in industry. These cases represent large to small Massachusetts companies and four different industrial sectors: metal finishing, electrical equipment manufacture, rubber products manufacture and vessel cleaning services. Three of the companies had completely eliminated use of DCM at the time of the study and presented the opportunity for retrospective analysis. The case study of the metal finishing company was undertaken prospectively: we identified a company interested in source reduction process change and we both assisted with this change and documented the process. Each case study includes a description of the following:

- 1) the industrial process prior to and after the source reduction effort
- 2) the steps each company took to accomplish the change

- 3) the company's motivations for the change
- 4) how they evaluated the project
- 5) assessments of worker exposures before and after the change
- 6) costs
- 7) benefits and problems resulting from the change
- 8) key lessons from the case as identified by the researchers.

This report's summary and conclusion section highlights points in these categories across the cases. The report concludes with recommendations for further research and action.

## 2 Background

### 2.1 Source Reduction as a Control Strategy

Early industrial hygienists sought to inspire confidence that we need not just treat or blame sick workers, but that hazards could be prevented or reduced through the application of engineering principles. Several major industrial hygiene texts adopted the public health model of "control at the source" of the hazard as the preferred approach for industrial hazard prevention.<sup>(2)</sup> In other cases, industrial hygienists created a hierarchy of hazard control methods and pointed to hazard reduction through product substitution as the first choice for hazard reduction methods.<sup>(3)</sup> Some, however, maintained a perspective that source reduction was not a practical approach, nor even theoretically superior to local exhaust ventilation, from a prevention standpoint.<sup>(4)</sup> This view has been supported by an assumption that control strategies that require changes to industrial processes or products are inherently "infeasible." Thus, "add-on" controls — ventilation systems and personal protective equipment—have dominated hazard prevention guidance and practice.<sup>(5-7)</sup>

On the environmental protection side, the acknowledgment of the problem of pollution "media-shifting," e.g. protecting the air by filtering contaminants through a water slurry and releasing them to a water source, has given rise to support for source reduction in place of "end-of-pipe" controls. The U.S. Pollution Prevention Act of 1990 established source reduction approaches as the preferred alternative to pollution control.<sup>(8)</sup> Many state governments have also adopted source reduction laws and established state agency infrastructure dedicated to promoting source reduction. Additionally, many companies have discovered the benefits of the approach and have championed their own efforts to reduce the impact of their businesses through source reduction.

Thus, source reduction has figured more prominently as an environmental hazard control strategy than an industrial hygiene control approach, but the activities on the environmental side have had a significant impact on the work environment. For example, in 1989 Massachusetts passed the Toxics Use Reduction Act (TURA)<sup>(9)</sup> with a mandate to reduce toxic chemical use in Massachusetts to protect the environment *and* to "reduce risk to the health of workers." Many of the technological breakthroughs that have occurred in chemistry, process engineering, and industrial equipment in response to demand for reducing the environmental impact of production have had the added benefit of removing hazardous chemicals from the work environment.

The traditional industrial hygiene approach is the reduction of air contaminant exposure levels to occupational exposure limits by engineering controls, supported by other means, such as emergency respirators, training, and work practice changes. The major focus of industrial hygiene control strategies has been local exhaust ventilation (LEV). While traditional

approaches, especially in combination, can often be effective methods of control, source reduction strategies, including substitution of less hazardous chemicals, may have additional benefits. For example,

- LEV systems are often designed to reduce contaminants to occupational exposure limits that may not be adequately protective, either because they are not low enough, the exposed population is a vulnerable one, skin exposure is an important route, or they don't exist for the contaminant of concern.<sup>(10)</sup>
- In the “real world,” LEV systems may not be designed properly, not installed as designed, be modified in use, not maintained, exposure conditions/processes may change, and/or replacement air may not be provided.<sup>(11)</sup>
- LEV systems generally offer no protection during equipment failure or accidental spills, as the distance between the contaminant source and the hood increases, or during non-routine tasks such as maintenance activities. For these conditions, respirators (with their own set of limitations) have typically been relied upon.
- The goal of LEV is the collection or re-direction of contaminants, thus such systems involve an inherent risk- and media-shifting process. Air cleaning devices collect contaminants (hopefully), but these collection media's destiny is may also be the environment (e.g., solid waste disposal of HEPA filters). Thus, LEV either facilitates the contamination of the environment, or if a contaminant collection or destruction device is attached, represents an “end of pipe” control with attendant potential for media-shifting.

Another concern stems from the missed opportunity represented by investment in an LEV system—the opportunity to improve the process while reducing hazard potential to both workers and the environment. Contaminant generation signifies waste and inefficiency. Source reduction strategies can reduce the quantities of chemicals used as well as their toxicity. Attention to the hazardous exposure potential of an operation often leads to ideas about new ways of increasing the productivity of the process and eliminating unnecessary steps. These improvements often have a financial benefit. Indeed, because pollution prevention projects are generally voluntary, their broad acceptance has been motivated by positive economic prospects. In contrast, most traditional occupational exposure prevention improvements require the outlay of significant sums for equipment that does not improve productivity because it does not change the industrial process.

Because source reduction process changes modify chemistries and processes, the potential exists for the introduction of new hazards while the hazard of concern is eliminated or reduced. Indeed, the focus on the environmental benefits of pollution prevention may cause proponents to overlook new worker hazards. For example, preliminary findings from a study underway in California has found an increase in peripheral neuropathy among auto mechanics following the introduction of an n-hexane-based “Green Cleaner” in response to a new state law requiring the elimination of perchloroethylene in brake cleaner.<sup>(12)</sup> Researchers investigating how TURA was implemented in its early years found that companies rarely fully considered the risk to workers or the environment of substitutes for “listed” toxic substances that the Act encouraged them to eliminate.<sup>(13)</sup> (A companion paper to this report explores these issues with regard to TURA technical assistance providers. See **Publications**).

History of industrial solvent use gives us reason for significant concern about “risk-shifting,” or the introduction of new hazards while eliminating others. This history shows a series of trade-offs between technical performance and worker safety and environmental safety. As described in Table 2.1, efforts to reduce fire hazards brought in solvents of greater toxicity.<sup>(14)</sup>

These were replaced by solvents that later proved to have detrimental effects on the environment which, when recognized, lead to a re-emergence of potentially more toxic and flammable solvents. Today, more and more companies are replacing solvents with aqueous cleaning and non-chlorinated solvents. While these chemistries appear inherently safer than the chemicals they replace, many have not been evaluated for long-term or comprehensive effects on the work environment.

**Table 2.1: The Eras of Solvent Substitution**

	<b>Solvent</b>	<b>Reasons for Substitution</b>
1940's	Aliphatic and aromatic hydrocarbons: kerosene, gasoline, benzene	
1950's	Carbon tetrachloride; Stoddard Solvent	Non-flammable (FP < 100 <sup>0</sup> F)
1960's-1970's	Chlorinated solvents: trichloroethylene (TCE), perchloroethylene (Perc), DCM	Perceived lower toxicity than carbon tet; better solvency; non-flammable
1970's	1,1,1-trichloroethane (TCA); Freon (CFC 113); other CFCs	Higher PEL; not a VOC; better solvency
<i>1987: Montreal Protocol restricts use of ozone-depleting substances and sets up phase-outs for Freon and TCA</i>		
1980's	HCFCs	Less ozone-depleting
<i>1990: Congress passes the Clean Air Act Amendments, states pass environmental laws restricting vapor degreasers, Hazardous Air Pollutants and VOCs (TCE)</i>		
1990's	Chlorinated solvents: TCE, Perc, DCM	Not VOCs (except TCE); high PELs; non-ozone depleting
	Non-listed and flammable hydrocarbons; semi-aqueous: terpenes, dibasic esters, n-methyl pyrrolidone	Non-listed and unknown toxicity
	Flammable hydrocarbons: acetone, toluene	Availability; cost; limited environmental regulation
<i>1997: OSHA Lowers PEL for Methylene Chloride from 500 ppm to 25 ppm</i>		
1990's-2000's	Aqueous Cleaners	Non-listed; low toxicity; non-flammable
2000's	??????	??????

Source:<sup>(15, 16)</sup>

Additionally, a truly unexplored area is the extent to which chemical hazards may be traded for ergonomic or safety hazards as processes are changed to make increased use of human and mechanical power. In a 1995 article "Substitution of Dangerous Chemicals — The Solution to Problems with Chemical Health Hazards in the Work Environment?" the author identified noise exposures as a concern in two source reduction cases: ultrasonic cleaning and water-based

glue by spray application.<sup>(17)</sup> The potential for new ergonomic hazards is clear in the recommendation of a pollution prevention manual to replace solvent cleaning, in part, with hand-wiping of parts.<sup>(18)</sup> Noise and musculoskeletal hazards have been identified as potential new hazards in one of the DCM source reduction case studies presented in this report. A strategy to avoid such conflicts is described in Rosenberg, et al.'s article, "The Work Environment Impact Assessment: A Methodological Framework for Evaluating Health-Based Interventions."<sup>(19)</sup>

A barrier to the integration of source reduction techniques into industrial hygiene practice is insufficient practical advice on source reduction strategies. Discussion of worker-process interaction in the pollution prevention literature is generally non-existent and it is difficult to find information on hazard elimination in the worker health literature. Substitution is mentioned in a handful of National Institute of Occupational Safety and Health (NIOSH) Health Hazard Evaluation reports, but little additional guidance is provided. For example, in NIOSH's *Hazard Control: Controlling Cleaning Solvent Vapors at Small Printers* gives detailed information about local exhaust ventilation controls, but only suggests under a "Substitution" heading that "Cleaning solutions should not contain potential carcinogens."<sup>(20)</sup> The articles on source reduction strategies that have appeared in the industrial hygiene literature have not been translated into occupational health technical assistance resources.

Some industrial hygienists and related professionals attempted to promote source reduction to reduce both workers' exposure to chemicals and the chemical burden in the environment.<sup>(1, 21, 22)</sup> In November 1993, the American Industrial Hygiene Association adopted a "Position Statement on Pollution Prevention and Toxics Use Reduction." This statement embraced these techniques as industrial hygienists' own and stated that "if workers and the community can be protected from harm through prevention, this is preferred over other control measures."<sup>(23)</sup> A few articles discussing the practical aspects of source reduction techniques have appeared in the industrial hygiene literature.<sup>(1, 24-26)</sup> In 1993, a Danish scientist published a paper entitled "An Analytical Approach for Reducing Workplace Health Hazards Through Substitution," in the *American Industrial Hygiene Association Journal*.<sup>(27)</sup> This article is expanded in the book Substitutes for Hazardous Chemicals in the Workplace which is available in English and is designed to assist occupational health advocates in choosing appropriate substitutes in light of a 1982 law in Denmark prohibiting the use of hazardous chemicals if safer substitutes are available.<sup>(28)</sup>

Conferences have been important forums for the discussion of preventive strategies and environmental and workplace protection integration. The draft report from the NIOSH sponsored conference: "Control of Workplace Hazards for the 21st Century: Setting the Research Agenda," held in March 1998, stated: "While ventilation is an important component of a comprehensive control plan, a more holistic strategy involving the prevention, minimization, and control of exposures can be used to provide optimum control." The American Industrial Hygiene Conference and Exhibition and the American Public Health Association Meeting Occupational Health Section have regularly featured several papers on the subject in past few years. In 1998 a NIOSH engineer presented "The Development of Controls and Ink Substitutes for Reducing Workplace Concentrations of Organic Solvent Vapors in a Vinyl Shower Curtain Printing Plant," based on research and practical work by the NIOSH Engineering Controls Branch.<sup>(29)</sup> In that case, environmental authorities required the company to better contain solvent vapors within the work environment and to cut dilution ventilation. This resulted in high exposures and respirator use by employees. NIOSH engineers then worked with the company to formulate low-VOC (volatile organic compound) inks. This source reduction strategy eliminated the need for

expensive end-of-pipe environmental controls and respirators and restored mechanical and natural air exchange between the indoor and outdoor environments.

This case was also cited at the historic conference “Common Sense Approaches to Protecting Workers And the Environment: Interagency Cooperation Towards Comprehensive Solutions,” jointly sponsored by OSHA, NIOSH, and U.S. Environmental Protection Agency (EPA) in June 1999. Charles Jeffress, then Assistant Secretary of Labor for OSHA, introduced the workshop by discussing the agencies’ mutual commitment to work together and the agenda of the conference which included coordinated rulemaking, cooperation at the enforcement and permitting levels, joint research projects and consultation efforts, and multi-agency partnerships with stakeholders to achieve risk reductions for both workers and the environment outside of the rulemaking or enforcement process.

Source reduction process change represents an under-exploited tool in the industrial hygiene toolkit. This report of four cases and the additional resources provided here can facilitate a greater role for the approach while illuminating its potential limitations.

## 2.2 Dichloromethane in the Work Environment

DCM was selected as the subject of this research in part because of its toxicity and extensive use in industry, as well as the important attention that it has received in the past few years from regulatory agencies. DCM is a U.S. Occupational Safety and Health Administration (OSHA) Category I potential occupational carcinogen and both the National Toxicology Program and the International Agency for Research on Cancer have identified DCM as potentially carcinogenic to humans based on toxicological and epidemiological evidence.<sup>(30-32)</sup> NIOSH classifies DCM as a potential occupational carcinogen and recommends that exposure to this chemical be limited to the lowest feasible concentration.<sup>(33)</sup>

Some important agencies and organizations have completely restricted DCM use in response to health and environmental concerns. The U.S. Food and Drug Administration has banned DCM in cosmetics.<sup>(34)</sup> The California South Coast Air Quality Management District has prohibited the use of DCM in adhesives, sealants or primers.<sup>(35)</sup> Through collective bargaining the Canadian Auto Workers and Daimler-Chrysler have agreed to eliminate DCM from paint stripping operations in auto manufacture.<sup>(36)</sup> Sweden has begun a phase-out of DCM with the goal of a complete ban.<sup>(37)</sup>

In 1997, OSHA promulgated a strict comprehensive DCM standard.<sup>(38)</sup> This standard lowered the 8-hour time weighted average (8-h TWA) permissible exposure limit (PEL) for the chemical from 500 ppm to 25 ppm. OSHA expected the new standard to decrease the risk of cancer for the 237,500 workers exposed to DCM by up to 97% and save 34 lives annually. Additionally, the standard was expected to prevent chronic central nervous system effects, cardiac damage (resulting from the metabolism of DCM to carbon monoxide) and eye, skin and mucous membrane irritation in exposed populations. However, the risk assessment that accompanies the standard estimates that even at the reduced concentration of 25 ppm, 399 excess cancer deaths over 45 years, or 9 deaths a year, can still be expected. These estimates do not include the potential lives lost due non-cancer end-points such as acute overexposure, accidents caused by worker central nervous system depression, carboxyhemoglobin-induced heart attacks and other systemic toxic effects.

In addition to reducing the PEL for DCM to 25 ppm, OSHA’s standard requires exposure monitoring, worker training, engineering controls, designation of restricted areas, spill and leak

prevention and medical surveillance. Medical surveillance is required for employees exposed to concentrations greater than the action level of 12.5 ppm for more than 30 days a year. In response to a petition by the United Automobile Workers, OSHA amended the standard to include a provision for wage replacement for workers removed from employment due to medical conditions related to DCM exposure. Under the rulemaking procedures, OSHA determined that the proposed standard was technically and economically feasible and that companies could comply with the new standard without eliminating DCM from industrial operations. It reinforced that elimination of DCM use was not its goal in an interpretation letter regarding foam manufacture.<sup>(39)</sup>

Engineering controls are mandatory in the standard and expected to control exposures in most work environments (vessel cleaning — one of the cases described here — is an exception). The standard emphasizes that respirators can be used only in limited circumstances. Because there are no acceptable air-purifying respirators available for protection against DCM vapors, (due to low breakthrough volume, limited warning properties and absence of end-of-life indicators) employers must provide supplied-air respirators to employees in those limited circumstances where exposure cannot be controlled by other means.

All employers were to have implemented engineering controls by April 2000. As appendices to the standard, OSHA provided extensive guidance for the control of DCM including useful work practices, engineering controls and personal protective equipment guidelines.<sup>(40)</sup> Although OSHA expressed confidence that engineering controls such as LEV and improved work practices could control exposures to below the PEL for most uses of DCM, studies of engineering controls in furniture stripping have shown a mixed record of effectiveness.<sup>(41-46)</sup> (See companion report on furniture stripping).

Unfortunately, the recommended engineering controls and work practices may contradict the goals of environmental protection by increasing point source and fugitive emissions of DCM to the environment. DCM is regulated as a Hazardous Air Pollutant (HAP) under the Clean Air Act.<sup>(47)</sup> Permits must be secured to discharge it to the atmosphere and companies must use Maximum Available Control Technology (MACT) for specific sources to prevent environmental contamination. The standard for vapor degreasers specifically recommends against LEV because of its potential role in generating emissions to the environment.<sup>(48)</sup>

The preamble to 1997 OSHA standard noted that DCM was used in over 92,000 establishments in the U.S. It is used to clean metal, strip paint from metal and wood surfaces, blow foam, coat tablets, formulate aerosols, cast film, carry adhesives, and dissolve plastic in a process called solvent welding. The greatest volume uses of the chemical are in paint removers and adhesives. DCM is considered desirable in many operations because it is not flammable, has good organic solubility, is inexpensive, and lacks photoreactivity and ozone-depleting properties. OSHA estimated that 97,000 workers are exposed to DCM in metal cleaning operations and 57,000 workers are exposed to paint strippers containing DCM.

DCM use has been steadily declining in the U.S. and use reported in 2000 is only one-third of the peak use reported in 1985. Table 2.2 shows the U.S. consumption of DCM in 1990 and 2000 by use sector. The total U.S. consumption of DCM was 197 million pounds in 2000.

**Table 2.2: U.S. Consumption of Methylene Chloride (millions of pounds)<sup>(49)</sup>**

	Paint Removers	Foam Blowing	Adhesives	Pharmaceuticals	Chemical Processing	Aerosols	Metal Cleaning	Other	Total
1990	120	35	small	30	40	20	35	81	361
2000	60	9	40	20	20	20	19	9	197

Other includes: film and food processing and miscellaneous applications

Occupational exposure to DCM can occur during its production and use as a paint stripper, cleaner, degreaser, process solvent and as an aerosol. With an odor threshold of around 250 ppm, DCM has poor warning properties and due to its volatility (vapor pressure = 350 mm Hg at 68° F), concentrations may rapidly approach high levels in poorly ventilated areas.<sup>(50)</sup> Fatalities due to DCM vapor inhalation in furniture stripping operations have been reported.<sup>(51)</sup> Table 2.3 reports high measured exposures in several industries and activities compared to the OSHA PEL of 25 ppm.

**Table 2.3: 8-hr Time-Weighted Average Exposures Typical of Industrial Activities**

Industry	Activity	Exposure Range (ppm)	Comments
Manufacturing <sup>(52)</sup>		31-561	
Polyester factory <sup>(53)</sup>	Mixing	396-504	
	Cleaning	501-742	
	Lab	161	
Casting room <sup>(54)</sup>		55-495	Range during 1968-72
Plastic film factory <sup>(54)</sup>		30-5,000	Range for 318 samples Average 627 ppm
Chemical plant <sup>(54)</sup>		0-5,520	

Following the ban of ozone-depleting substances such as chlorofluorocarbons, DCM has been used as a substitute.<sup>(55)</sup> For example, DCM has substituted for 1,1,1-trichloroethane (TCA) in adhesive formulations for the foam industry<sup>(56)</sup> and in metal degreasing operations.<sup>(57)</sup> Despite the new stringent OSHA standard, the potential exists for continued and new use of DCM as a replacement for the heavily regulated and expensive ozone-depleting and global-warming substances, such as TCA.

Source reduction has not figured prominently in NIOSH and OSHA control suggestions. NIOSH's Current Intelligence Bulletin 46: Methylene Chloride provides a list of employer ideas for controlling worker exposure; substitution with a less hazardous solvent is ninth in a list of eleven.<sup>(58)</sup> A few substitutes for DCM are briefly given in OSHA's compliance guides that accompanied the standard, but these guides focus on local exhaust ventilation and work practices as the best ways to lower exposure.<sup>(59)</sup> Indeed, in response to complaints about the lowering of the PEL for DCM, the agency replied: "OSHA has determined that the final DCM standard is feasible in all affected industries without the need for substituting to alternative chemicals. It is not OSHA's intention to force industries to abandon MC..."<sup>(39)</sup>

Tremendous chemical, process and technological research and practical application have produced a generous array of DCM source reduction strategies for the principle uses of DCM. (Table 2.4) Indeed, it is one leading expert's opinion that effective substitute chemistries and technologies exist for virtually every current application of DCM in industry.<sup>(60)</sup> However, one of the leading "drop-in" chemical substitutes for DCM, n-methyl pyrrolidone, has several potential health hazards associated with its use.<sup>(61)</sup>

**Table 2.4: Examples of DCM Source Reduction Strategies in Principal Use Sectors**

Industrial Activity	Source Reduction Strategy
Paint stripping (Aircraft, Ship, Metal)	Benzyl alcohol-based stripper <sup>(62)</sup> ; Pyrolysis; <sup>(63)</sup> Sodium Bicarbonate Medium, Carbon Dioxide Blasting Operations, Fluidized Bed Paint Stripper, High And Medium Pressure Water Paint Stripping Processes, Plastic Media Blasting (PMB) Paint Stripping, Degreasing And Paint Stripping Using Sponge Blasting, Paint Stripping Using Wheat Starch Blasting, Vacuum Sanding System Paint Stripping Process, Benzyl Alcohol Paint Stripping; N-Methyl Pyrrolidone, Laser Decoating, Waterjet Stripping, FLASHJET Coating Removal Process, UNICARB Supercritical CO <sub>2</sub> Coating Spray System <sup>(64)</sup>
Paint stripping (Furniture)	No and low DCM alternative strippers <sup>(65)</sup> (xxSee companion report)
Pharmaceutical Tablet Coating	Water-based <sup>(66)</sup>
Caffeine Extraction	Supercritical CO <sub>2</sub> <sup>(67)</sup>
Foam (Flexible/Polyurethane)	CO <sub>2</sub> <sup>(68)</sup> ; Reduced pressure foaming, <sup>(56)</sup> formic acid <sup>(69)</sup>
Foam (Rigid)	Self-cleaning piston system <sup>(70)</sup>
Degreasing and cleaning	Acidic Aqueous Solutions, Alkaline Aqueous Solutions, N-methyl Pyrrolidone, Terpenes, Ethyl Lactate, Surfactants, Neutral Aqueous Solutions, Petroleum Distillates, Dibasic Esters, Glycol Ethers, Pure Water, Acetone, Alcohol, Ultrasonics, Low Pressure Spray, Power Washer, Semiaqueous Cleaning, Steam, CO <sub>2</sub> Snow, Abrasives, Immersion Cleaning, CO <sub>2</sub> Pellets, Brushing, Megasonics, High Pressure Spray, Wiping, Plasma, Supercritical CO <sub>2</sub> Bicarbonate of Soda Stripping, Carbon Dioxide, Ice, Laser Ablation, Metal Media, Organic Media, Plastic Media Blasting, UV/Ozone Cleaning, Wheat Starch, Xenon Flash Lamp <sup>(57), (71), (72)</sup>
Adhesives	Water-based, Hot-melt, Radiant-Cured <sup>(73), (74)</sup>

### 2.3 The Source Reduction Method

It is not a simple matter to implement process change at any facility. The current process is used because it works, and companies frequently are loath to switch from certainty to uncertainty. This section describes a process that toxics use reduction strategists in Massachusetts have designed to facilitate process change and to optimize the results by analyzing all possible alternatives and comparing them in a comprehensive fashion.<sup>(75)</sup> (A similar approach based on functional analysis is utilized in Denmark<sup>(27)</sup>) The components of the method are options identification, options assessment and options implementation. Evaluation is also a critical step. This method is particularly suited to a participatory approach utilizing a team with representatives from the facility's management, environmental health and safety department, production staff, research department and labor force. But where participation is constrained, particularly in those companies without Total Quality Management or other integrated work teams, or where hierarchical management styles dominate, these steps may be carried out by a single manager with or without technical assistance from a public or private source, or by an outside consultant.

Options Identification includes basic research on the specific industrial processes undergoing the intervention and research into all available alternatives, including drop-in chemical substitutes, alternative technologies, modernization and process modification.

Obviously, this stage involves research into both the needs and resources of the company and investigation into available substitutes, equipment and processes. Some suggestions might include new expensive technologies, but they may also include simple administrative changes such as altering the order in which processes occur in a facility or eliminating an unnecessary cleaning step. Where teams are utilized, this step is a dynamic process where ideas are brainstormed without prejudice to what is “realistic.” This options list can be narrowed by eliminating all those that are clearly not possible, such as those that are illegal or against company policy. The team will then try to narrow the resulting list to from one to five alternatives and take these to the options assessment step.

In the options assessment, the identified options must be evaluated using three distinct criteria. The first is the *technical assessment* where the identified alternatives are assessed to determine that the product will meet the required technical specifications. For DCM used as a solvent, for example, one technical specification might be the level of surface cleanliness after cleaning. The technical assessment is often very difficult, since some alternatives may not be proven technologies. Often laboratory or pilot-scale testing, modeling, case studies from other industries, or other such information must be collected. The end result of this step is the narrowing of the list of candidate alternatives to only those that are likely to be acceptable technically.

Given the initial satisfaction of technical requirements of the cleaners, the next step is the *health and safety assessment*. (An initial health and safety assessment will eliminate bad actors from technical consideration). The environmental and occupational health and safety impacts of each of the alternatives identified as feasible under the technical assessment must be evaluated in a systematic fashion. It is important that all possible impacts be identified and evaluated. In order to assist in this task, the Toxics Use Reduction Institute at the University of Massachusetts Lowell (TURI) has developed a spreadsheet-based program titled “Pollution Prevention Options Assessment System,” or P<sup>2</sup>OASys (available for download at: <http://www.turi.org/publications/p2oasys.htm>). This system facilitates the simultaneous comparison of many potentially hazardous characteristics of alternatives such as toxicity measured as LD<sub>50</sub>, irritant tendencies, flammability, ergonomic impact, global warming potential, environmental persistence, etc. Users of this program are prompted to estimate the potential impacts of changes in a wide variety of areas and to weight these impacts in the comparison. This systematic process is designed to prevent media-shifting (from an air to a water pollutant) or “risk-shifting” (from an environmental hazard to a worker hazard.)

The final comparative tool is the *financial assessment*, where the costs of each alternative are compared. It is important when performing this analysis that the principles of Total Cost Assessment be followed.<sup>(76)</sup> Total Cost Assessment allocates all costs associated with a particular process directly to that process, rather than ignoring them or burying them in facility overhead. For example, vapor-phase degreasers use water in their cooling coils; the Total Cost Assessment allocates the costs of buying and disposing of that water directly to the degreaser, whereas traditional accounting might just have one water bill for the entire facility. It is only by properly allocating *all* costs associated with the current production method that an adequate cost comparison among the current method and the suggested alternatives can be made. In order to properly carry out a total cost assessment of several alternatives, the Tellus Institute has developed a spreadsheet-based program called P2/Finance (publicly available at <http://www.tellus.org/general/software.html>).

Option Implementation involves the comparison of the several options using the

information collected during the options assessment phase, the selection of the optimum option, and its implementation at the site. Of course, the optimum option will be defined by those using the system and will be a balance of the optima in each category: technical, environmental/health and safety and financial. Evaluation is the final step; as described below, this report attempts to evaluate the real world source reduction strategies at four Massachusetts companies.

### 3 Methods

This study used in-depth qualitative investigation methods to describe four cases of process change for hazard prevention. Case studies are widely used in the environmental field to describe and promote pollution prevention approaches. Descriptions of how an actual company managed a difficult change and benefited from it can be effective in promoting new technologies and persuasive in arguing for their adoption. Hundreds of pollution prevention case studies written to aid and encourage companies to adopt cleaner production can be found on the web (see for example <http://www.p2gems.org>).

Case studies are also a particular mode of social science investigation that is especially appropriate to intervention research. Using the case study approach, we can gain in-depth knowledge through qualitative and quantitative investigation of the total phenomena embodied in a particular case.<sup>(77)</sup> The particular utility of this approach for research questions related to the feasibility and effectiveness of source reduction process change for hazard prevention is that it generates a rich data set useful in understanding the barriers to process change as a hazard control technique, limitations of the approach, potential for missed opportunities to improve the work environment, unintended consequences, future directions for preventive approaches, and research needs. We approach each case with categories of inquiry, but allow the case to shape their own responses according to what also matters to them. This manner of study is especially suited to formative research such as this.

Our case study research project was modeled, in part, on the report Evaluation of Alternatives to Chlorinated Solvents for Metal Cleaning.<sup>(57)</sup> This report by investigators at the University of Massachusetts Toxics Use Reduction Institute for the EPA, investigated alternatives to chlorinated solvents used for metal degreasing at three companies, including one company using DCM. The result of this work was the identification of acceptable cleaning substitutes for each company, along with comprehensive financial and health and safety assessments of the proposed alternative technologies. The components of the toxics use reduction implementation strategy outlined in Section 2.3 above guided the structure of the case studies and the prospective intervention study.

The cases were selected from companies who because of their use of DCM in quantities greater than 10,000 lb/y have submitted Form S under the Massachusetts Toxics Use Reduction Act of 1989. The two criteria for inclusion were that they had used or were using DCM at the time of the study in an industrial process and not as a component in a product, and they agree to participate in a scientific study and provide access and information as necessary to that study. Based on these criteria, four Massachusetts companies were enrolled in the proposed study. The study protocol included site visits, telephone and in-person interviews and review of company-provided and public documentation. Interview guides following Patton's qualitative evaluation guidelines were developed for each company.<sup>(78)</sup> Interviews notes were taken by hand. Institutional Review Board approval for research involving human subjects was sought and achieved for this study and all participants signed informed consent forms.

A description of the surface cleaning test methods and DCM exposure assessment methods utilized in the metal finishing company prospective case are described in the company's case study, Section 4.1.5.

## **4 Results**

Four Massachusetts companies' experiences of DCM source reduction are profiled below. The first case, compiled from three site visits, company-provided documentation, and two in-person interviews, describes a prospective study of a metal finishing company's efforts to reduce DCM use over two years. The next three cases are "retrospective"; they describe the experiences of three companies (a rubber products company, an electrical equipment manufacturer and a vessel cleaning company) that had already eliminated use of DCM at the time of the study. Each of these cases was developed from on-site visits and in-person interviews, as well as documentation such as reports from TURI's Demonstration Site program. The case studies include the following sections: the industrial process prior to and after the source reduction efforts; the steps each company took to accomplish the change; the company's motivations for the change; how they evaluated the project; assessments of worker exposures before and after the change; costs; benefits and problems resulting from the change; and key lessons from the case as identified by the researchers. A summary of findings across the cases follows the four cases.

### **4.1 Metal Finishing Company Case Study**

#### *4.1.1 Background*

This metal finishing company (NAICS 332813; SIC 3471 Plating and Polishing) performs copper, chrome and nickel plating on aluminum, brass and steel fabricated parts on a job-ordered basis. Seventy percent of the company's business comes from a motorcycle manufacturer. The company employs 60 production workers over three shifts. Founded in the late 1940's, it is privately held and was bought by the present owner and president in 1985.

All parts must be thoroughly cleaned before they can be plated. Lightly soiled parts are cleaned in-line (as part of the plating line) using standard acid and caustic cleaning processes. The company also has a small off-line (e.g. not a part of the plating line) ultrasonic aqueous cleaning tank, but this is used solely to clean polishing compounds off of specialized products. Some types of materials, particularly small parts, convoluted parts or parts coated with heavy protective oils, have traditionally been cleaned in a DCM vapor degreaser before they entered the plating line. DCM was selected because of its relatively high vapor pressure, requiring less heating to enter the vapor phase, and because it had a higher flashpoint than other degreasing solvents. Because of potential worker health concerns, the owner had considered substitution to 1,1,1-trichloroethane, but did not follow through, due to the planned phase-out of the chemical under the Montreal Protocol on Ozone Depleting Substances.

The degreaser has an automated hoist to raise and lower baskets and "trays" of parts, a manually operated cover and a spray nozzle attachment. The degreaser's tank holds 250 gallons, while the reservoir that supplies the degreaser during operation holds 60 gallons and the spray tank holds 20 gallons. The degreaser is approximately 7ft tall by 3.5ft deep by 5.5ft wide (see figure 1). It is fed DCM through an automated feed line from a near-by tank. Spent DCM is



**Figure 1 Metal Finishing Company Degreaser. Source: Cora Roelofs**

automatically fed into recycling system to be reused. The holding tank is charged by bulk feed from a tanker truck.

In the early 1990's, in response to the requirements of the Clean Air Act's Hazardous Air Pollutants National Emission Standards requiring MACT, and in order to decrease the volume of DCM used to below the TURA and Toxics Release Inventory (TRI) reporting threshold of 10,000 lb/yr, the degreaser's refrigerated coils were refurbished and new work practices were introduced to reduce the degreaser's emissions. These work practices included using the cooling coils beyond the time when the degreaser was being used, weekly monitoring of the coils, covering the degreaser when not in use, and lowering hoist speed to 8.5 ft/min to reduce drag-out. The degreaser has a freeboard (height above the coils to the lip) of 2.5 ft. The unit is not fitted with LEV. Operators are instructed to wear protective clothing including safety glasses and chemical protective gloves when using the degreaser.

DCM use at this company declined significantly since 1996 as shown in Table 4.1. Total use had declined by 82% between 1996 and 2002. Three factors have accounted for this dramatic reduction. The company's DCM use went below the TURA and TRI reporting thresholds in 1998, largely due to the improved controls on the degreaser that prevented losses and therefore conserved new use. Further reductions were achieved by the TUR process undertaken in conjunction with this study and are described below. Additionally, two regular finishing jobs that consistently "required" DCM degreasing were discontinued, thus decreasing the amount of work headed to the degreaser by almost 30%. At present, 70% of the work formerly degreased with DCM is now cleaned with water and an alkaline cleaner. In 1999, at the beginning of this study, the company operated the DCM degreaser up to four hours a day, five days a week for a total of 20 hours a week. At the conclusion of the study two years later, it was used twice a week for a total of eight hours a week.

**Table 4.1: Metal Finishing Company DCM Use**

Year	Total Use/lbs	Total Released*	Reduction in Use from 1996
1996	19,000	12,444	
1997	17,500	15,300	8%
1998	9,600	n/a	49%
1999	5,900	5,900	69%
2000	4,100	n/a	78%
2001	3,500	n/a	82%

Source: Company and TURA Data

\* Total Released = stack and fugitive emissions

#### 4.1.2 DCM/Substitute Process and Process Change Descriptions

In conjunction with the company president, the investigator determined that aqueous cleaning might be an acceptable alternative to DCM cleaning based on a number of factors. Numerous case studies had shown that aqueous cleaning was a proven technology that was frequently used in place of vapor degreasing in other similar companies. Additionally, aqueous cleaning was also identified as a good potential alternative because of the company's experience with aqueous cleaning in other applications and because hydrocarbon substitute degreasers were expected to pose greater potential toxicity and environmental problems. Additionally, much of the work was already being cleaned aqueously in-line, and the company was eager to shift more of the work in-line for production efficiency reasons. The barrier to doing so was inadequate aqueous cleaning effectiveness, thus "requiring" DCM degreasing as a pre-cleaner.

According to the Solvent Alternatives Guide, alkaline aqueous solutions are the most common form of aqueous cleaning chemistry.<sup>(71)</sup> The cleaning solutions are most often proprietary mixes of water, alkalis, sequestrants, and surfactants. They can be used for most of the cleaning applications previously performed by chlorinated solvents and are better at removing rust and scale. Alkaline cleaners can remove cutting oils and coolants, salts, grease and waxes, fingerprints, shop dirt, oil, polishing and buffing compounds.

Once aqueous cleaning was identified as a potential alternative, the challenge was to find the best-performing cleaner for the company's applications. In order to determine this, the company was requested to submit parts for a series of test cleanings at TURI's Surface Cleaning Laboratory. These tests are described in the Evaluation, Section 4.4.5 below. Following the laboratory studies, experimental cleaning runs were conducted on-site to determine the feasibility of expanded aqueous cleaning with the new chemistry. The company president determined that these trials were successful and quickly introduced the better performing substitute to one of the production lines. He then purchased a new pre-cleaning tank and began using the new cleaner on the two remaining plating lines. These actions reduced the use of the DCM degreaser as most of the work pieces no longer required solvent pre-cleaning.

Subsequent steps were consultation with the company's chemical supplier for a less expensive version of the new cleaner, tests of the recommended cleaner, and determination of bath maintenance schedules. Finally, the company also had to consult with their hazardous waste hauler to determine any potential additional costs for treatment of wastewater associated with this process. These costs were deemed acceptable. The company president determined that the

substitution of the better performing, less-expensive substitute chemistry was successful.

No additional steps are planned to further reduce use of the DCM degreaser. Currently, convoluted parts, parts with blind holes and other “difficult to clean” parts are pre-cleaned with the degreaser. The company president and production manager feel that they cannot get rid of the degreaser completely because of these “problem” parts. When asked what the company would do if the degreaser was banned, the company president said that he would most likely purchase a small off-line aqueous cleaning system with ultrasonic capacity. (Ultrasonic generators convert electrical current into sonic waves that generate small bubbles on parts to be cleaned. As the bubbles are formed and “pop,” they provide a gentle mechanical agitation that helps to loosen contaminants.) He noted that the capital and operating cost involved in adding ultrasonic technology to the current lines so that all parts could be cleaned in-line was prohibitively expensive due to the large tank sizes. Bringing in a small ultrasonic system off-line would not improve upon the current production inefficiency of cleaning off-line with the DCM degreaser, thus there was no motivation at present for this investment.

The case study now turns to a summary of the steps involved in the source reduction strategy for this company. These steps are described in detail in the sections that follow.

#### *4.1.3 Process of Change*

1. Company overhauls degreaser equipment and work practices to reduce DCM emissions.
2. Research investigator consults with company and initiates a process to introduce more aqueous cleaning in place of DCM degreasing.
3. Exposure assessment reveals potential for over-exposure.
4. The total volume of work “requiring” DCM degreasing is reduced by 30% due to production shifts unrelated to environmental concerns.
5. Series of cleaning tests is conducted on company parts at TURI’s Surface Cleaning Lab.
6. Company conducts its own technical assessment by plating parts cleaned by the Surface Cleaning Lab, buying a small amount of the recommended cleaner and running the production line with this cleaner.
7. Satisfied with the on-site tests, the company contacts their regular chemical supplier for a lower cost aqueous cleaner comparable to the one recommended and evaluated.
8. The lower cost cleaner recommended by the chemical company is evaluated on-site. A positive evaluation leads the company to adopt this cleaner as a drop-in replacement for current aqueous cleaner.
9. A second cleaning tank is added to one line and the substitute chemistry is used on three plating lines. 70% of work formerly pre-cleaned by the degreaser is shifted to in-line aqueous cleaning.

#### *4.1.4 Motivations*

The company president reported that he was motivated to reduce the company’s use of DCM by Clean Air Act restrictions and TURA reporting requirements. Worker health concerns also played a part in motivating the exploration of alternatives. The most compelling motivation was the president’s interest in improving the overall efficiency of the plating process by moving cleaning operations “in-line” with the other plating operations, thereby reducing labor costs and other production inefficiencies.

#### 4.1.5 Evaluation Protocol

Technical and performance criteria dominated the evaluation process. Because the aqueous cleaners had few reported health or safety hazards, especially in their diluted form, Material Safety Data Sheets (MSDS) were the beginning and end of the resources consulted by the company to gain information about potential environmental, health or safety concerns. Project staff undertook a more thorough investigation, but did not discover any concerns that would lead us to recommend that the company avoid certain products or processes. Additionally, financial concerns did not figure prominently in the evaluation of the alternatives. A financial analysis is included below, but in general, the company president did not express concern about costs within the scope of the proposed project. However, financial concerns appeared to play a role in the company's decision to continue use of the degreaser on a limited basis rather than invest in alternative technology for the remaining work that could not be cleaned with the substitute.

As discussed above, technical criteria were used to determine that aqueous cleaning would be an appropriate alternative. To evaluate aqueous cleaner technical performance — which cleaner would work best with the company's parts — a series of tests was conducted at the Surface Cleaning Laboratory at the Toxics Use Reduction Institute. In order to find potential products to test, the Surface Cleaning Laboratory's Vendor Database was searched for cleaners appropriate to the metal plating application, to the substrates to be cleaned (brass and steel), and to the contaminants to be removed (oils and dirt). From these were selected several non-emulsifying cleaners. Non-emulsifying cleaners allow the oil and dirt to be separated from the cleaning solution thus permitting reuse of the cleaning solution and reducing water use. Typically this cleaning process would be used with an oil/water separator and filtration unit — an additional piece of equipment.

Four rounds of testing were conducted on different parts and with different cleaners. The company sent parts that they typically clean in the degreaser, i.e. parts that because of their shape, crevices, and/or contaminants were difficult to clean. The testing protocol consisted of immersion of the supplied contaminated parts in 10% solutions in heated water (70° F). The parts were agitated in this solution for 10 min. The parts were rinsed in hot water (120° F) for 30 seconds and dried with a hot-air gun for at least one minute, or until apparently dry. Due to rusting problems (which would be unlikely under production conditions), anti-rust agents were added to the rinse for steel parts and the parts were thoroughly hot-air dried. Then the parts were evaluated for cleanliness with a swab test. The parts, the swabs, the Lab's report and the alternative cleaning chemistries' MSDS were sent to the company. The company was advised to plate these parts to determine the technical performance of the chemistries. Additionally, the company was asked to send more parts for testing to verify the results of the first test and to test additional cleaners.

The results of the cleaning tests on these parts are reported below in Table 4.2. In general the tested cleaners appeared to adequately clean the parts, however the "real" test was whether the parts cleaned in the lab would "plate," i.e., permit adhesion of the finishing material to the part substrate. The company president reported after the first round that all the parts had plated correctly. Additionally, the company was informed that the cleaning performance of these cleaners could be improved with on-site "tweaking" of the cleaning protocol. Performance of cleaners can be a factor of several parameters including solution strength, cleaning time, solution

temperature, rinse time and temperature, and the presence or absence of bath or parts agitation or ultrasonic generator. In this phase of the technical assessment, all cleaners were tested under a standard simple protocol of immersion cleaning with an agitated bath at “average” temperatures and cleaning times. Varying these parameters during on-site pilot testing would be likely to enhance performance of the cleaners, but this initial phase was useful to select candidates for on-site testing.

**Table 4.2: Surface Cleaning Lab Testing Results  
Aqueous Cleaners for Metal Finishing Company**

Round	Type of Parts	Cleaner	Results
1	Brass cylinders: light, green oil and light dirt	A	“Little marking” on swab
		B	“Little marking” on swab
		C	“Very little marking” on swab
2	Hollow brass bolts and steel tubes: oil and dirt	A	All cleaners were determined to have removed oily film and dirt from both parts.
		C	
		D	
		E	
		F	
3a	Stainless and non-stainless steel parts, cylinders and other parts with crevices: oil and dirt	A	Clean
		B	Clean
		C	Mostly clean
3b (re-test due to rust resulting in prior round)	Stainless and non-stainless steel parts, cylinders and other parts with crevices: oil and dirt	B	Visibly cleaner than C
		C	Clean

On the basis of these tests, Cleaner B was recommended to the company for on-site trials. The company ordered this cleaner, replaced their current aqueous cleaner with this new cleaner, and found satisfactory results. However, this new cleaner was deemed expensive and so the company’s chemical supplier was contacted to locate a less expensive “generic” version of Cleaner B. One was found and was substituted in the process. From a technical standpoint, the company described this substitute as “magic” due to its cleaning power and longevity. No additional evaluation efforts are planned.

#### 4.1.6 Exposure Analysis

Workers are potentially over-exposed to DCM when operating the DCM degreaser. The reduction in the use of the degreaser has reduced worker exposure significantly by reducing the amount of time of potential exposure and the number of workers potentially exposed. The following section details the initial exposure assessment including air monitoring, other potential health and safety exposures and a post-intervention exposure assessment.

At the time of the first contact with the company in 1999, the degreaser was operated an estimated maximum total of four hours a day over the three shifts with most degreasing

occurring during the first shift. Eight to ten different workers operated the degreaser (one at a time). The refrigerated coils operate simultaneously with the vaporizer (and for extended periods to control vaporization after the vaporizer is turned off). DCM recovered by the refrigerated coils is drained to the recycling unit. The operator is present to load the parts using the hoist into the degreaser and then leaves for the cleaning cycle, unless the parts need spraying with a hand sprayer. A cleaning cycle lasts 10-15 min for baskets of small parts. The worker comes back to remove the parts and close the cover if the degreaser is not to be used further. (A full log of degreasing tasks is in the Appendix).

Potential exposure opportunities include standing over the degreaser to lower and raise parts, spraying parts, guiding the clean parts (that may contain residual DCM or drag-out that follows the basket) to the floor, and opening and closing the cover. While the lower hoist speed may prevent drag-out, it may also increase exposure times. The degreaser cover may also be a mixed blessing. As the operator rapidly opens or closes the cover, he may be exposed to surges of DCM escaping the tank due to air currents and a piston (closing) or vacuum (opening) effect. Maintenance work including weekly filling and inspection of the coils, recycling system and supply tank and the yearly degreaser clean-out may also result in exposure to DCM. There are no other workers in the vicinity of the degreaser and it is expected that only the vapor degreaser operators, maintenance workers and, possibly supervisors, have potential exposure to DCM above low background levels.

In 1998 the company requested and received an OSHA consultation that included personal air sampling for DCM exposure. The operator was sampled for 64 minutes at a flow rate of 0.2 L/min. The flow rate suggests that NIOSH Method 1005 may have been followed, but it was not possible to confirm this from the documentation provided. The 8-h TWA DCM concentration was reported to be 0.2 ppm. Based on this sampling, work patterns, and the OSHA consultant's assurances, the company assumed that they were in compliance with the 1997 DCM standard and PEL of 25 ppm and Action Level of 12 ppm (8-hr TWA).

In March 1999 we conducted air monitoring for DCM in the breathing zone of an employee operating the degreaser. The worker was sampled for four cycles of degreasing and the worker estimated that he had two more rounds to go and the rest of the day would not be



Figure 2 Degreasing Operator at Work . Source: Cora Roelofs

operating the degreaser. At the time of the assessment the operator wore green chemical resistant gloves, protective eyewear and a paper dust mask. (See Figure 2). The sampling protocol was based on "OSHA 80" which requires Carbosieve tubes, a flow rate of 0.05 L/min, and a limit of one hour per tube. The samples were analyzed by ESA Laboratories of Chelmsford, MA. Full results, including area monitoring, air velocity measures and environmental factors, are presented in the Appendix.

The relative humidity was measured at 75%, reflecting the presence of hot water baths. It is possible that this high humidity could affect samples by occupying active sites on the carbon-based sampling media, thereby resulting in an underestimate of exposure. No conclusions can be drawn based on the other parameters, such as air movement around the degreaser: no particular pattern emerged in the velocity measurements.

To compare the results we found with the OSHA PEL of 25 ppm, the results were combined with the estimated exposures for the remaining work for the shift (See Appendix). Based on this information, the estimated time-weighted eight-hour exposure for this employee was 71 ppm (Table 4.3). Although no short-term exposure samples (15 minutes) were taken, it is suspected from these results that the worker was also exposed above the OSHA STEL of 125 ppm. The company was informed of these results and advised to take immediate steps to comply with the DCM standard.

**Table 4.3: DCM Exposure Assessment Summary  
Metal Finishing Company**

<b>Personal Samples</b>	<b>Time (min)</b>	<b>Avg. Time Per Round</b>	<b>Conc. (ppm)</b>	<b>Avg. Conc Per Round</b>
Round 1	40	40	157	157
Round 2	60	60	118	118
Rounds 3 and 4	90	45	199	100
<b>Total-TWA</b>	<b>190</b>	<b>48</b>	<b>165</b>	<b>125</b>
<b>Projected 6 Rounds</b>	<b>287</b>	<b>48</b>	<b>151</b>	<b>125</b>
<b>Projected 8 Hr TWA Based on 6 Rounds and No Exposure for Remaining 3 1/4 Hours</b>				<b>71</b>

Following receipt of our findings, the company contacted the OSHA consultation service again and they conducted air sampling during one day in May 1999. The OSHA consultant determined a time-weighted average result of 5 ppm. According to the company and the OSHA consultant who conducted this second round of exposure assessment, the company was told that they were in compliance with the DCM standard and below the action level of 12 ppm. (The company gave permission for the investigators to contact the consultant). The consultant also told the company to use LEV if they were concerned about exposure and to subcontract out the bottoms cleanout or to use supplied air respirators for this task. The consultant reported using the "OSHA Method for Methylene Chloride" including a flowrate of 0.05 L/min and "charcoal tubes." No information was available regarding whether spraying occurred during sampling, or if these samples were side by side samples or continuous samples on one tube.

While the company had installed MACT controls on the degreaser and instructed workers in methods to avoid DCM loss and subsequent exposure, the sampling results from our visit suggest the potential for over-exposure. In addition, the company reports of almost 10,000 lb of DCM a year lost from the degreaser indicated that exposure potential was real. Work practices, especially the time allowed for parts drying prior to removing the work pieces, appear to greatly influence exposure potential. The more time allowed for degreasing activities, the lower the potential exposures by reducing drag-out. However, production pressures will potentially increase exposure. Additionally, although no sampling was conducted during clean out procedures, it is expected that these intermittent exposures would be quite high.

Because of the high exposure potential and the availability of safer alternatives, as well as the inappropriate protective equipment used by the operator, we recommended to the company that they explore aqueous cleaning as an alternative to vapor degreasing with DCM. Despite the OSHA consultation service's "clean bill of health," the company elected to continue research and technical assessment of alternatives.

Other aspects of the exposure assessment included a noise assessment, ergonomic analysis and a safety checklist (see the Appendix). Due to an equipment malfunction, a sound level evaluation was not possible, but noise did not appear to be a significant factor in this work environment. On the ergonomics and psychosocial front, the worker described degreasing as an "easy" job compared with other jobs in the company, such as running a plating line. This was attributed to the built-in break time while the parts degreased and the lack of heavy lifting. A stooped posture was required while spraying, loading and unloading (see Figure 2), but these were not lengthy tasks. There was essentially no repetitive motion and forceful exertions were minimized by the automatic hoist. Safety factors during the degreasing operation related to electrical hazards, hoist safety, and elevated work platforms. The work platform was approximately 2 ft high with two 1 ft risers and was unguarded on three sides (see Figure 1). Other than a risk of tripping or falling off of this low platform, there were no apparent serious potential safety hazards.

In shifting much of the pre-cleaning work to in-line aqueous cleaning, the company greatly reduced potential worker exposure to DCM. Use of the degreaser was reduced from approximately twenty hours a week to four hours twice a week for a total of eight hours a week—a 60% reduction. No air monitoring has been conducted since the consultant's follow-up visit in 1999, but it is unlikely that exposure conditions have significantly changed. Thus, workers may still be potentially over-exposed to DCM, but the reduced schedule of use means that fewer of them could be potentially over-exposed and those who are operating the degreaser are doing so for shorter periods of time. While it was not possible to conduct follow-up air monitoring, it is reasonable to conclude that the workers' DCM exposure potential has been significantly reduced by this change in processes to aqueous cleaning.

What about the workers' potential exposure to the new aqueous cleaner? The company selected an alkaline liquid cleaner based on sodium metasilicate (14%). Other ingredients include diethylene glycol n-butyl ether (5%) and sodium carbonate (2%). It is used at a 10% dilution. It is compared with DCM in the summary of the potential hazards shown below in Table 4.4.

Repeated exposure to this undiluted alkaline cleaner could have potentially serious health effects including skin, eye and respiratory irritation and burning. However, workers are unlikely to have any more than brief exposure to the chemical in its undiluted form. The smallest of the three baths (1,400 gallons) is changed every three weeks. The chemical is added to the bath via pumps from drums. The other two baths are changed annually, but the chemical is added

routinely as needed to make up the correct concentration. However, the plant chemist said that very little make-up chemical was needed.

**Table 4.4: Summary of Potential Hazards -- Alkaline Cleaner vs. DCM**

Potential Hazard	Alkaline Cleaner	DCM
Acute Health	Caustic irritation (pH: 13-14): Respiratory, skin, eyes	Central nervous system suppression: headache, dizziness, nausea; dermatitis
Chronic Health	Skin defatting, tissue damage.	Suspect carcinogen, heart problems, liver damage
Safety/Physical/Ergonomic	Electrical/hot water	Electrical
Environmental	Alkaline wastewater, oil and soil waste	Chlorine, Hazardous Air Pollutant; hazardous waste

Source: MSDS for Alkaline Cleaner, <sup>(79, 80)</sup>

In its dilute form, the pH of the solution would be slightly less caustic than the concentrate, but still would be potentially hazardous as an irritant. Workers wear chemical resistant gloves and eye protection when handling the chemical and while they may breath in the water vapor above the heated tanks, they are unlikely to inhale the chemical. However, no monitoring has been conducted to determine the pH of this vapor. The company president said that workers had not complained about irritation. In summary, the potential hazards associated with the use of the substitute chemical include acute irritation and burns from accidental exposure due to spills or splashes. It is not expected that routine exposure under the conditions described would result in potential long-term irritation or other health effects.

#### 4.1.7 Costs

The company did not conduct a financial analysis of this change. The company president's attitude was that if there were no significant capital costs (expenditures for less than \$10,000 are not considered significant), then the anticipated savings in labor costs and production inefficiencies that would result from incorporating pre-cleaning into the production line would more than pay for any possible additional costs associated with the new process.

Although costs were not perceived to be a barrier to the implementation of an environmentally-preferable cleaning method, the company did attempt to minimize costs associated with the change. The company contacted their chemical supplier to find a less expensive, though comparable, chemical to the one that we had recommended. The selected chemical was half the cost per gallon of the recommended chemical. Additionally, the decision to maintain use of the DCM degreaser rather than replace it with a new off-line aqueous cleaning process (such as ultrasonic cleaning) was made, in part, because of the potential expense of the new equipment and the lack of perceived financial benefit from the change. Finally, the company elected to use an emulsifying cleaner and pay for disposal of wastewater, rather than purchase a "skimmer" to clean the bath, extend its life and have lower disposal costs. Thus, the company made what it perceived to be financially beneficial changes and avoided expenditures that it did not perceive would benefit the bottomline.

Table 4.5 below estimates the annual savings and pay-back period for the changes

undertaken at this company. Savings achieved primarily through the reduced cost of the cleaning agent, will allow the company to recoup its investment in the new cleaning tank within 1.2 years. Costs for maintenance, waste disposal and electricity are considered comparable for these two systems. However, this is a conservative assumption. Others have estimated higher costs for these categories for vapor degreasers.<sup>(57)</sup> Many of the costs and benefits of the two cleaning systems are not considered here, including those related to production, regulation, health, environment, worry, training and insurance. These items are generally costs while using the degreaser and become benefits after a switch to aqueous cleaning.

The most significant cost savings – that resulting from labor savings and other production efficiencies – is not incorporated into this analysis. Prior to the change, 20 hours of labor per week were devoted to off-line pre-cleaning. After the change, this activity required only 8 hours per week. Most of the labor associated with aqueous cleaning was already being done prior to the change in chemical, although some new labor may be associated with more aqueous cleaning. Based on a conservative estimate of avoiding only 75% of the labor associated with off-line DCM degreasing, an annual savings of \$9,000/y in saved labor costs is expected. After the payback period of 14 ½ months, the company is estimated to reap over \$12,000/y from this source reduction strategy.

In the appendix to this report is a generic financial analysis estimating the cost of replacing DCM degreasing with an aqueous cleaning process (see the Appendix). This financial analysis includes an investment of over \$20,000 in new equipment, including an oil/water separator and filtration unit. Even given this significant capital cost, the payback period is estimated to be less than five years. The payback period would have been even shorter if potential savings in labor and environmental compliance costs were included.

**Table 4.5: Metal Finishing Company Estimated Cost Comparison**

<b>Aqueous Cleaning v. DCM Degreaser</b>				
<b>Aqueous Cleaning</b>				
<i>Operating Costs</i>	Cost/Gal	Dilution	Gal/Yr	Cost/Yr
* Aqueous Cleaner	\$7	10%	385	\$2,695
Water	\$0.002	90%	3,465	\$6.93
<b>Total Annual Costs</b>				<b>\$2,702</b>
* <i>Equipment Costs (New Tank)</i>				<b>\$4,000</b>
<b>DCM Degreaser</b>				
<i>Operating Costs</i>	Cost/lb	Lbs/Yr		Cost/Yr
* DCM	\$0.64	9,500		\$6,080
<b>Total Annual Costs</b>				<b>\$6,080</b>
<b>Economic Analysis Summary</b>				
Annual Savings for Aqueous Cleaning				\$3,378
Aqueous Equipment Costs				\$4,000
<b>Payback Period for Investment in Equipment (years)</b>				<b>1.2</b>
<b>Labor</b>	Cost/Hr	Hrs/Yr	Cost/Yr	Saved/Yr
DCM Degreasing Before	\$20	1000	\$ 20,000	
DCM Degreasing After	\$20	400	\$ 8,000	\$ 12,000
<b>Attributable Savings (75%)</b>				<b>\$ 9,000</b>
<b>Total Annual Savings Following Payback</b>				<b>\$ 12,378</b>

*Sources*

\* Company communication 11/19/01

Water costs from <sup>(57)</sup> based on Waltham, MA water costs.

**4.1.8 Benefits and Problems**

The company perceived the primary benefits of this change to be the increased production efficiency resulting from the ability to incorporate most cleaning operations within the production line rather than as separate off-line operations. They are also pleased with the decreased environmental and health and safety protection burdens.

**4.1.9 Key Lessons**

1. Improving production efficiencies was a significant motivator for process change. In the context of anticipated production efficiencies, operations costs related to the change were not considered to be important.
2. The entire operation of cleaning had to be analyzed to discover that other cleaning operations needed to be modified to reduce reliance on DCM degreasing.
3. Despite taking steps, including significant expenditures, to control DCM emissions, the company was still motivated to further reduce or eliminate use of the chemical.

4. Technical assistance, especially the services of the Surface Cleaning Laboratory, played a key role in demonstrating the feasibility and effectiveness of alternatives and motivating change.
5. The company's chemicals vendor directed them to substitute cleaning products.
6. A significant potential exposure to DCM via inhalation was reduced, but not eliminated
7. Alkaline aqueous immersion cleaning did not appear to pose significant hazards.
8. Barriers to eliminating DCM vapor degreasing included a lack of faith in substitutes and costs of alternative cleaning equipment.

## **4.2 Rubber Products Company**

### *4.2.1 Background*

This rubber products company (NAICS 326299/SIC 3069, Fabricated Rubber Products) employs as many as 1,100 people over three shifts and makes over 3,000 rubber specialty products including windshield wipers, copier toner blades, golf grips and respirator face pieces. Their manufacturing processes utilize 4,000 different chemicals, although only 30 are used in large quantities. Processes include mixing and curing of rubber, spray coating, tumbling, forming and adhesion of rubber and metal parts.

Since 1990, the company has undertaken several projects that have resulted in the reduction and elimination of solvent use, improved material dispensing, reduction in toxicity of inks, recycling, and water and electricity conservation. The Director of Environmental Health and Safety (EHS) has championed these projects as well as an overall system of reducing environmental impact through their ISO 14,000 program, life cycle analysis and Design for the Environment initiatives. These projects are popular at the company, in part, because they save an estimated \$2 million a year. The company is recognized as an environmental leader.

The company has developed its own systems for discovering TUR opportunities and for evaluating new processes for their environmental and health and safety impact. Regulated processes — operations that create EPA regulated emissions and wastes — are automatically candidates for source reduction. Additional projects are planned based on the “rating” of the current processes. A team consisting of EHS staff, department supervisors and experienced production workers rate current processes using specially designed “Impact Forms.” Processes are rated on a scale of 0-10 in the areas of waste disposal and raw material cost, environmental health and safety impact on humans, likelihood of non-compliance, energy requirements and resources intensiveness. The EHS Director describes the rating process as an “intuitive” system, but one he deems “as good as doing epidemiological studies.” The cost of a material plays a significant role in “suggesting” to the raters its relative environmental or worker safety hazard. Higher total cost (including disposal) chemicals are generally believed to be more hazardous than lower cost ones. MSDSs are sometimes consulted if a new product is being used; otherwise, rating is based on the raters' experience with the chemical and relative to other chemicals used in the plant. The EHS Director reported that the rating process is generally perceived to be reliable across raters.

For new processes or products, or proposed changes to processes, including TUR-related changes, the company undergoes “Advanced Product Quality Planning.” This process includes an EHS review using an “EH&S Assessment Sheet.” This form requires that the proposed process or product be scrutinized for potential chemical and mechanical (safety) hazards and

required controls. This process incorporates Life Cycle Assessment principles by asking reviewers to consider EHS impacts of the process beyond the company, i.e., environmental hazards resulting from vendor production of supplies or customer disposal of the product. Out of this review comes health and safety specifications that are imposed on equipment suppliers for electrical safety, noise (below 85 dBA), machine guarding, emissions (e.g., chemicals in synthetic hydraulic oils) and others. Additionally, the EHS Assessment gives the company an estimate of the costs associated with the proposed process. The director notes that “Anytime you have a health and safety exposure, you have a cost associated with it — exposure monitoring, potential for accidents, insurance, claims, administrative costs because of tracking with regulations, permit fees, etc.”

#### 4.2.2 *DCM/Substitute Process and Process Change Descriptions*

Between 1990 and 1991, the company phased DCM out of their urethane mixing vessel and tool cleaning operations and phased in two drop-in substitutes: dibasic esters (DBE) and polyethylene glycol. In the urethane mixing vessel operation, following the automated mixing and discharge of the urethane into a bucket, the system is automatically purged with solvent – formerly DCM, now DBE. While the operator is pouring the hot urethane from a bucket onto a forming belt, about 16 ounces of DBE are forced through the system and into a waiting bucket. The urethane is heated to 200° F. Thus, the DBE are emitted mostly as liquid, but also as a visible vapor from contact of the liquid with the urethane-heated equipment. About three batches are run per hour.

In the change from DCM to DBE, the total volume of the solvent used was decreased through the rescheduling of batch jobs to reduce the vessel cleaning frequency and through the use of disposable and Teflon<sup>®</sup> vessels which are cleaned mechanically (wiping and scraping) rather than chemically. The company also installed a vacuum distillation system to reuse the DBE. Less than 1,000/gal of DBE per year are currently purchased by the company. This compares to the approximately 5,700 gal/y of DCM that were purchased by the company prior to the change.

The second operation is the cleaning of mixing tools used to make urethane. Tools are soaked or agitated in buckets of DBE (instead of DCM) and then soaked and rinsed in a tank of hot polyethylene glycol, also known as Carbowax<sup>®</sup>. The company is currently investigating the substitution of liquid sodium chloride (salt) as a cleaning agent in place of the DBE/Carbowax<sup>®</sup> process to further the company’s goals of toxics use reduction and cost savings.

#### 4.2.3 *Process of Change*

The company’s process of change consisted of the following steps:

1. Target DCM as a chemical for reduction based on environmental criteria.
2. Identify substitutes through independent research by EHS director. Substitutes sold as consumer products preferred due to inferred safety.
3. Technical assessment and process adjustment.
4. Phase in of substitute over one year.
5. Equipment changes to facilitate use of substitute.
6. Evaluation of technical performance and, at urging of environmental authorities, potential

environmental impact of substitutes.

7. Continued evaluation of the process to examine feasibility of replacing substitutes with simpler, less expensive and even less toxic new substitutes.

#### *4.2.4 Motivations*

DCM was targeted in the context of an aggressive pollution prevention program in this environmentally-conscious company. According to a case study written in conjunction with the company's designation as a TURI Demonstration Site grant recipient, the company's overall objective is "Designing products to minimize environmental, health and safety impacts in production, use, reuse and ultimate disposal." The company's motivations for setting this objective include creating a positive image with customers, limiting liability, improving compliance with regulations, lowering insurance and accident costs, improving the company's image with employees and thereby increasing loyalty, furthering good community and employee relations, reducing waste and, most importantly, saving money. DCM was eliminated, in part, because of worker health concerns and, in part, because of its classification as a HAP under the Clean Air Act. Additionally, the EHS director described the loss of DCM to the environment (as much as 20 tons/y) as "money up the stack."

#### *4.2.5 Evaluation Protocol*

The company identified two potential drop-in substitutes for DCM. It selected DBE over n-methyl pyrrolidone (NMP) because of superior technical effectiveness. The change was evaluated in a company-designed process that looked at perceived EHS impact and costs. DBE was determined to be acceptable from an EHS perspective because it was used in a 3M consumer product. The EHS Director commented: "If this is good for a consumer product, it should be good for our employees working with it as well."

As described above, the company uses an EHS Assessment Report format for evaluating new processes and products. The EHS Assessment may describe the potential impact of proposed new processes, products or equipment, but it does not include a rating procedure for evaluating alternatives. The EHS Director suggested that there were few choices by the end of a technical and initial environmental assessment process, and gave the example of the company's choice between NMP and DBE as a substitute for DCM. DBE were ultimately selected because they performed better than NMP and were deemed "safer." While neither the Impact Form nor the EHS Assessment Sheet detail health and safety criteria, discussion with the EHS Director indicates that categories considered are comprehensive, even if the evaluation process is not systematic. For example, in addition to projects aimed at lessening chemical hazards, process changes have occurred to reduce mechanical safety and ergonomic hazards.

It is not clear whether alternatives are further evaluated for EHS impact once they have passed technical evaluation, although the company is, in general, committed to continuous improvement. The EHS director described air sampling that had been done for DBE in response to requests from state environmental authorities. He was not successful in monitoring the substance with an organic solvent sampling method and concluded, that due to the low volatility of DBE, there was no significant air contamination. Additionally, he did an evaporation study and found that after a week, a beaker containing DBE had no significant change in weight. Thus, losses in DBE are largely unexplained, but may be due to spills and generation of

contaminated/spent product. Additionally, the EHS director suggested that it may bind with the urethane and either become incorporated in the product or be vented through the forming belt exhaust system. Observation of the process suggested losses due to vaporization of the product at high temperatures.

#### 4.2.6 *Exposure Analysis*

DCM exposure study results were not available, but according to the EHS director, measured DCM exposure levels were “an order of magnitude below the standard,” which at the time would have been a PEL of 500 ppm. However, it is possible that had workers continued to use DCM to clean tools and to perform the vessel cleaning tasks, they might have been exposed above the new PEL of 25 ppm. The vessel mixing and discharge rooms were relatively small, enclosed spaces and were noticeably elevated in temperature. These conditions, combined with the discharge of solvent at elevated temperature following its trip through the hot equipment, would have created the potential for over-exposure. This exposure would have been mitigated by the slot ventilation on the equipment at the point where the chemicals enter the bucket. However, other tasks with potential for high exposure were uncontrolled, such as pouring solvent into the system and pouring the used chemical into the recycling or waste containers.

In the cleaning operations, the largely manual, uncontrolled processes, including pouring, stirring, mechanical cleaning, and emptying contaminated DCM into either waste containers or the recycling distillation unit, would have contributed to potential over-exposure.

Obviously, the substitutes have eliminated workers’ exposure to DCM. The introduction of substitutes with extremely low volatility has also reduced the potential for inhalation of the substitute solvent in these tasks. The initiatives undertaken to minimize the use of DBE – introducing Teflon buckets – also benefited workers by lessening their potential exposure, especially skin exposure. For both processes, DBE must be handled manually. They are poured into the urethane mixing equipment or into buckets for tool cleaning. Used DBE are also fed into the recycling still. Workers are exposed to DBE during cleaning and in pouring used DBE into the distillation unit. Workers were observed to be wearing cotton gloves. Exposure to DBE is not considered to be a hazard by the company. DuPont, the manufacturer of the product, provided a guideline occupational exposure limit to the company upon request and the company believes that occupational exposure to DBE is well within this guideline.

Current knowledge of DBE occupational health effects would suggest that they are considerably less harmful to workers than DCM (see Table 4.6). However, DBE are hazardous chemicals and can cause skin, eye and respiratory tract irritation. They are absorbed through the skin and prolonged exposure can cause blurry vision (DBE are metabolized to formic acid). According to the MSDS for polyethylene glycol, there are little or no health effects associated with exposure to the chemical. The American Industrial Hygiene Association has established a Workplace Environmental Exposure Level of 10 mg/m<sup>3</sup>, 8-hour, TWA for polyethylene glycol.<sup>(81)</sup> The very low vapor pressure of DBE and polyethylene glycol would mitigate against inhalation, but skin and eye contact are possible.

**Table 4.6: Summary of Potential Hazards -- Dibasic Esters/Polyethylene Glycol vs. DCM**

Potential Hazard	DBE	Propylene Glycol	DCM
Acute Health	Respiratory, skin, eyes irritation; blurry vision	Respiratory and eye irritation at high temperatures	Central nervous system suppression; headache, dizziness, nausea; respiratory and skin irritant
Chronic Health	None reported	None reported	Suspect carcinogen, heart problems, liver and skin damage
Safety/Physical/Ergonomic	None expected	None expected	None expected
Environmental	Moderately toxic to aquatic life	None reported	Chlorine; HAP; Hazardous Waste

Source: MSDS for Dibasic Esters and Carbowax 400; <sup>(82)</sup>

#### 4.2.7 Costs

The costs of using DCM, particularly for hazardous waste disposal, raw material, and compliance related activities, were a major motivation for the elimination of DCM. DBE are more expensive than DCM, but a considerably lower volume of chemical is purchased due to the process changes described above and the lower volatility of the chemical. The equipment expenditures that were required during the substitution were the remanufacture of equipment O-rings that were destroyed during technical evaluation of the substitute and some new mixing tools. The new mixing tools were estimated to have cost “a couple thousand dollars.” The company manufactured the new O-rings themselves. The distillation equipment had been purchased for DCM recycling. All potential DCM compliance-related costs were avoided. While a complete financial assessment has not been performed by the company, the EHS director believed that considerable savings had been generated by the project.

#### 4.2.8 Benefits and Problems

The only problem identified by the EHS director resulting from the substitution was the destruction of the mixing vessel O-rings during the technical evaluation. This would have been a costly problem had the company not manufactured O-rings. After this problem was corrected, no problems have been reported. The worker performing the mixing tool cleaning tasks reported that he and co-workers were dubious at first that the substitute would perform as well as DCM, but now were very happy with the substitution. He said that DCM had caused skin and eye irritation; DBE did not. In particular, he was relieved to not have to worry as much about the consequences of accidental splashes.

#### 4.2.9 Key Lessons

1. Pending environmental restrictions under the Clean Air Act in conjunction with worker health concerns, motivated the company to eliminate DCM.

2. The hazard reduction was facilitated not only by chemistry changes, but also by process changes that reduced the total quantity of chemical used.
3. The elimination of DCM was perceived as generating cost savings.
4. MSDSs and chemical companies were the main source of information on substitute chemistries and their potential hazards. These sources of information about hazards were trusted as reliable.
5. EHS staff believed that consumer products are safer than industrial products and, therefore, are preferred.
6. Technical criteria are the most important in evaluating substitutes. Evaluations of substitutes may focus on technical performance and not systematically address potential health and safety hazards.
7. Equipment problems may result from introducing substitutes, thus benchtop evaluations are recommended.
8. Workers may be concerned that substitutes may make their jobs more difficult.

### **4.3 Electrical Equipment Manufacturer**

#### *4.3.1 Background*

The third case is that of a company that makes electrical and electronic capacitors (NAICS 335999/SIC 3629) for original equipment manufacturers, white good manufacturers, lighting manufacturers, telecommunications and other light manufacturing companies. The company was founded in 1923 in Long Island and moved to Massachusetts in 1936. Due to environmental contamination, the company entered into a consent agreement with the EPA to mothball its plant and relocated in 2001 to a new, purpose-built facility. The company has 285 manufacturing employees and 100 support staff. It runs three shifts with 60% of the manufacturing workers on the first shift. It is a public company with two plants in the U.S., two in Mexico and one in England.

The company's EHS program is currently in transition due to the recent move and the departure of the EHS manager in December 2000. The company decided to not replace the EHS manager and instead moved health and safety functions to Human Resources and environmental functions became part of the facility manager's responsibilities. The company's worker/management health and safety committee now has responsibility for health and safety management. It meets monthly and publishes minutes for all employees. Additionally, the company hires environmental and industrial hygiene consultants for specific needs. Currently, there is no TUR Planning Committee, although one operated and was very active during the tenure of the former EHS manager.

The TUR committee targeted two processes that used DCM for TURA planning. The goal was first reduction of use and then eventual elimination of use of DCM. There was no apparent health and safety motivation for the reduction of use; planning and program activities for reduction and elimination of DCM occurred in 1997 prior to the new standard. DCM was eliminated from operations in 1999.

#### *4.3.2 DCM/Substitute Process and Process Change Descriptions*

One of the first TUR projects at this company was the drop-in substitution of NMP for

DCM as an equipment cleaner. NMP was identified as a substitute by their chemical supplier. After the equipment completes a batch coating of small capacitors with an epoxy coating, the equipment is purged with the solvent. Isopropyl alcohol is preferentially used as a clean-up solvent, but NMP is now also used (as DCM was) as a general clean-up solvent for tools and equipment. NMP is received in drums and decanted into solvent safety cans, squirt bottles and open containers.

DCM also had been used as a diluent for an adhesive used to seal the covers onto capacitor units. The adhesive also contained some DCM. This process has always been a partially automated one: most covers can be automatically sprayed with adhesive, but in some cases, workers had to manually apply the thin layer of adhesive using a small oil can applicator. In both cases, workers manually mixed DCM with adhesive for application. The company contacted the manufacturer of adhesive for information about what substitute materials would work with their product. The company suggested a chemical called Hubtron 141b (CAS 1717-00-6) also known as Freon 141b and dichlorofluoroethane. It is a hydrochlorofluorocarbon and is one of the principal drop-in substitutes for the banned CFCs. The company began purchasing this chemical as a drop-in substitute for methylene chloride.

Over the two-year process to eliminate DCM from this operation, the adhesive manufacturer also eliminated DCM from the adhesive by substituting aromatic hydrocarbons (xylene). Additionally, the company made equipment changes that increased the amount of this work that could be automated and reduced the requirement for diluting the adhesive for automated operations. Thus, the Hubtron is currently only used for manual operations, which are a small part of the process. Due to Hubtron's ozone-depleting potential it is scheduled to be phased-out in 2003 and the supplier has informed the company that it will shortly no longer be available to supply it. The company is currently looking for ways to change their equipment to eliminate the need for a diluent in manual application of the sealant.

#### *4.3.3 Process of Change*

The process of change at this company consisted of the following steps:

1. Stimulated by the TURA, the company's TUR committee set goals of reducing and then eliminating DCM.
2. Consultation with chemical suppliers identified substitutes.
3. Substitutes were evaluated for technical performance and, in part, environmental criteria.
4. In the first DCM replacement project, a drop-in substitution was made in the "easy" case where equipment or process changes were not necessary.
5. A two-year process of technical evaluation of the substitute and changes to the process and equipment resulted in the replacement of DCM in the second project.
6. Further work is underway to improve the second process to eliminate the need for a diluent – the original role of DCM.

#### *4.3.4 Motivations*

The company was motivated by environmental concerns, specifically TURA and wanting to improve its environmental record.

#### 4.3.5 Evaluation Protocol

Evaluation consisted primarily of assessing the technical performance of the substitutes. The company assumed that substitutes that recommended by chemical suppliers would be environmentally acceptable. MSDSs were reviewed by the EHS manager. They were not reviewed by the health and safety committee. There was no other apparent evaluation to gauge impact on the production process, environment or health or safety conditions of the change. Costs and benefits were not assessed. During the site visit, a worker doing the purging and cleaning operation was asked what he thought of the change. He noted that he thought that the NMP was more irritating to the skin than DCM.

#### 4.3.6 Exposure Analysis

Workers are no longer exposed to DCM at this company. No DCM exposure records were available and the facility manager did not think that any exposure monitoring had ever been done. Given DCM's high volatility and the mostly uncontrolled nature of the operations using DCM, the old process would seem to hold the potential for over-exposure (above the STEL of 125 ppm and/or the PEL of 25 ppm).

In the cleaning operation, other than decreased exposure due to reduced volatility of NMP, exposure potential remained the same as it had been when workers were using DCM for equipment purging and general clean up. Both tasks are uncontrolled, manual processes and there is the potential for skin exposure from splashes and sprays and inhalation exposure due to vaporization of bulk chemical from open containers. Work practices included throwing 20 ounce paper containers full of contaminated NMP into an open garbage container.

**Table 4.7: Summary of Potential Hazards -- N-Methyl Pyrrolidone vs. DCM**

Potential Hazard	N-Methyl Pyrrolidone	DCM
Acute Health	Moderate eye and skin irritant	Central nervous system suppression: headache, dizziness, nausea; respiratory and skin irritant
Chronic Health	Reproductive toxin: fetal death and abnormalities in second generation of exposed female and male rats	Suspect carcinogen, heart problems, liver damage
Safety/Physical/Ergonomic	None	None
Environmental	Hazardous waste, Toxics Release Inventory reporting	Chlorine; HAP; hazardous waste

Source: MSDS for NMP, <sup>(61)</sup>

Table 4.7 shows a comparison of hazards related to NMP and DCM. NMP has potential for acute and chronic worker health problems. (The U.S. Air Force has determined not to use it as a substitute for DCM because of both potential worker health and performance concerns.<sup>(64)</sup>) It is an eye and skin irritant, has a noxious odor and it has been found to cause fetal death and fetal abnormalities in rat studies.<sup>(61)</sup> NMP's vapor pressure at room temperature is very low, thus minimizing the chance of exposure by inhalation. However, it is adsorbed through the skin, and

this is thought to be the main route of exposure.

In the sealant operation, the mixing of the sealant had occurred without LEV, although the manual and automatic application work area was equipped with LEV, as was the oven that flashed off the solvent. The potential for DCM exposure during the sealant application process was lowered due to the use of LEV, although it was not possible to determine the effectiveness of the design or functioning of the system for that operation. The potential for DCM exposure during mixing and decanting operations probably had been quite significant.

After the process changes, much less diluent was required, and fewer workers performed manual operations due to the increased automation of the operation. The facility manager said that mixing operations were a small fraction of what they had been when DCM was used. The mixing area, which was adjacent to the process, was uncontrolled and very messy. Additionally, the work area/conveyer belt was also covered in the red sealant material. The process was not in operation during the site visit, so current work practices were not observed. The operator's green chemical resistant gloves were sitting partially turned inside out on top of the machine.

Hubtron is quite volatile and can cause the health effects of organic solvents, plus the health effects of chloro-fluoro carbons, i.e., cardiac arrhythmia. A comparison of health effects of Hubtron and DCM is summarized in Table 4.8.

**Table 4.8: Summary of Potential Hazards -- Hubtron vs. DCM**

Potential Hazard	Hubtron	DCM
Acute Health	Skin and eye irritant. Central nervous system suppression: headache, dizziness, nausea; loss of concentration. Cardiac arrhythmia.	Central nervous system suppression: headache, dizziness, nausea; respiratory and skin irritant
Chronic Health	Cardiac arrhythmia; risk of heart attack.	Suspect carcinogen, heart problems, liver damage
Safety/Physical/Ergonomic	None	None
Environmental	Ozone-depleting; hazardous waste	Chlorine; HAP; hazardous waste

Source: MSDS for Hubtron 444

Because, in both cases, the operations were essentially unchanged from the previous ones that used DCM, there was no apparent impact on noise, ergonomics or safety. It is possible that manual material handling was decreased due to the decreased volume of chemical used; barrel loading and decanting tasks became less frequent with the new chemicals.

#### 4.3.7 Costs

No financial accounting of the old process or the new one was undertaken as part of the change. The facility manager noted that NMP and Hubtron were both more expensive than DCM. NMP is estimated to be almost four times as expensive as DCM on a per gallon basis. However, due to the equipment and process changes, and NMP's lower volatility, much less of the new chemicals are used compared with DCM. According to the facility manager, the proposed investment in equipment changes to facilitate the sealant project required justification ("a song and dance") to the financial managers. The company ordinarily requires an 18-month

payback on capital investments (recover the cost of the investment through savings or increased revenues within 18 months) and this project was presented as an additional cost without monetized benefits. As a result, the project was approved on environmental grounds rather than financial ones. The production manager perceived non-quantified financial benefits of the change, including increased efficiency and flexibility and reduced environmental compliance requirements.

#### *4.3.8 Benefits and Problems*

The benefits of the project were described as increased environmental compliance and increased efficiency and flexibility in production. No problems were mentioned by the facility manager.

#### *4.3.9 Key Lessons*

1. TURA was an effective motivator to eliminate DCM and undertake process changes with the potential to benefit workers' health.
2. The chemical supplier was the first and only place the companies turned for information about substitutes. The chemical supplier made "name brand" recommendations and provided chemical and process engineering support in the transition.
3. The company relied on their chemical supplier to appropriately screen substitutes for potential environmental, health or safety hazards.
4. The company appeared to make sub-optimal choices for substitutes, from both an environmental and worker health perspective. This may have been a result of limited technical resources to evaluate alternatives.
5. Other than technical performance, the company did not perform comprehensive evaluation of substitutes.
6. Poor work practices and protective equipment practices persisted after the process change.
7. The cost of change was not a barrier when faced with compelling environmental rationale.
8. The company was motivated to innovate or improve their processes' efficiency as a result of environmental restrictions.

### **4.4 Vessel Cleaning**

#### *4.4.1 Background*

This vessel cleaning company (NAICS 81131/SIC 7699, Industrial Equipment Repair and Maintenance) employs 12 workers over two shifts and does \$1 million in business a year cleaning the inside and outside of tanker trucks and 300-gallon chemical totes. There were many long-term employees and, like other small companies, management will sometimes also do the required work. The company management has experience in hazardous waste management. Common contaminants cleaned from the tanks and totes include flocculating agents for water treatment, latex, formaldehyde, acids and bases, coatings, paper industry chemicals and adhesives. The company will not clean tankers or totes with highly flammable or toxic contents and maintains a list of what they will and will not clean, but they will consider new contaminants if they think they can clean them safely and profitably, while abiding by hazardous waste and

water permits. Additionally, the manager said that he asks employees how they feel about cleaning a new contaminant after review of the MSDS. Customers are contractually mandated to supply an MSDS for all tank or tote contaminants.

OSHA's Preamble to the DCM standard noted that it felt that engineering controls such as LEV were feasible to control DCM exposure below the PEL in all applications with a few exceptions, including vessel cleaning. The Preamble states that respiratory protection equipment has been used in the past in vessel cleaning and it expected that it would be relied upon under this standard.

#### *4.4.2 DCM/Substitute Process and Process Change Descriptions*

The general cleaning process is as follows. First, workers use a "Pyurator" — a low volume high pressure (200 psi) water washer at 200° F followed by a cold water flush to clean the outside and inside of the tank or tote. A caustic detergent solution is then sprayed followed by a steam cleaning designed to remove solvents. The detergent is called (Company) Tank Cleaning Solution — a sodium metasilicate based detergent (150 psi, 170° F). Use of this detergent has greatly reduced the use of sulfuric acid for neutralization. As necessary, the workers will also do a "dried product removal" via mechanical and manual means, primarily manual scraping. This generally requires a confined space entry permit. The company maintains a "heel" recycling program. The heel is any usable residual product remaining in the tanker or tote; it is transferred to barrels and sold.

Of particular concern to the company was the process required to clean an adhesive used in the automotive industry from chemical totes. Prior to the process change described below, the workers cleaned the inside of these totes with DCM and manual scraping. The adhesive contained significant amounts of very volatile toluene and methyl ethyl ketone. As the company manager said: "Just to take the lid off, it would fill this room up with vapors." The cleaning process for this contaminant involved a worker pouring two gallons of DCM into a tote, tipping and rolling it, releasing the lid to "degassify" it (as the manager explained it), getting into the tote and scraping for eight hours a day for three days. The workers also used DCM to clean the outside of the totes. Air-purifying cartridge respirators were worn by employees performing these tasks.

The company management consulted TURI's Surface Cleaning Laboratory and jointly selected a very effective substitute cleaner based on NMP and DBE. This change reduced the hazardous waste cost from \$250 to \$70/tote, but the cleaning process still took several days. The company also considered sand blasting, but determined that it would be too harsh on the totes.

At the end of July 1998, the company moved to a baking soda blast (100 psi, 150 cfm) process for this task. A small amount of water is mixed with baking soda (to suppress dust) and the worker directs the spray through a nozzle. The task now takes two workers one day to do each tote. For the task of cleaning the outside of totes, the workers now use high-pressure water instead of DCM.

#### *4.4.3 Process of Change*

1. Management identified a problem with the existing process due to concerns about hazardous waste, low productivity and potential hazards.
2. Company approached Surface Cleaning Lab for help in finding a drop-in substitute.

3. The company began using the substitute, but kept looking for a better way to perform the work.
4. The company applied for and was awarded a matching demonstration grant from TURI for implementing a baking soda blast process that eliminated the use of DCM and the intermediate drop-in substitute.
5. Satisfied with the change, no further work was planned, with the exception of possibly building a booth to minimize the release of dust and noise to the rest of the work environment.

#### *4.4.4 Motivations*

The company began to look into alternatives out of concern over the volume of hazardous waste produced by this cleaning operation and the toxicity of the chemicals. Each tote produced a half of a barrel of hazardous waste consisting of the adhesive heel and DCM. Additionally, this project was motivated by production cost concerns. The company was looking for a faster, less labor-intensive method. This became especially important after the company got a large contract for this work at a time when the company lost a significant portion of other work.

The introduction of the 1997 OSHA standard for DCM also provided a significant incentive for this change. The manager said he thought that the cost to comply with the new standard would be very expensive, especially the cost of the air-line respirator. An additional factor that not only motivated, but also assisted with the change, was a demonstration project grant from TURI. The grant helped defray the cost of the change and it was accompanied by technical assistance. The free services of the Surface Cleaning Laboratory were utilized to find substitute chemistries.

#### *4.4.5 Evaluation Protocol*

As with the other cases, evaluation primarily concerned technical performance. The Surface Cleaning Lab played a key role in evaluating potential substitutes and in suggesting alternative cleaning methods. Costs were also evaluated, but did not seem to factor significantly in the company's decision to change its process. On the contrary, clear cost savings were anticipated. What was not anticipated or thoroughly evaluated was the potential for new worker health and safety hazards from the change. New exposures — to noise, dust and awkward postures coupled with forceful exertions — were introduced with the new process and it is not clear that the company adequately anticipated these hazards or undertook steps to reduce their potential impact on the workers.

#### *4.4.6 Exposure Analysis*

This change eliminated a very serious potential DCM exposure. In the old process, workers were at risk of acute over-exposure from working in a confined space with this highly volatile and toxic chemical. Additionally, the work as described would most likely have resulted in chronic over-exposure — although the manager said that prior to new DCM OSHA standard, he believed that this process was “under the regulations” (less than 500 ppm). The new process greatly minimized the toxicity of the chemical exposure in this process, but introduced new physical hazards including noise and ergonomic stress. Table 4.9 summarizes the potential

hazards resulting from the new process.

**Table 4.9: Summary of Potential Hazards – Baking Soda Blast vs. DCM**

Potential Hazard	Baking Soda Blast	DCM
Acute Health	None reported on MSDS (mild respiratory irritant)	Central nervous system suppression: headache, dizziness, nausea; respiratory and skin irritant
Chronic Health	None reported	Suspect carcinogen, heart problems, liver damage
Safety/Physical/Ergonomic	Electrical/hot water, noise, physiological load, awkward posture, force, vibration	Awkward posture, force, physiological load
Environmental	Non-toxic	Chlorine; HAP; hazardous waste

Source: MSDS for Baking Soda Blast

The new process has several potential ergonomic hazards including awkward postures and forceful exertions from carrying and directing the nozzle. Thumb pressure on the nozzle is a particular ergonomic concern. Management has told workers to rest and to “alternate fingers” to reduce the risk of injury. Noise from the new blasting equipment was not measured, but was perceived by the investigator to be potentially hazardous. Reportedly, the sales representative told management, with regard potential concerns about the noise levels of the equipment, “they’ll get used to the noise.” Due to the noise and some dust from loading operations, management reported an interest in building a sound booth to contain both noise and the dust. The baking soda is a mild respiratory irritant and for that reason, the workers wear dust masks. Additionally, they use woven gloves, hearing protection, Tyvek or cotton uniforms, safety glasses and boots. Four to six hours of this work is very hard but, according to management, the workers are much happier with the current process than they were when working with DCM – a process that involved forceful manual scraping in awkward postures for days at a time. This case illustrates the potential for new potential noise and ergonomic hazards resulting from a move from chemical power to mechanical power and a lost opportunity to mediate the ergonomic stresses associated with vessel cleaning.

#### 4.4.7 Costs

Table 4.10 details the company’s estimated cost savings of \$910/tote over the old process. The new process is estimated to cost 74% less than the cost with the DCM process. Non-quantified savings include the avoided costs of complying with the OSHA standard. The manager specifically mentioned OSHA compliance costs, especially the cost of the airline respirator, as a motivation behind the project. Other cost benefits included the ability to take on more of this work without expanding the labor force, and faster turn over of the work. The company’s costs of the project were minimized by TURI’s demonstration matching grant of \$10,200 and the savings gained from finding a used compressor. Management describes the costs of the new process, with the exception of the purchase cost of the compressor, as minor.

**Table 4.10: Cost Comparison Per Tote -- DCM vs. Baking Soda Blast**

	<b>DCM</b>	<b>Baking Soda</b>
Tyvek Coveralls	\$100	\$10
Respirator/Air	\$100	\$10
Chemicals	\$30	\$50
Labor	\$750	\$200
Waste	\$250	\$50
<b>Total</b>	<b>\$1,230</b>	<b>\$320</b>
<b>Savings Per Tote</b>	<b>\$910</b>	

Source: Company communication.

#### 4.4.8 *Benefits and Problems*

Productivity gains are a significant benefit of this project, in addition to the elimination of the health and environmental risks associated with DCM. Due to labor and time savings, the cleaning effort per tote is approximately one-quarter of that under the old process, resulting in financial and production benefits. Customers have also had a positive response, according to the company. There are some technical limitations —the new process is reportedly very good on adhesives, coatings and solvent-based contaminants, and less good on rust and mill scale. The new process is also messier.

As discussed above, although the workers' effort is still considerable, this new process is regarded as "easier." From an environmental and health and safety perspective, the new process is much safer and the compliance burden much reduced. However, problems associated with the change include new potential noise and ergonomic hazards.

#### 4.4.9 *Key Lessons*

1. The Surface Cleaning Lab services and TURI's grant and technical assistance played a key role in facilitating the change.
2. Moving from chemical to mechanical cleaning processes can introduce new ergonomic and noise hazards.
3. Technical concerns remain paramount: economic and environmental health and safety concerns are not evaluated as thoroughly.
4. This project eliminated the need for air-supplied respirators. Compliance with the DCM standard using engineering controls was not considered feasible and the company would have relied on air-line respirators.
5. Elimination of DCM in vessel cleaning is not only feasible and effective, but profitable.

## 5 **Discussion/Case Summary**

### 5.1 **DCM Process Changes in These Cases**

- ✓ Three companies eliminated and one reduced their use of DCM.
- ✓ In two companies, DCM was used (and eliminated) in more than one process.
- ✓ Out of seven processes using DCM in these four companies, two were adhesive thinning operations and five were cleaning operations.

- ✓ In three processes, “drop-in” substitutes were used with no production process modification.
- ✓ Four process changes required some equipment or production process modification. Three of these were minor, and in one, the entire process was replaced.
- ✓ Two process changes involved using mechanical means in conjunction with new chemical substitutes.
- ✓ In one case, an alternative safer cleaning process was in place, but did not perform well enough to “take over” the work of DCM. Thus, a substitute was sought and found to improve the alternative safer cleaning process already in place, so that DCM could be relieved of its duties.
- ✓ Commercially-available substitutes were used.
- ✓ Change happens all the time in industry as demand for products and services change. Some of these changes facilitate source reduction for hazard prevention. A loss of orders enabled one company to use less DCM. An increase in orders prompted another to seek out an alternative to DCM.
- ✓ Two companies continue to look for substitutes for their original substitutes. In one case, it is in response to the environmental concerns of the substitute and in the other, it is to lower costs.

## **5.2 Processes of Change**

- ✓ The three companies that eliminated DCM use did not first attempt to control worker and environmental exposure with engineering controls, but looked for substitutes directly. The company that minimized, but continued to use DCM, followed the MACT degreaser standard and reduced DCM loss and exposure.
- ✓ One company made an interim substitution and then continued to look for better substitutes.
- ✓ Three of the companies relied on their chemical suppliers for advice about substitutes.
- ✓ Two utilized technical assistance and laboratory services of the Toxics Use Reduction Institute.

## **5.3 Motivations**

- ✓ Companies were strongly motivated by environmental compliance and goals. Specifically, they sought to improve compliance with the Clean Air Act, reduce their reporting under TURA, and reduce hazardous waste.
- ✓ Worker health concerns, including compliance with the new OSHA standard, were a motivating factor in three cases.
- ✓ Improving production efficiency was the major motivation in two cases of process change. In a third, the costs of using a volatile chemical such as DCM also motivated the changes.

## **5.4 Evaluation Protocols**

- ✓ The focus of evaluation efforts was fixed on technical performance concerns. However, potential substitute chemistries that could introduce obvious environmental concerns were not evaluated to see if they would work.
- ✓ Financial, environmental and worker health evaluations of substitutes were minimal.

## 5.5 Exposure Analyses

- ✓ Three companies completely eliminated exposure to DCM in routine and non-routine operations. The fourth significantly reduced over-exposure potential by limiting the duration of potential exposure.
- ✓ Based on available information, the reduction and elimination of DCM use resulted in dramatically lessened potential exposure to hazardous chemicals.
- ✓ Reductions in quantities of total chemical used and increased automation reduced potential exposure to substitute chemicals.
- ✓ In three cases, the principal potential hazard of the substitutes is eye, skin and/or respiratory irritation.
- ✓ One company selected potentially hazardous substitute chemistries. One is a potential reproductive hazard with potential for exposure through skin adsorption. The other chemistry was an ozone-depleter and a potential cardiovascular toxin. However, in the later case, the total quantities used and potential for exposure in this operation were minimal.
- ✓ In one company, potential ergonomic hazards of the old process using DCM were eliminated with DCM, but the new process introduced new potential ergonomic hazards. A noise hazard was also introduced.

## 5.6 Costs

- ✓ Within general constraints of not wishing to invest large amounts of money in capital equipment, the companies were not especially concerned about potential negative financial impacts of the changes. Only one company conducted a financial analysis of the change.
- ✓ The companies sought to minimize and economize on the costs of the change.
- ✓ Two companies anticipated and reaped significant financial benefits from the changes – mainly through improved production efficiency.
- ✓ While the new chemistries cost more than DCM on a volume basis, the lower volatility and improved operations from the source reduction process changes resulted in lower chemical consumption and costs.

## 5.7 Benefits and Problems

- ✓ All of the companies were glad to be rid of (or lessen dependence on) DCM.
- ✓ All of the companies perceived environmental and worker health benefits as a result of the change.
- ✓ Two companies reported significant financial benefits from the change and one appreciated new production efficiency and flexibility.
- ✓ Technical problems with the changes were minor and were resolved.
- ✓ In two cases new significant potential hazards were introduced. These were not anticipated and were not adequately controlled.

## 5.8 Study Limitations

The major limitations of this study are the lack of generalizability of the findings due to small sample size, selection bias due to a required convenience sampling frame, and limited data

collection. Due to the limitations of the scope of the project, and restrictions in the amount of time and resources of the participating companies, the cases describe source reduction evaluation process that fall short of the ideal described in Section 2.3.

## **6 Conclusions and Key Lessons**

These case studies help to demonstrate the feasibility and effectiveness of source reduction process change for hazard prevention and bring to light some of the limitations of the approach as practiced in the “real world.” In all cases, complying with the new DCM standard with engineering controls would have been difficult and expensive. The alternative route taken by these companies appeared to gain them the benefits of both regulatory compliance, and in most cases, process improvements. New processes and chemicals sometimes introduce new hazards, however, and these were, in general, not adequately anticipated or addressed in companies conducting process changes on their own without trained assistance. This study found that effective, feasible and safer alternatives to the use of DCM exist in a variety of industrial sectors, processes and facility sizes. Key lessons from these cases include the following:

1. Source reduction strategies can be a feasible and effective approach to compliance with standards and reduction of worker health hazards. In its DCM standard, OSHA had concluded that engineering controls were not feasible for vessel cleaning and this industry would rely on air-line respirators for exposure control. This study found that for this sector (and others), source reduction process changes that eliminated DCM use were not only feasible, but beneficial to production and environmental protection goals.
2. Technical assistance is key to facilitating process change. Companies may make sub-optimal choices, from an occupational health and safety or environmental standpoint, with inadequate information about alternatives. Typically, technical concerns are top-priority and many companies trust that “unlisted” products are “safe.” Thus, technical assistance sensitive to both technical and occupational and environmental health concerns could help maximize the benefits of the process.
3. Source reduction strategies can result in financial gains, without even considering the benefits from improved regulatory compliance. When companies look at processes, they often try to improve them overall, by reducing the problems they cause (environmental contamination and worker exposure) and innovating production improvements. Financial concerns of change, other than significant capital investments, do not appear to be a major barrier to the utilization of source reduction strategies, especially when the changes are motivated by regulatory compliance.
4. This research suggests that source reduction strategies motivated by strict regulation have the potential to drive significant industrial innovation and reduction of worker health hazards, but should be accompanied by technical assistance sensitive to technical performance and worker and environmental health concerns.

## **7 Recommendations and Future Research**

A recommendation based upon these project findings is that source reduction be considered in the category of feasible and effective strategies for compliance with standards and reduction of health hazards. Because companies may miss opportunities to improve processes, both from an environmental, worker health, and production standpoint without adequate

technical assistance that comes from non-commercial sources, NIOSH and OSHA should devote resources to this task and/or link companies to such resources. Technical assistance programs and small grants and loans are also critical to facilitating the innovation that can be realized from source reduction. This may be especially true for small businesses without resources to do extensive research or modeling of alternatives. The TURI Surface Cleaning Laboratory has played a critical role in assisting Massachusetts firms in finding alternatives and demonstrates a positive model for other states.

Research is needed to find ways of coordinating technical assistance with regulation and compliance activities to maximize efficient and effective dissemination of source reduction strategies. For example, in this study it was found that chemical distribution companies appear to be a primary and often exclusive source of information on alternatives. Efforts could be targeted to improve the quality of information and services provided to companies through their chemical suppliers.

Finally, this research focused on one chemical and just a few industrial processes. While many of the lessons from these cases are broadly applicable, research is needed to examine the feasibility and effectiveness of source reduction in other applications, particularly where the hazard in question is a formulated constituent of a company's product and change would require re-engineering of the product itself, rather than of an auxiliary process.

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## Appendix

### DEGREASING ACTIVITY LOG

<b>ROUND ONE</b>			
<b>Task</b>	<b>Start</b>	<b>Stop</b>	<b>Minutes</b>
Setup: load 30"x3'x16" basket, 3 parts deep (325 parts), turn on heating and cooling coils in degreaser, open cover (odor on left)	10:15	10:29	14
Loading: put on ppe (paper mask, glasses, gloves), guide hoist/basket in (hoist at 8ft/min), spray for 2 min	10:29	10:32	3
Operation: operator leaves platform and degreasing area	10:32	10:44	12
Spray: leans over and slightly in to use hand sprayer	10:44	10:46	2
Operation: operator leaves platform and degreasing area	10:47	10:57	10
Spray: leans over and slightly in to use hand sprayer	10:58	11:00	2
Unload: starts hoist almost immediately after spraying ends, guides out of degreaser, stands in front of basket (2 mins), closes cover, unload basket into cardboard box, little odor	11:00	11:09	9
<b>ROUND TWO</b>			
Set-up: (as before). Cover up at 11:19	11:10	11:20	10
Loading: (as before). Spray for 3 min.	11:20	11:24	4
Operation: worked in area for 1 min then left	11:24	11:37	13
Spray	11:37	11:40	3
Operation (worker not in area)	11:40	11:50	10
Spray	11:50	11:54	4
Operation (worker not in area)	11:54	12:01	5
Spray	12:01	12:02	1
Unload: shook basket with hoist and manually, 2 min to set down basket, closed cover, timer turned off hot and	12:02	12:10	8

cold coils, unload basket			
<b>ROUND THREE</b>			
Setup	12:12	12:19	8
Loading: cover open, load, spray for 2 mins	12:20	12:25	5
Operation: (worker not in area)	12:25	12:38	8
Spray	12:38	12:40	2
Operation (worker in area, but not near degreaser)	12:41	12:50	9
Spray	12:50	12:52	2
Unload: degreaser off, unloaded parts, tested for grease	12:53	1:00	7
<b>ROUND FOUR (lunch break from 1:00 to 1:16)</b>			
Setup: degreaser on at 1:23 and cover open	1:16	1:26	10
Load: load and spray for 2 mins.	1:26	1:30	4
Operation: (worker not in area)	1:30	1:40	10
Spray	1:40	1:42	2
Operation: (worker not in area)	1:43	1:56	13
Spray	1:57	1:58	1
Unload, close cover at 2:00, unload parts, degreaser off at 2:05	1:59	2:05	6
Notes: Operator would shake the basket a little when unloading, but did not leave basket above the vapor before hoisting it out. Rounds One and Two were sampled on separate tubes; Rounds Three and Four were sampled on one tube. Operator reported that he had two more rounds to do that day, and that that day's work load was typical.			

## DCM EXPOSURE ASSESSMENT RESULTS

### Sampling Results from Metal Finishing Company March 25, 1999

Sample	Flow Rate l/min	Sample Time (min)	Sample Vol (l)	DCM (mcg)	DCM Conc. (mg/m <sup>3</sup> )	DCM Conc. (ppm)
Personal F2 R1	0.050	40	2.0	1100	553	157
Personal F3 R2	0.050	60	3.0	1240	416	118
Personal F8 R3	0.050	90	4.5	3150	704	199
Area Lip F7 R1	0.050	46	2.3	2610	1125	319
Area Lip F6 R2	0.050	57	2.9	1380	480	136
Area Lip F4 R3	0.050	85	4.3	5910	1379	391
Area Aft F5 R1	0.051	43	2.2	27	12	4
Area Aft F9 R2	0.051	55	2.8	31	11	3
Area Aft F10 R3	0.051	85	4.4	119	27	8
Blank				0		

1 ppm = 3.53 mg/m<sup>3</sup> DCM

**Metal Finishing Company  
Ambient Temperature and Humidity**

Measurement	° F	° C
WBGT out	67.7	19.7
WBGT in	67.9	20.0
WB	65.5	18.6
DB	71.0	21.8
GT	73.0	22.7
RH	75%	

Measured with the Rueter-Stokes Heat Stress Monitor, March 25, 1999 on the operator's work platform adjacent to the degreaser

**Velocity Map — Arial View (all measurements in ft/min)**

Inside coils	25		43			30	
Two ft above lip	13		2			14	
Face	5		10		24	19	
	25		20	10	20	31	11
Front Lip	18		26			4	At "spraying position" breathing zone
Right Side	78	82	68	Ctr Platform - 1' up, 1' from tank		72	
At rear sampling pt	24		Ctr Platform - 2' up, 1' from tank			27	

**OSHA CONSULTATION SERVICE  
EXPOSURE ASSESSMENT AT METAL FINISHING COMPANY  
May 1999**

Activity	Time (min)	Conc. (ppm)
whole process	120	0.4
Unloading	7	120
Unloading	7	71
Unloading	6	52
whole process	120	5
Unloading	3	36
Unloading	3	41
whole process	60	15
whole process	40	8
Unloading	11	62
<b>Reported 8hr TWA</b>		<b>5</b>
<b>Calc. TWA - whole process only</b>		<b>5</b>
<b>Calc. TWA - all results</b>		<b>12</b>
<b>Calc. 8 h TWA - whole process only</b>		<b>4</b>
<b>Calc. 8 h TWA - all results</b>		<b>9</b>
<b>Std Dev whole processes</b>		<b>6</b>
<b>Std Dev unloading</b>		<b>30</b>

(Table based on personal communication with M. Lewiton, May 1999).

## SAFETY AUDIT GUIDELINE

**Tripping and Falling:**  
**Crowded Accessways:**  
**Sharp/Awkward Corners:**  
**Machine Access:**  
**Ladders and Platforms:**  
**Hoists:**  
**Flammable Liquids:**  
**Gases/Pressurized Cylinders:**  
**Chemical Storage:**  
**Machine Pinch Points:**  
**Equipment Temperature:**  
**Electricity:**  
**Lockout/Tagout:**  
**Maintenance:**  
**Confined Space:**  
**Fire Suppression:**  
**Emergency Equipment:**  
**Process Safety:**

**Notes:**

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## GENERIC ESTIMATED COST COMPARISON: AQUEOUS CLEANING V. DCM DEGREASER

Aqueous Cleaning				
Operating Costs				
	Cost/Gal	Dilution	Cost/Tank	Cost/Yr
1 Alkaline Cleaner	\$ 7	10%	\$ 189	\$ 756
2 Water	\$ 0.002	90%	\$ 0.49	\$ 1.94
<b>Total</b>				<b>\$ 758</b>

3 Equipment Costs (including installation, plumbing and training)	
Wash/Rinse	\$ 8,500
Filtration Unit	\$ 15,000
<b>Total</b>	<b>\$ 23,500</b>

DCM Degreaser			
Operating Costs			
	Cost/lb	Lbs/Yr	Cost/Yr
4 DCM	\$ 0.64	9500	\$ 6,080

### Economic Analysis Summary

Annual Savings for Aqueous Cleaning:	\$ 5,322
Aqueous Equipment Costs	\$ 23,500
Payback Period for Investment in Equipment	4.42 yrs

### Notes

Costs for labor, waste disposal, maintenance, and electricity are considered comparable for these two systems. However, this is a conservative assumption. Thomas (1997) estimated higher costs for these categories for vapor degreasers. Many costs/benefits are not considered here including those related to production, regulation, health, environment, worry, training, insurance. These items are generally costs while using the degreaser and become benefits after a switch to aqueous.

### Sources

1. Price per Oakite Corp., 5/1/00, for purchase in 55 gal drums.
2. Thomas (1997), based on Waltham, MA water costs.
3. Three estimates were used to estimate this cost (all three include installation). Thomas (1997) reports a company paying \$20,000 for a complete system including wash and rinse tanks, oil skimmer and filtration unit. The Navy (2000) reports \$6,000 for the wash and rinse system plus \$30,000 for the oil/water separator (probably for a larger unit than required here). Karris (1994) reports \$14,250 for the wash and rinse tanks and \$21,000 for a high tech filtration unit.
4. Actual price paid by metal finishing company.

## **Selected Internet Resources on Source Reduction**

Canadian Pollution Prevention Information Clearinghouse  
<http://www.ec.gc.ca/cppic/en/index.cfm>

Enviro\$en\$e (U.S. EPA's all-purpose resource) <http://es.epa.gov/>

U.S. EPA's Office of Pollution Prevention and Toxics: [www.epa.gov/oppt](http://www.epa.gov/oppt)

Great Lakes Information Network P2Tech listserv and archives: <http://www.great-lakes.net/lists/p2tech/>

Institute for Research and Technical Assistance: <http://home.earthlink.net/~irta/>

Joint Armed Services Pollution Prevention Opportunity Handbook  
[http://p2library.nfesc.navy.mil/P2\\_Opportunity\\_Handbook](http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook)

National Pollution Prevention Roundtable  
<http://www.p2.org/inforesources/InfoHouse.cfm>

Northeast Business Environmental Network  
<http://www.nben.org/HTMLSrc/Resources/Technology.html>

Pacific Northwest Pollution Prevention Resource Center (adhesives, esp)  
<http://www.pprc.org/>

Pollution Prevention Resource Exchange  
<http://www.p2rx.org/>

Solvent Alternatives Guide <http://clean.rti.org/>

Tellus Institute (P2 Finance): [www.tellus.org](http://www.tellus.org)

Toxics Use Reduction Institute (including case studies and Surface Cleaning Lab and P2OASys)  
[www.turi.org](http://www.turi.org)

## List of Publications

The following publications are based upon the work funded (in part) by National Institute for Occupational Safety and Health Grant Number: 1 R03 OH04155-01 "Intervention Effectiveness of Process Change Techniques" and are enclosed with this report.

Roelofs, C.R., R. Moure-Eraso, and M.J. Ellenbecker, Pollution Prevention and the Work Environment: The Massachusetts Experience. *App Occup Environ Hyg*, 2000. 15(11): p. 843-850.

Roelofs, C.R., et al., Prevention Strategies in Industrial Hygiene: A Critical Literature Review. *Am. Ind. Hyg. Assoc. J*, 2003. 64(1): p. 62-67.

Roelofs, C.R. and M.J. Ellenbecker, Results of the Massachusetts Methylene Chloride End-Users Survey. *App. Occup. Environ. Hyg.*, 2003. 18(2): p. 132-137.

Roelofs, C.R. and M.J. Ellenbecker, Source reduction for prevention of methylene chloride hazards: cases from four industrial sectors. *Environ Health*, 2003. 2:9.

The principal investigator's doctoral dissertation was also supported by this grant:

Roelofs CR: *Losing Controls: The Case for a Preventive Industrial Hygiene*, ScD Thesis, University of Massachusetts Lowell, 2001.