Environmental Strategies for the New Millennium

THE SEARCH FOR SAFER AND GREENER CHEMICAL SOLVENTS IN SURFACE CLEANING: A PROPOSED TOOL TO SUPPORT ENVIRONMENTAL DECISION-MAKING

Carole A. LeBlanc

The Search for Safer and Greener Chemical Solvents in Surface Cleaning:
A Proposed Tool to Support Environmental Decision-Making

De zoektocht naar veiliger en milieuvriendelijker chemische oplosmiddelen voor oppervlaktereiniging:
een instrument ter ondersteuning van milieubesluitvorming

Thesis

to obtain the degree of doctor from the
Erasmus University Rotterdam
on the authority of the Rector Magnificus
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by

Carole Ann LeBlanc
born at Winchester, Massachusetts, U.S.A.

About the Cover

Fractal art is based on fractal (i.e., non-integer) geometry, a branch of mathematics developed from the study of complexity and chaos. Fluctuations of the stock market, the turbulence of fluid motion and the distribution of galaxies in the universe can all be described in fractal dimensions. Fractal geometry has also been applied to such diverse fields as weather forecasting and the chemical industry. In fractal art, the image is governed by a formula (set of equations). The artist then manipulates the variables and creates a color palette. *Courtesy of Graphx Edge, Inc.*

Doctoral committee

Thesis supervisors:	Prof.dr. D. Huisingh Prof.dr. K. Geiser
Other members:	Prof.dr. G.I.J.M. Zwetsloot Prof.dr. L. Reijnders Prof.dr. drs. F.H.A. Janszen

In Memoriam

Dedicated to the memory of the victims,
Both young and old alike,
Who succumbed to chemically-contaminated water
In Woburn, Massachusetts
In the latter half of the last century.

And to Evelyn

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DUTCH SUMMARY NEDERLANDSE SAMENVATTING

In dit proefschrift is een interactieve matrix voor de identificatie van veiliger en milieuvriendelijker chemische reinigingsmiddelen ontwikkeld: de *Waterbasis Aanpak*. Er is aangetoond dat dit instrument potentieel bruikbaar is op de website. Het gebruik van het instrument was oorspronkelijk alleen bedoeld voor besluitvorming over de reinigingsmethodiek bij industriële toepassing, maar het is ook succesvol gebruikt bij schoonmaakprocessen in grote kantoorgebouwen. De matrix is ontwikkeld gedurende een vijfjaren programma van het Oppervlakte Reiniging Laboratorium van het `Toxics Use Reduction Institute' van de Universiteit van Massachusetts, Lowell (USA). De auteur heeft vragenlijsten voor aanbieders en gebruikers van schoonmaakprocessen ontworpen. De vragenlijst is ontworpen ten behoeve van een vergelijkend onderzoek tussen een testprotocol voor reinigingsmiddelen, die niet op waterbasis zijn geproduceerd en voor alternatieven op waterbasis.

De effectiviteit van het instrument hangt af van verschillende factoren. Zo is de toegang tot de testdatabanken van het Oppervlakte Reiniging Laboratorium belangrijk om (1) de tijd toebedeeld aan het onderzoek naar reinigingsalternatieven te *verminderen* en (2) de vaardigheid voor de uiteindelijke selectie van reinigers te *vergroten*. De presentatie van de matrix als onderdeel van een achterliggende `kritisch denken'-methodologie is ook essentieel, sinds kennis van computerprogrammering, productkennis en reinigingsvaardigheden sterk variëren bij doelgroepen als overheden, bedrijven, onderzoekers en reinigingspraktijkmensen.

Zodoende is de `Kritisch Denken Over Reiniging Alternatieven'-methodologie bedacht en voor deze dissertatie succesvol getest als het beste middel om de *Waterbasis Aanpak* te implementeren. Gebaseerd op een stevige greep op milieu-, gezondheid- en handhavings-aspecten van chemische reinigingsmiddelen is deze aanpak een hulpmiddel en niet een alternatief voor toepassingsgericht testen. Educatie kan worden uitgebreid met de oprichting van een netwerk van openbaar gesteunde en gefinancierde laboratoria over de hele wereld voor de eliminatie van gevaarlijke oplosmiddelen en de ontdekking van alternatief samengestelde oppervlaktematerialen.

Wanneer chemische informatie op de website betrouwbaarder en gemakkelijker verkrijgbaar wordt, kunnen verschillen in handhaving tussen landen verminderen. In een wereldeconomie moeten chemische leveranciers verschillende formuleringen aanbieden om aan de regionale handhavingseisen te voldoen. Het selecteren van de veiligste alternatieven kan worden vertaald in de vraag naar producten die in het land met de hoogste standaard worden verkocht. Het instrument kan de relatieve plaats van milieu-, gezondheid- en veiligheids- parameters van geselecteerde reinigingsmiddelen rangschikken door databank-onderzoeken van afzonderlijke chemische componenten. Deze assessment gaf aan dat de op waterbasis ontwikkelde reinigingsmiddelen, die tot nu toe eensluidend veiliger en milieuvriendelijker werden beoordeeld dan hun equivalent op basis van gechloreerde oplosmiddelen, niet allemaal dezelfde uitkomst bieden. Daarnaast werden ook potentiële effecten als de verstoring van de hormoonhuishouding op deze manier ontdekt.

De holistische aanpak wordt enigszins beperkt door de toegang tot informatie die wordt bewaard in databanken met patenten en `Materiaal Veiligheid Data Sheets', die alleen in de Engelse taal zijn gemaakt. Beleidsmakers zouden informatieverwerving over chemische veiligheid moeten loskoppelen van de financiële mogelijkheden van geïnteresseerden. Dit zou de mogelijkheid van *volledige chemische informatie ontsluiting* te bevorderen. Voor een werkelijk duurzame samenleving zou geen verschil moeten bestaan tussen enerzijds het risico aan chemische blootstelling door schoonmakers op minimum loon basis en anderzijds de technicus in de reinigingsruimten in de halfgeleiders industrie.

Het promotieonderzoek bevestigt dat de toekomst van oppervlaktereiniging moet worden gebaseerd op betere reinigingsstandaarden en op een rangorde systeem voor energie en water efficiency van gerelateerde hulpmiddelen. Meer toxicologische studies zijn nodig voor nieuw ontwikkelde oplosmiddelen, zoals ionische vloeistoffen. Dit houdt ook de enzymatische of op natuurlijke methoden geïnspireerde reinigers in. De specifieke hoedanigheid van die reinigers biedt hoge verwachtingen, maar het uiteindelijke milieuresultaat kan ook zorgen geven. Tenslotte, wetenschappers hebben bij het onderzoek van substraatoppervlakten innovatieve analytische middelen nodig om niet alleen `Hoe schoon is schoon?', maar ook `Hoe schoon is schoon genoeg?' te kunnen vragen.

Contents

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[1] Material Safety Data Sheets
[2] Toxicology, Occupational Medicine and Environmental Series®
[3] American Society for Testing and Materials

Executive Summary

The interactive matrix, *The Aqueous Way to Go* developed for this thesis, was shown to be a potentially useful web-based tool for the identification of safer and greener chemical cleaners. Originally intended for industrial parts cleaning, the tool was also successfully applied to institutional (i.e., janitorial) cleaning processes. The matrix was developed during a five-year evaluation of the Toxics Use Reduction Institute's Surface Cleaning Laboratory (SCL) at the University of Massachusetts Lowell. The author designed cleaning questionnaires for end users and suppliers, constructed a test protocol for aqueous cleaners and conducted a comparative investigation of non-aqueous cleaning alternatives. These endeavors required an understanding of state-of-the-art cleanliness inspection techniques, the details of which are provided.

The tool's effectiveness depends upon a number of factors. Access to the test databases of the SCL is important to (1) *decrease* the time allotted to the search for cleaning alternatives and (2) *increase* the proficiency of the final cleaner selection. Presentation of the matrix as part of a larger critical thinking methodology is also essential, since expertise in computer programming, product knowledge and cleaning skills vary widely among groups of stakeholders including governments, companies, researchers and cleaning practitioners recognized as target audiences.

Consequently, the methodology, *Critical Thinking for Cleaning Alternatives* conceived and successfully field-tested for this thesis is the best vehicle for implementing *The Aqueous Way to Go*. Based on a thorough grasp of chemical cleaners' environmental, health and regulatory issues, this training is an aid and not a substitute for application-specific testing. Education could expand to establish a network of publicly supported laboratories throughout the world for the elimination of hazardous solvents and the discovery of alternative composite surface materials.

As web-based chemical information becomes more reliable and easier to obtain, regulatory differences among nations may begin to diminish. In a global economy, chemical suppliers must offer various formulations to meet regional regulations. Selecting the safest substitutes may translate into requesting products sold to the country with the highest standards. To illustrate, the tool was able to rank the relative environmental, health and safety parameters of select detergents by conducting database searches on their individual chemical components. This assessment of cleaners, heretofore deemed uniformly safer and greener than their chlorinated-solvent counterparts, revealed that not all aqueous cleaners are created equal. Potential endocrine disrupters were detected in this way.

This holistic approach is somewhat limited by access to information contained in proprietary databases and English-only Material Safety Data Sheets. Policy makers should make every effort to disassociate chemical safety from the individual's ability to pay, to further the cause of *complete chemical disclosure*. For a truly sustainable society, there should be no difference in the risk of chemical exposure for the janitor making minimum wage and the cleanroom technician in the semiconductor industry.

The thesis' research confirms that the future of surface cleaning relies upon better cleaning standards and a ranking system for energy and water efficiency of related equipment. More toxicological studies are necessary for newly developed solvents such as ionic liquids. This includes the enzymatic or bio-inspired cleaners as well, whose specificity is a source of great hope but whose ultimate environmental fate may be a concern. Finally, innovative analytical devices are needed for scientists to examine substrate surfaces and ask not only, *'How clean is clean'* but also *'How clean is clean enough.'*

Foreword

Cornell University, located in New York state, is several hours drive from the Toxics Use Reduction Institute at the University of Massachusetts in Lowell. Accordingly, I planned to listen to audiotaped books along my trip. One in particular, *A Civil Action* by Jonathan Harr (Random House 1995), had caught my eye the day before in the neighborhood bookstore.

It was May 1996. I had been asked to present a paper about the application of 'green chemistry'[a] principles in laboratory management for the local chapter of the Association of Official Analytical Chemists (AOAC) that was holding its regional meeting at Cornell. I had not been working at the Institute for very long, and I was somewhat apprehensive.

But the day was beautiful for a long drive and when the reception to my favorite radio stations was lost, I loaded the tape into the cassette player. *A Civil Action* is a riveting tale of what can happen to people, especially children, when they are exposed to common industrial degreasing solvents. In this case, the contamination was via well water from businesses within the community of Woburn, Massachusetts. It chronicles the ordeal of several families as loved ones succumb to various forms of cancer. It follows their search for answers and for justice.

Being so touched by their story, I could not continue to drive and pulled off the highway to regain my composure. What right did I have to be apprehensive? More important than any presentation, any dissertation was the *raison d'etre* for the work I had embarked upon. As a mother, I needed no further inspiration.

Most forensic scientists concur: the victims are the true heroes. It is to their memory that I dedicate this thesis.

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Lowell, 18 January 2001

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[a] The term *'green chemistry'* was coined by Paul Anastas of the U.S. Environmental Protection Agency. Its usage assumes that most industrial chemical processes have negative environmental impacts that can be replaced with less polluting on non-polluting alternatives. See the American Chemical Society's web site http://www.acs.org/education/greenchem/epaprogram.htm and the Green Chemistry Institute at http://www.lanl.gov/greenchemistry for more information.

Acknowledgments

The author wishes to express her thanks to advisors, Professors Donald Huisingh of Lund University, Lund, Sweden and initiator of the Erasmus University International Off-Campus Ph.D. Programme in Rotterdam, the Netherlands and Kenneth Geiser of the Toxics Use Reduction Institute (TURI), University of Massachusetts, Lowell, USA. Many thanks as well to Leo Baas and Wim Hafkamp of Erasmus University, Center for Environmental Studies, Rotterdam, the Netherlands.

I would also like to convey my appreciation for the excellent technical advice of Dr. Gerard Zwetsloot of the Dutch Institute for the Working Environment, NIA, Amsterdam, the Netherlands. I am thankful, too, for the motivating lectures of Dr. Nicholas Ashford of the Massachusetts Institute of Technology, Cambridge, Massachusetts, USA and for the support of TURI's Associate Director, Dr. Michael Ellenbecker.

There is little doubt, however, that this work would never have been finished without the encouragement of fellow graduate students in the Cleaner Production, Cleaner Products, Industrial Ecology and Sustainability Ph.D. Program. I am deeply indebted to all of them.

This thesis would be incomplete without acknowledging the important contribution of the test databases created by Jason Marshall, TURI's Surface Cleaning Laboratory (SCL) Technician who is himself well on his way to receiving a Master's Degree from the University of Massachusetts. Diane Barrus, formerly of the Institute's Technology Transfer Center, ably assisted with literature searches and reference materials. Steven Greska, TURI educator and trainer, and Anne Basanese, the Institute's event coordinator, helped with the methodology's field testing.

Dr. John Bulko, my predecessor as the Institute's laboratory manager, masterfully outfitted the lab with processing and analytical equipment well suited to the task of solvent-substitution testing and surface-cleanliness inspection. The list of talented graduate students/lab interns participating in some of the projects included: Dr. Donald Garlotta, now working for the United Stated Department of Agriculture (USDA), Ramesh Sethuraman and Prashant Trivedi. TURI Research Associate Elizabeth Harriman was responsible for the initial vendor questionnaires of the cleaning industry and former SCL technician Jay Jankauskas applied his considerable computer skills to the development of this database.

More than anyone else, Joseph Sipitkowski of Micro Engineering (Southampton, Massachusetts) was instrumental in piquing my curiosity to explore all things aqueous with regard to industrial surface cleaning. Dr. John Stemniski, retired from the Charles Stark Draper Laboratories (Cambridge, Massachusetts) critiqued some of the manuscript and rendered the experienced counterpoint to ensure scientific objectivity.

The influence of many colleagues' work can be found within the pages of the text. This list includes but is not limited to Dr. John Durkee of Creative EnterpriZes (Lake Jackson, Texas), Barbara Kanegsberg of BFK Solutions (Pacific Palisades, California), Malcolm McLaughlin of Alconox, Inc. (New York, New York) and Harry Crossman formerly of Osram Sylvania (Beverly, Massachusetts).

Crossman, Stemniski and Sipitkowski have served on SCL's Advisory Committee. Erle Janssen, CIH (University of Texas at Austin) was most helpful concerning the potential spread of infection of resistant strains of microbes resulting from clean (i.e., hospital) conditions.

Excerpts of this document have appeared in issues of *Precision Cleaning* and *Parts Cleaning* Magazines as well as A^2C^2*: the Journal of Advancing Applications in Contamination Control*. My gratitude goes to Michael Christian of Witter Publishing Corporation (Flemington, New Jersey) and Patrick Murphy and Dorothy Rosa of Vicon Publishing, Inc. (Amherst, New Hampshire) in the USA.

AFL-CIO Local 254, a Service Employees International Union (SEIU) affiliate representing the professional staff on the Lowell University campus and the Massachusetts Women in Public Higher Education (MWPHE) graciously awarded partial funding for the conference travel required to participate in this doctoral program. Training in facilitative leadership at the Interaction Institute for Social Change (IISC) of Cambridge, Massachusetts helped focus the author's work, having written SCL's 'mission, vision and value' statements with their assistance. A copy of the thesis has been furnished to all three groups.

A special tribute is owed to the late Father William J. Sullivan, S.J., Director of the Boston College Cancer Institute, Chestnut Hill, Massachusetts, USA. My first employer as well as my mentor, Father taught me not *what* to think but *how* to think, a critical skill for an investigator. Often commenting that it was his job to make me a better scientist than he was himself, a goal I could not hope to attain, his words still challenge me today in dealing with my own students.

But perhaps most importantly, recognition is due to the Massachusetts state legislators for their visionary view of pollution prevention, leading to the passage of the Toxics Use Reduction Act (TURA) in 1989. None of this research would have been possible without this policy. As a consequence, the voluntary participation of Massachusetts' companies in the TURA solvent-substitution testing program provided the backbone for the thesis' empirical work.

Finally, I am very grateful to my children, Sarah and Jon, who have exhibited remarkable patience with their mother throughout this five-year period. God bless you both.

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1 General Introduction

This chapter serves as an introduction to the study. Its purpose is to familiarize the reader with the reasons leading to the investigation s (section 1.1), the formulation of the research hypothesis and the central scientific questions it poses (section 1.2) and the organization of material within the thesis (section 1.3).

1.1 Statement of the Problem

"There is still no universally accepted method of determining, *'How Clean Is Clean.'* " So ended the Eighth Annual International Workshop on Solvent Substitution and Eliminating Toxic Substances and Emissions in Phoenix, Arizona, USA with a quote from the Workshop Steering Committee President, Mr. Earl Groshart in December of 1997.[b]

Industrial surface cleaning is performed for a number of reasons. It may be required to prepare the surfaces of parts prior to other manufacturing processes such as welding or painting. It may be performed for aesthetic reasons as an aid to marketing and sales. Or it may be necessary to ensure that the finished product will perform without failure caused by contamination. As an engineer with the Boeing Company for many years, it is this final category that occupied Mr. Groshart's attention during his career.

Because of the serious mechanical accidents that can occur as a result of poor surface cleaning and/or inspection, almost all cleaning regimes are developed on an application-specific basis. Add to this already intense R&D effort, the highly competitive nature of aerospace industries, and solving cleaning problems *en masse* becomes a daunting task.

Nevertheless, much data on cleaning enterprises has been gathered by personnel within individual companies, defense contractors and the military service branches. Some government agencies have been instrumental in compiling these case studies into databases. Yet the information derived from them does not usually reveal the selection process of what chemical cleaners and cleaning equipment were tested and, equally importantly, how they were tested. The knowledge gained is often anecdotal and is not integrated into an on-going learning process.

This situation would continue to be true, without considering the negative environmental and health impacts associated with traditional methods of surface cleaning, discussed in this thesis.

Because most industrial cleaning occurs on metal substrates for the removal of lubricants, oils and greases, etc., petroleum-based and/or solvent-based chemicals have been routinely employed. The flammability and carcinogenicity of most of these substances were determined first, followed by the discovery of the destruction of the earth's ozone layer by halogenated solvents such as the chlorofluorocarbons (CFCs). As workers began to suffer with exposure to these agents (with ensuing

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[b] For more information on this annual international workshop, visit New Ideas in Pollution Regulation (NIPR) web site at http://www.worldbank.org/nipr/conferences/solventsubs.htm.

liabilities) and environmental legislation regulated their use, solving surface-cleaning problems efficiently and economically has become even more daunting and urgently needed.

The difficulty in finding safer substances and procedures for these chemicals is often reflected in companies' unwillingness to share success stories within their own business sectors. These sources of 'lessons learned' represent major outlays of time, labor and money.

1.2 Research Hypothesis and Central Scientific Questions

What is needed, then, is a more scientific yet holistic approach towards surface cleaning; taking into account all available technical and regulatory data while maintaining the necessary application-specific nature of this industrial practice. Doing so should enhance successful production and help to avoid contamination-related catastrophe for products, for the people who make and use them and for the environment.

Research Hypothesis

Consequently, will the development of a test-based tool/materials information methodology assist governments, companies, researchers and cleaning practitioners in the identification of more sustainable (i.e., greener and safer) cleaning chemicals and processes?

Central Scientific Questions

Specifically, will this methodology and/or tool:

(1) Decrease the time required to conduct a search for safer, greener chemical cleaners?
(2) Increase the proficiency and safety of the final selection?
(3) Reveal useful trends in cleaning applications?
(4) Uncover heretofore-unknown differences in cleaning systems?
(5) Expand to incorporate the discovery and testing of new cleaning chemicals and processes?

The Meanings of Terms

A *methodology* is a systematic application of a set of *related tools*, principles or practices. However, a *singular tool* or method (for example, a surface inspection technique) may or may not be part of a methodology. The term *method* may also be used to denote a test protocol. The terms *tool*, *matrix*[c] and *interactive matrix* are used interchangeably to describe the computer-enhanced program developed for this thesis.

1.3 Structure of this Thesis

As stated previously, this chapter serves as an introduction to the thesis. Chapter two is also an introductory chapter, providing the historical background in which the stage was set for the development of alternative cleaning chemicals and processes due to environmental, health and safety issues. Environmental regulatory efforts are traced on the international, national (i.e., United States) and, finally, on a state level in Massachusetts. Particular attention is paid to the role of the chorine atom in the debate, and a thorough treatment of chemical families and cleaning mechanisms is provided.

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[c] From the Latin, *mater* (mother). Webster's dictionary defines a matrix as "something within or from which something else originates, develops, or takes form."

The chemical cleaner's evolution culminated in the return to aqueous-based (i.e., water-based) cleaners described in chapter three. In this section, the activities of all important chemical constituents in aqueous and semi-aqueous cleaners are detailed, as well as the four major operating conditions of water-based cleaning: temperature, agitation, concentration and time, known collectively as *TACT*. A discussion of the critical nature of rinsing and drying cycles follows. Chapters two and three end with the investigator's observations.

Chapter four chronicles the work of the Toxics Use Reduction Institute's (TURI) Surface Cleaning Lab (SCL) at the University of Massachusetts in Lowell, MA following the development of a cleaning questionnaire by the author. Companies wishing to conduct tests with the SCL must complete this form. Chapter four also discusses the six primary cleanliness inspection methods used by this laboratory. Information on other surface analysis techniques is included to afford the reader a broader perspective.

Chapter five outlines the initial five-phase test method for aqueous cleaners created by the author for this study. This test method did, indeed, form the basis for future work performed by the Institute's laboratory. Chapters four and five contain results, conclusions and recommendations for each of the major sections.

Chapter six focuses on safer and greener cleaning methods that are not water-borne, specifically, blasting with crystalline sodium bicarbonate (baking soda) and extracting with supercritical carbon dioxide. In addition, the author undertook the development of new vendor questionnaires for (1) chemical cleaners, (2) cleaning equipment and (3) related products and services.

In the search for more sustainable cleaning practices, the use of sources of technical information such as Micromedex' database, the Toxicological, Occupational, Medical and Environmental Series (TOMES®) and the role of innovative support organizations like TURI is explained in chapter seven. A thorough examination of the specialty testing databases at the SCL is included. Examples of the kinds of experimental data obtained thus far and categorized by substrate surfaces are presented. Chapters six and seven contain results, conclusions and recommendations for each of the major sections.

Chapters eight and nine are concluding chapters. Chapter eight summarizes the research's most notable findings, that is, answers to the central scientific questions and, based on these results, proposes a decision-making tool or matrix known as *The Aqueous Way to Go*. The potentially interactive, web-based tool relies on a broader educational methodology designed by the author and known as *Critical Thinking for Cleaning Alternatives*. Chapter eight describes attempts in applying the tool and field-testing the methodology, revealing both the strengths and weaknesses of the entire decision-making process. It ends with an overview of the shortcomings of current aqueous-based cleaning technologies, in particular, water and energy consumption.

Chapter nine is the final chapter. Its purpose is to move the reader into the future, both in terms of (1) anticipated advances in research and development such as ionic liquids and (2) public policies such as the precautionary principle. Founded on evidence from the semiconductor industry's need for surface cleanliness many times greater than those required in surgical fields, this chapter also extrapolates the plausible effects on the people and the biological systems imposed by unnatural, super-clean regimes. Speculation, not conclusive evidence, is warranted.

Annexes

Following the epilogue, the thesis is concluded with a glossary of acronyms and terms, appendices of chemical and laboratory reports and forms, bibliography and the curriculum vitae of the author.

2 The Evolution, Exposure Consequences and Regulation of Cleaning Solvents

2.1 Water: The Universal Solvent

Water is considered, by many, to be the 'universal solvent', capable of dissolving many inorganic and some organic contaminants or 'soils.' Soils can be defined as any extraneous or unwanted material(s) deposited and/or attached to a substrate surface. But not all soils readily dissolve in water alone.

Soap is a natural cleansing agent produced by the reaction of an alkali, typically sodium hydroxide (NaOH) and animal fat or vegetable oil used to enhance aqueous (i.e., water-based) cleaning. The earliest literary reference to soap dates from the third millennium BC. Detergents, sometimes referred to as synthetic soaps, were first introduced in 1930 and were found to perform better than soaps in hard (i.e., mineral-laden) water because they contained water softeners to effectively treat magnesium and calcium carbonates, $MgCO_3$ and $CaCO_3$. The development of complex phosphates following World War II, primarily sodium tripolyphosphate $Na_5P_3O_{10}$, increased the detergents' cleaning power. Unlike more modern laundry detergents, these formulations contained 'phosphate builders', not often found in soaps that contributed to the accelerated eutrophication of rivers, lake and streams throughout Europe and the Americas since they contained phosphorus, an essential nutrient for algae and other water plant growth.

In addition to soaps, some terpenes, natural organic compounds occurring in the essential oils and oleoresins of plants (lemon, orange) and conifers (balsam, pine) have solvating powers. Unsaturated hydrocarbon polymers of isoprene (C_5H_8), terpenes can be constituents in semi-aqueous cleaners. These materials are discussed in more detail in chapter three.

2.2 Organic and Chlorinated Industrial Cleaner Solvents: Like Dissolves Like

The principle of 'like dissolves like' was quickly ascertained by simple visual observation in the search for cleaning materials. 'Natural' soaps and detergents simply did not dissolve greases and oils, common industrial contaminants, on their own.

Halocarbon chemistry played an important role in the development of synthetic cleaners when in the 1890's researcher F. Swarts discovered that the C-F bond could be formed by the stoichiometric reaction of SbF_3 with activated C-Cl bonds:[2]

$$CHCl{=}CClCCl_3 + SbF_3 \longrightarrow CHCl{=}CClCF_3 + SbCl_3$$

He then determined that the addition of trace quantities of pentavalent antimony as a fluorine carrier allowed the reaction to be extended to other chlorocarbons:

$$CCl_4 + HF \xrightarrow{SbCl_5} CF_xCl_{4-x}{=}xHCl$$

In this manner, carbon tetrachloride (CCl_4) also known as 'carbon tet' or tetrachloromethane, became the chemical precursor of $CFCl_3$ (CFC-11) and CF_2Cl_2 (CFC-12). 'Carbon tet' was first produced in Germany in 1839 and marketed under the trade name Katharin as a grease remover. It is obtained by chlorinating carbon bi(di)sulfide (CS_2), itself a valuable but flammable and toxic rubber solvent made by heating carbon and sulfur together.[3] Carbon tetrachloride is an important solvent for fats and oils, asphalt, rubber, bitumens and gums and it is used as a degreasing and cleaning agent in the dry-cleaning and textile industries. Although it is notable as a nonflammable solvent for many materials sold in solution, its vapors are highly toxic.

Swarts' work laid the foundation for the first commercial refrigeration systems, some thirty years later that utilize, among other compounds, CH_3Cl, C_2H_2Cl, CH_2Cl_2 and hydrocarbons. These flammable and toxic chemicals were replaced in home refrigerators in 1928 by CCl_2F_2 (CFC-112) and promoted as a joint venture by DuPont and General Motors, owner of Frigidaire. Over the next 50 years, continuous reactor processes were developed to control the degree of fluorination of the carbon molecule for the manufacture of CFC-11, CFC-12, $CF_2ClCFCl_2$ (CFC-113), CF_2ClCF_2Cl (CFC-114) and CF_3CF_2Cl (CFC-115). While most of the synthesized compounds possessed refrigerant or propellant properties of the freon series, some, like CFC-113, exhibited unique characteristics as a solvent and cleaning agent (Figure 2.1).[4]

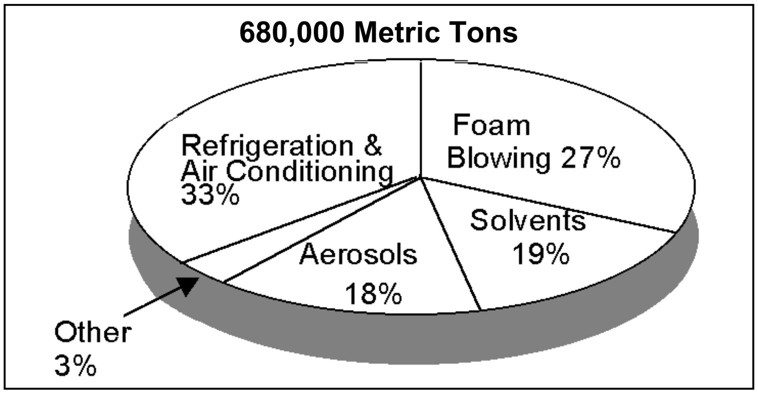


Figure 2.1 WORLDWIDE CFC USAGE BY APPLICATION IN THE 1990s[5]

The CFC-alternative, CHF_2Cl (HCFC-22) was mass-produced based on the same initial stoichiometric reaction between $SbCl_2F_3$ and CCl_4, whereby carbon tetrachloride and hydrogen fluoride/ hydrofluoric acid gas (HF) were continuously fed to a reactor containing pentavalent antimony. Chemical precursors might include the resin-dissolver $CHCl_3$, widely known as the anesthetic chloroform (or trichloromethane or methenyl trichloride). Cleaning solvent trichloroethane $C_2H_3Cl_3$ known as TCA (or methyl chloroform or MCF), used in the metal working trades, was also the raw material for CFC alternatives. The dry cleaning solvent perchloroethylene (PCE or 'perc'), still used in the textile industry, likewise became the raw material for CFC-113.

Thus, while attempts were made to make the finished products 'safer', that is, less toxic or less dangerous to handle, the hazardous nature of their common chemical feedstocks was apparent prior to the determination of HCFCs' ozone depletion potential (ODP). The following diagram

(Figure 2.2) illustrates the complexities and interactions of the chemical synthesis routes for CFCs, HCFCs and related compounds.

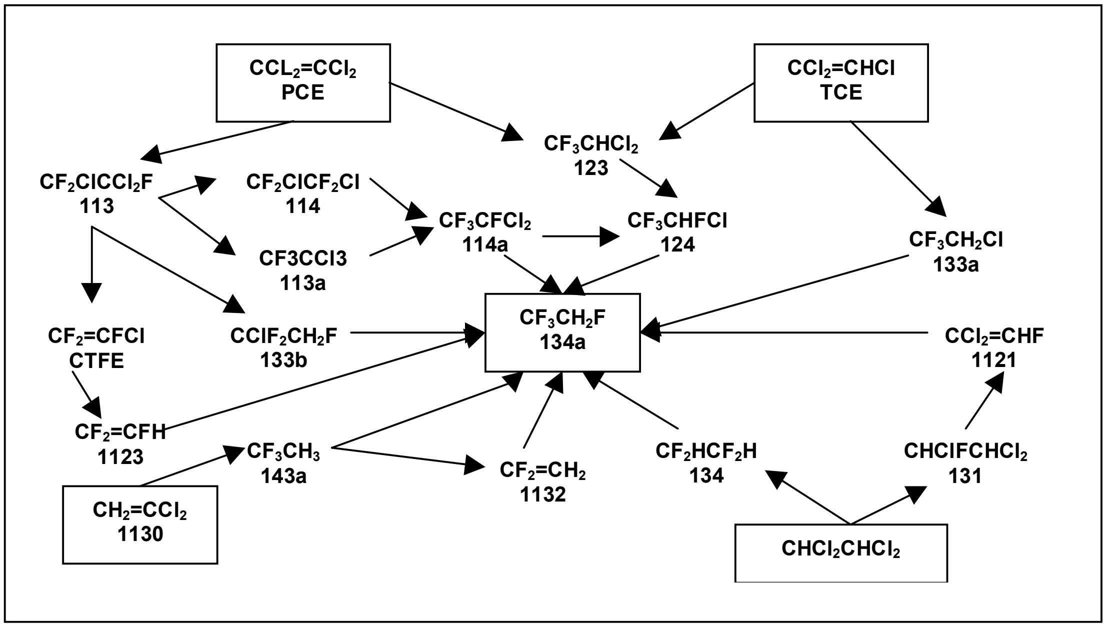


FIGURE 2.2 POTENTIAL CHEMICAL SYNTHESIS ROUTES OF CFC-RELATED PRODUCTS[6]

2.3 Characterization of Chemical Types

The carbon atom forms the basis for all life and chemistry on earth. The length of the carbon chain and the kinds of chemical attachments emanating from it determine, in large part, the behavior of a particular substance.

Hydrocarbons can be derived from petroleum, coal and natural gas. They are compounds containing only carbon and hydrogen molecules, the simplest being methane gas, CH_4. Aliphatic or fatty acid-based hydrocarbons such as mineral spirits are used in cleaning operations. They are distinguishable from the aromatics (toluene, $CH_3C_6H_5$, benzene C_6H_6, and xylene $C_6H_4(CH3)_2$ family of compounds also used as solvents) by the absence of a fused ring system.

Carbon tetrachloride (CCl_4) is an example of a **halocarbon** or, in this case, a fully **chlorinated hydrocarbon** containing carbon and chlorine. Other halogenated compounds containing fluorine or bromine demonstrate good cleaning ability but represent no improvement in health or environmental considerations. Carbon tetrachloride is also a volatile organic compound (VOC). Evaporating into the atmosphere at ambient conditions, VOCs include almost all cleaning solvents as well as fuels. Ozone, the primary component of smog, can be formed when VOCs are released and undergo photochemical reactions with atmospheric oxides of nitrogen. The calculation of the amount of VOC in a particular product or process is therefore important.

Chlorofluorocarbons (CFCs) differ from chlorinated hydrocarbons by the insertion of fluorine, as previously discussed. **Hydrochlorofluorocarbons** (HCFCs) are similar to CFCs except that some of the chlorine (and fluorine) atoms are substituted with hydrogen. Touted as less toxic replacements for ozone depleting substances (ODSs) like the CFC solvents, the reduction in chlorine or fluorine accomplished by the addition of hydrogen molecules decreased but did not eliminate the compounds' ozone-layer damaging effects. **Hydrofluorocarbons** (HFCs), other potential CFC alternatives, can be produced via HCFCs and CFCs synthesis routes as well. Though they contain no chlorine, their high vapor pressure and low solubility make them poor cleaners, with the possible exception of HFC-4310.

Chlorofluorocarbons (CFCs) and **hydrochlorofluorocarbons** (HCFCs) also contribute to global warming. The numeric values attributed to a halogenated solvent's atmospheric lifetime and global warming potential (GWP) can be used to determine its environmental consequences. Many HCFCs used for solvent cleaning are blends or azeotropic mixtures containing alcohols and/or ethers. The ODPs and GWPs of these mixtures can be obtained by taking the individual characteristics for each chemical, multiplying by their respective weight fractions and summing them together.[8]

Some common chlorinated solvents are listed in Table 2.1. The ODPs and GWPs of many of these compounds can be found in Table 2.2.

Common Name	Chemical Name	Chemical Formula
CFC-11	Trichlorofluoromethane	CCl_3F
CFC-12	Dichlorodifluoromethane	CCl_2F_2
HFC-134a	Tetrafluoroethane	CH_2FCF_3
HFC-152a	Difluoroethane	CH_3CHF_2
HCFC-22	Chlorodifluoromethane	$CHClF_2$
HCFC-123	Dichlorotrifluoroethane	$CCHCl_2CF_3$
HCFC-124	Chlorotetrafluoroethane	$CHClFCF_3$
HCFC-141b	Dichlorofluoroethane	CH_3CCl_2F

Table 2.1 CHEMICAL NAMES AND FORMULAS FOR COMMON CFCs/HFCs/HCFCs

Hydrofluoroether (HFE) or $C_4F_9OCH_3$ (methoxynonafluorobutane, iso and normal) is a halocarbon acknowledged in 1996 as a potential replacement solvent for methyl chloroform and CFC-113 in metal, electronic and precision cleaning applications. It has a GWP of 150-480 based on a 100-year horizon and an atmospheric lifetime of 4.1 years.[9] **Perfluorocarbons** (PFCs), which contain only carbon and fluorine atoms, also exhibit good cleaning properties. Extremely inert and therefore not viewed as a danger to the ozone layer, their atmospheric lifetimes are thought to be thousands of years and so these compounds have a very strong potential for enhancing global warming.

In addition to the above-mentioned compounds, **brominated hydrocarbons**, for example, dibromomethane (methylene bromine or CH_2Br_2) are also used for cleaning, although on a much smaller scale. Bromination may be several times more damaging to atmospheric ozone than chlorination.[8]

Section 2.5 contains more information on the environmental effects of different solvent types.

2.4 Modes of Solvency vs. Methods of Cleaning

Solvency is defined as the ability to dissolve. A solvent is a substance, usually a liquid that is capable of dissolving another substance and forming a homogeneous mixture called a solution. The mixture is physical and no chemical action takes place since the principal qualification of a solvent is that it must be able to dissolve something without reacting with it. Some materials are soluble in certain other materials in all proportions, while others are soluble only up to a definite percentage and the residue is precipitated out of solution.

A second important characteristic of a solvent is its volatility, as judged by its boiling point. Solvents that have reasonably low boiling points can be more readily removed from a reaction mixture by distillation or evaporation. The most common application for industrial cleaning solvents is to put dirty solid matter (parts, products, etc.) into a solvent for dissolving surface foreign matter, leaving the clean substrate hopefully unchanged and undamaged after removal of the solvent and the soil.

Organic Solvents
As already discussed, the traditional solvents for the removal of organic materials are alcohols (e.g., methanol), benzene, turpentine and ether. Another compound, methyl ethyl ketone $CH_3COC_2H_5$ (MEK), also known as ethyl methyl ketone or 2-butanone (derived from the dehydration of 2-butanol or the oxidation of n-butenes in the presence of an alloy catalyst) deserves mentioning in this class of solvents, a favorite for clean up of paints, oils, resins and celluloses.

Chlorinated Solvents
Chlorinated fluorocarbons (CFCs) are a particular type of organic solvent that have powerful solvating action on fats, waxes and oils. In addition to the HCFCs previously mentioned, trichloroethylene or TCE ($Cl_2C{=}CHCl$) is of major commercial significance in metal cleaning. The dry-cleaning fluid PCE is a mixture of trichloroethylene and tetrachloroethylene ($Cl_2C{=}CCl_2$) used because of its non-flammability, high solvency, vapor pressure and stability. Dichloromethane (CH_2Cl_2), also known as methylene chloride is another colorless, nonflammable liquid (boiling point 39.8^o C) that is soluble in alcohol and is used in paint removal, dewaxing and degreasing as well as a refrigerant.

Besides immersion, vapor degreasers are employed with this type of industrial cleaning but their mechanical action can be viewed as secondary because of these solvents' excellent solvating powers. In the vapor phase cleaning process, the final rinse of the parts being cleaned is achieved by condensing solvent vapors on the parts.

Aqueous Cleaning
Surface cleaning or degreasing can be defined as the removal of contamination, or unwanted

material, from a surface.[10] The process of lifting soil from a surface by displacing it with surface-active materials that have a greater affinity for the surface than they do for the soil is known as **detergency**.

Differing from the prior two categories, aqueous cleaners may not depend on solvent penetrability for their cleaning efficiencies. Aqueous cleaners containing detergents are more complex and are usually mixtures containing surfactants, alkaline or other 'builder' materials, and sometimes non-aqueous components.

Detergents rely on a combination of processes such as: solubilization, wetting, emulsification, deflocculation, sequestration and saponification.[11]

Semi-Aqueous Cleaning

Semi-aqueous cleaning incorporates the principles of aqueous and organic cleaners. This is accomplished by combining a surfactant with a low-volatility hydrocarbon such as a terpene, in particular, limonene and pinene (citrus or pine in origin), to form a cleaning blend. Terpenes are homocyclic hydrocarbons with the empirical formula $C_{10}H_{16}$ having a characteristic odor; turpentine is an illustrative solvent that is a mixture of terpenes.

Unlike traditional vapor degreasing, cleaning with semi-aqueous cleaners does not rely on boiling liquids nor is it restricted to a constant boiling composition. In its simplest form, semi-aqueous cleaning involves two steps: (1) the organic component to dissolve the soil and (2) the water component to remove the residues of the blend and any other water-soluble soils.[12] The surfactant ensures the water-solubility of the otherwise insoluble hydrocarbon.

Aqueous and semi-aqueous cleaning processes are also discussed in chapter three.

2.5 Environmental and Health Effects

The rationale of the following sections on ozone depletion and global warming, as these two phenomena pertain to solvent usage, is to present the scientific data in an objective setting. So much disinformation is still promulgated by chemical manufacturers that the public misunderstands or does not accept many of the sciences' well-established tenets. Without this explanation, the purpose of a search for greener solvents remains unclear.

2.5.1 Atmospheric Ozone Depletion and the Role of the Chlorine Atom

The toxicity and flammability of petroleum-based cleaning solvents were discerned from the Industrial Revolution.[13] The CFC solvents developed to replace them proved to be one of the most useful classes of compounds ever developed: they were nonflammable, non-corrosive and low in relative toxicity.[14] They were also readily available, rather inexpensive and quite stable.

It is precisely because of their chemical stability that CFCs have long atmospheric residence times. Chlorofluorocarbon releases, emanating mostly from the northern hemisphere, tend to accumulate in the lower or tropospheric atmosphere.

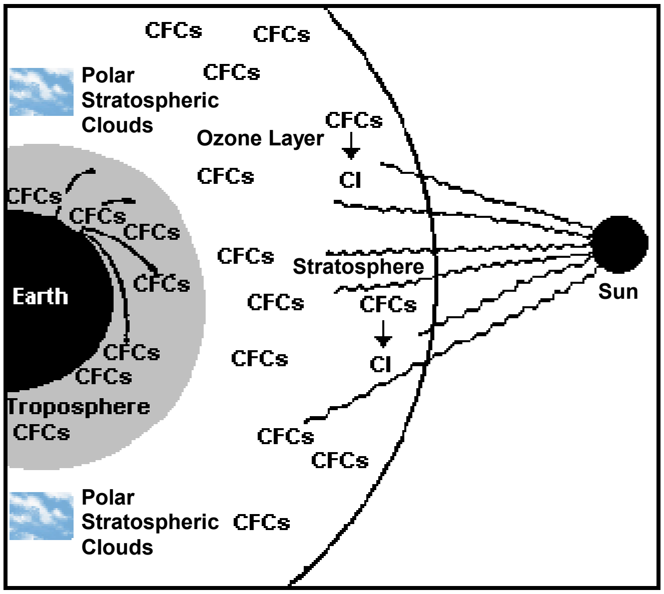


Figure 2.3 THE OZONE LAYER SHIELDS EARTH FROM MOST UV SOLAR RADIATION[19]
But CFCs slowly mix in the upper or stratospheric atmosphere where they dissociate, freeing chlorine atoms that may then catalyze the destruction of the earth's protective ozone (O_3) layer.[15]

While the more prevalent atmospheric oxygen (O_2) blocks ultraviolet (UV)light, only ozone absorbs in the 280 nanometer (nm) to 320 nm range, providing a filter against potentially harmful UV-B radiation (Figure 2.3).[16] Approximately 90% of all ozone is located in the stratosphere with an average concentration of only 3 parts per million (ppm), peak concentrations reaching 10 ppm at 15 kilometers (km) to 25 km, at polar to equatorial latitudes, respectively.[17] Chronic UV-B exposure poses risks to the environment in terms of reduced or inhibited photosynthesis by phytoplankton at the bottom of the food chain and to human and animal health, causing some forms of cancer (skin melanomas), eye cataracts and DNA (immunogenic) damage.[18]

Briefly, ozone is continually produced in the stratosphere where UV radiation dissociates molecular oxygen to form atomic oxygen:

$$O_2 + hv \longrightarrow O + O$$
$$O + O_2 \longrightarrow O_3$$

These reactions occur rapidly over the tropics, where solar radiation is intense. But even though most ozone is produced at low latitudes, it is more abundant at higher latitudes because circulation in the stratosphere constantly moves ozone away from the equator and towards the poles. In addition to regional differences in stratospheric ozone concentrations, seasonal fluctuations occur. Variations can be as great as 25% at high latitudes except Antarctica where, in 1985, the British Antarctica Survey discovered ozone levels drop by as much as 50% within a few weeks each spring, and now forms a 'permanent' hole.[16]

Ozone is destroyed when it absorbs UV light that would otherwise reach the earth's surface:

$$O_3 + hv \longrightarrow O_2 + O$$

There is no net ozone depletion since this process produces atomic oxygen that can react with molecular oxygen to form yet another ozone molecule. Problems arise with the introduction of other chemicals, both man-made and naturally occurring radicals (halogens, nitrogen, hydrogen and oxygen) that increase the rate of ozone destruction in the upper atmosphere.

Fully halogenated compounds are particularly destructive because they are essentially inert in the troposphere until they randomly reach the stratosphere. After rising above most of the ozone layer, CFCs are photolyzed by ultraviolet light, producing chlorine atoms. In the case of CFC-12, for example:

$$CCl_2F_2 + hv \longrightarrow CClF_2 + Cl$$

These halogen atoms can combine with a hydrogen atom from methane gas (CH_4) and form hydrogen chloride (HCl) or they can participate in the catalytic destruction of ozone for a net loss:

$$\begin{aligned} Cl + O_3 &\longrightarrow \mathbf{ClO} + O_2 \\ \mathbf{ClO} + O &\longrightarrow Cl + O_2 \\ \hline O_3 + O &\longrightarrow 2O_2 \end{aligned}$$

Known as the *ClO_x chain reaction* and identified in the laboratory over 50 years ago, its incidence in the stratosphere was hypothesized by Cicerone and Stolarksi in 1973.[20] As in any chemical catalysis, only minute amounts of catalytic material are required to continue the process almost indefinitely: reactive halogenated materials are regenerated on either side of the equations so that one chlorine atom can literally destroy 100,000 ozone molecules. Thus, HCFC and HFC usage in place of CFCs reduces but does not eliminate these photochemical reactions.[8]

Statistical analyses calculating the long-term effects of ozone depleting substances (ODSs) must factor in other complications, including the eleven-year solar cycle as well as regional differences. Ozone measurements are recorded in Dobson units (D.U.), named after Britain's Gordon B. Dobson who began his atmospheric studies in Antarctica in the 1950s (Figure 2.4).[21]

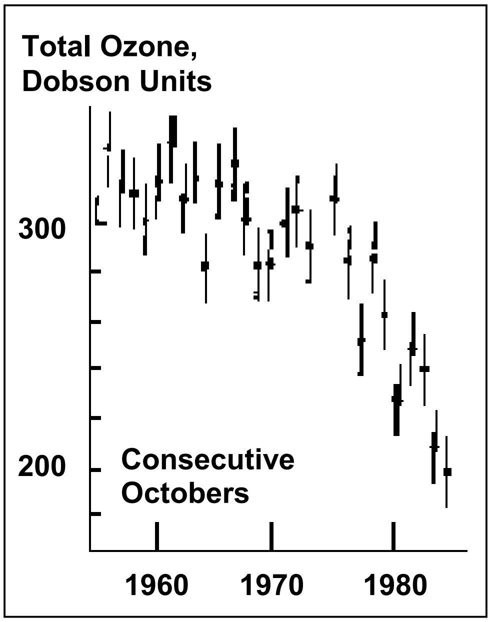


Figure 2.4
ANNUAL SEASONAL
OZONE MEASUREMENTS AT
HALLEY BAY, ANTARCTICA (1957-1984)[16]
Refer to Figure 2.5 for more current data

In the Antarctic stratosphere, the major ozone destructive cycle depends upon the reaction of chlorine monoxide with itself to regenerate chlorine atoms:

$$\begin{array}{lll}
2\,(\mathrm{Cl} + \mathrm{O_3} & \longrightarrow & \mathrm{ClO} + \mathrm{O_2}) \\
\mathrm{ClO} + \mathrm{ClO} & \longrightarrow & \mathrm{Cl_2O_2} \\
\mathrm{Cl_2O_2} + \mathrm{hv} & \longrightarrow & \mathrm{Cl} + \mathrm{ClOO} \\
\mathrm{ClOO} & \longrightarrow & \mathrm{Cl} + \mathrm{O_2} \\
\hline
2\mathrm{O_3} + \mathrm{hv} & \longrightarrow & 3\mathrm{O_2}
\end{array}$$

The release of atomic bromine (from brominated fluorocarbons, etc.) causes even more ozone-destroying phenomena, similar to the $\mathrm{ClO_x}$ chain reaction.

Supersonic planes exhausting nitrogen oxide into the stratosphere present a special consideration since nitrogen dioxide can react with chlorine monoxide to form chlorine nitrate. Typically inert, it reacts during the deep Antarctic winter to form molecules that dissociate into the active chlorine radicals upon exposure to light (hv):

$$\begin{array}{lll}
\mathrm{ClONO_2} + \mathrm{HCl} & \longrightarrow & \mathrm{Cl_2} + \mathrm{HNO_3} \\
\mathrm{Cl_2} + \mathrm{hv} & \longrightarrow & 2\mathrm{Cl}
\end{array}$$

The destructive nature of CFCs in the upper atmosphere was first suspected in 1974 by F. Sherwood Rowland and Mario J. Molina of the University of California, Irvine.[22] By 1988, data from the U.S. National Aeronautics and Space Administration (NASA) revealed that ozone had decreased 2.5% globally between 1969 and 1986 (Figure 2.5).[23] Researchers determined that substances containing chlorine and less-prevalent bromine were associated with more significant ozone losses over Antarctica, the hole that was first reported in 1985. Evidence confirming CFCs as a causal agent to that damage was discovered by Susan Solomon of the U.S. National Oceanic and Atmospheric Administration (NOAA) on two polar expeditions by 1987.[24,25] That same year, an ozone-depleted air mass originating from Antarctica reached Melbourne, Australia resulting in the lowest summer ozone readings ever recorded for that city.

By 1991, NASA satellite information concluded that the rate of ozone destruction was accelerating over other populated areas. In February of 1992, NASA scientists found that active ozone levels persist at very high concentrations in the stratosphere, which led them to predict that an Arctic ozone hole would develop in this decade, the milder polar vortex air stream in northern winters having prevented major ozone losses thus far. Variations in land mass and, therefore, cloud formation (upon which ultraviolet photolysis can occur in the stratosphere) between the poles is responsible for this climatic difference. Ozone declines were especially pronounced in late 1992 and early 1993 in the northern hemisphere's mid-latitudes, 13-14% below normal, the lowest readings NASA had observed in 14 years.[26] A volcanic eruption in 1991, Mount Pinatubo in the Philippines, may also have been a contributing factor by affecting wind patterns and/or accelerating chlorine-catalyzed ozone destruction

None of these detrimental decreases in upper/stratospheric ozone should be confused with reductions sought in lower/tropospheric ozone levels due to air pollution concerns.

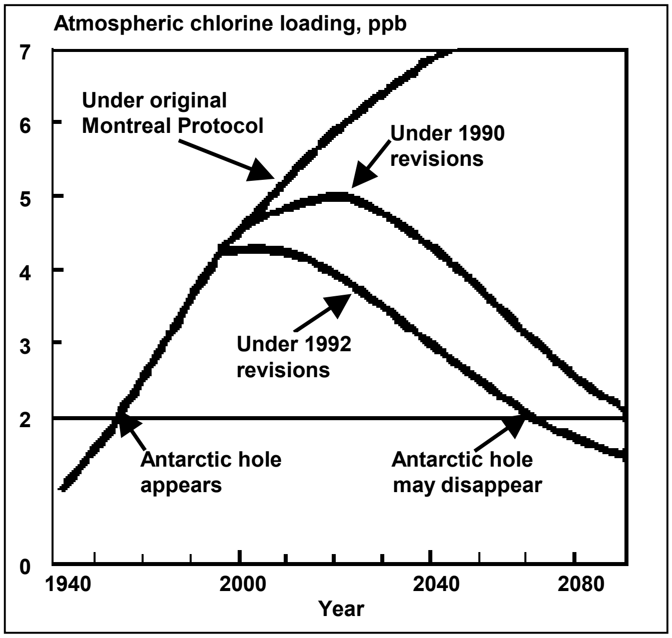


Figure 2.5 CHLORINE PEAKS BY YEAR 2000 BUT ANTARCTIC OZONE HOLE PERSISTS[19]
For the past 50 years, stratospheric chlorine background concentrations have increased from 0.5 parts per billion (ppb) to 3.5 ppb. Chlorine levels will continue to rise until the end of this century and it is estimated that it will take several hundred years before the atmosphere is free of CFCs and halons, even after their production stops.

In 1994, American and Australian researchers reported that the breakdown products of HCFCs and HFCs might also deplete ozone.[26] If correct, the ODPs of HCFCs, now accurate only to a 10%-20% range, would need to be revised upward. Long-lived, high ODSs like HCFC-142b that are relatively unreactive in the troposphere may have an insignificant impact on ozone layer depletion whereas short-lived, low ODSs like HCFC-123 could have a dramatic effect because they are highly reactive and readily attacked by the hydroxyl radical in the lower atmosphere.

The proposed mechanisms for ozone depletion by HFCs in the stratosphere is the oxidation of the radical CF_3 resulting in the production of by-product CF_3O followed by the reaction:

$$CF_3O + O \longrightarrow CF_3 + O_2$$

Thereby utilizing an oxygen atom that could otherwise generate ozone; or, by reacting with ozone itself which may lead to the catalytic loss of ozone:

$$CF_3O + O_3 \longrightarrow CF_3O_2 + O_2$$
$$CF_3O_2 + NO \longrightarrow CF_3O + NO_2$$

Subsequent trials revealed an upper limit for the ODP of HFC-134a (by the reaction of CF_3O and O_3) somewhat below the ODPs from HCFCs -123 and -124 (due to Cl release). This means that the ODPs of HFCs probably lie between zero to below that of the least-active HCFCs. As of this writing, most scientists concur that the chief chemical of concern, the CF_3O radical, would preferentially react with NO (or CH_4), rather than ozone.

2.5.2 Global Warming and Acid Rain

Increased Global Warming

Ozone absorbs much of the UV radiation entering the earth's atmosphere and indirectly converts it to heat, especially at altitudes between 35 km and 50 km. This heat source high in the atmosphere is responsible for the existence of the stratosphere, a region characterized by temperature inversions with lows of –60° C to –75° C at the bottom (the tropopause) and temperatures close to 0° C at the top. Conversely, tropospheric temperatures decrease steadily from an average of 15° C near the planet's surface to the much colder conditions at the tropopause.

The primary radiation given off by a planetary body is dependent upon its surface temperature. The sun gives off visible radiation at 5727° C while the earth gives off infrared (IR) radiation at 15° C. Natural laws governing a balance of energy for the two bodies require that (1) the total amount of energy absorbed by the sun equals the energy radiated back into space OR (2) the earth warms steadily until its IR emissions, favored by higher temperatures, balance the energy coming from the sun. The prime IR absorbers in the earth's atmosphere are gases, carbon dioxide (CO_2), ozone and water (H_2O). Gaseous absorption is not uniform at all wavelengths. It is most efficient when a compound's IR frequency approximates the oscillary vibrations in the trapping or absorbing molecule. Satellite observations confirm that IR energy escaping into outer space is substantially reduced at the wavelengths analogous to the vibrational frequencies of O_2 , O_3 and H_2O. It is estimated that the temperature of the earth's atmosphere would be 35° C lower without this natural "greenhouse effect" of gaseous infrared absorbers.[16] This phenomenon is more commonly referred to as global warming (Figure 2.6).

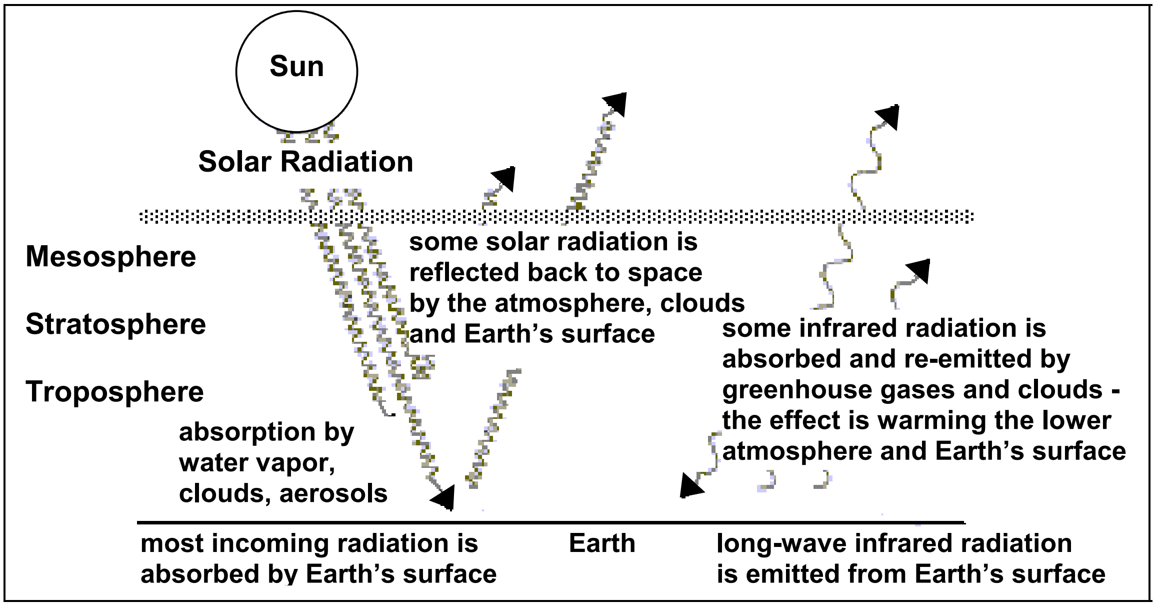


Figure 2.6 THE GREENHOUSE EFFECT[18]

Some solar radiation is captured by the earth's carbon dioxide-rich atmosphere, causing worldwide temperature increases.

The development of a numeric GWP system made possible the measurement of the emissive effects of trace gases on future global warming trends relative to an emission of a standard gas of equal mass. Carbon dioxide, the major contributor to global warming, is typically used as the reference gas. To illustrate, the 100-year GWP of CFC-113 ($C_2Cl_3F_3$) is 5000 which means that a one-time release of 1.0 kilogram (kg) of CFC-113 is equal to the emissive effects over the next 100 years of a one-time release of 5000 kg of CO_2. This notion is further complicated by the fact that different gases are eliminated from the atmosphere at different times and by different processes and different rates.

The use of carbon dioxide as a reference point is also useful since many of man's activities such as product manufacture require energy and CO_2 emissions are well established for a corresponding use of fossil fuel (coal, gas and oil) and the generation of electricity. The indirect effects of carbon dioxide emissions from lifetime energy use plus the direct effects of the release of greenhouse gases (GWP x the released mass) equals an index for the total equivalent warming impact (TEWI).[27] Due primarily to the continued and increased combustion of fossil fuels, CO_2 concentrations in the global atmosphere were observed to be steadily on the rise throughout the 1960s and 1970s. In 1973, Ramanathan reported that the elevation in atmospheric concentrations of CFCs was a significant finding because these molecules are capable of absorbing IR radiation emitted from the earth.[28] The energy of this radiation is not sufficient to destroy the CFC molecules but is converted to heat instead. Other studies during the 1980s showed that several other gases, including CFCs, contribute to the atmosphere's infrared absorption properties. The combined IR trapping of several gases makes substantial global warming more ominous than anticipated solely from an increase in CO_2 levels: if more radiation is intercepted, then the earth's temperature must increase proportionally and more IR radiation must escape through the invisible wavelengths to reach a new energy balance (to compensate for the reduced atmospheric transmission in the intercepted wavelengths).

Carbon dioxide absorbs most if not all of the radiation, which matches its vibrating signature. CFCs, present in the atmosphere at much lower concentrations than CO_2 (1: 1,000,000), capture terrestrial radiation at wavelengths not covered by the absorption of carbon dioxide, ozone or water vapor. Even small additions of these chemicals in the atmosphere are therefore bound to act at full absorption capabilities. Per molecule, CFC absorption is approximately 15,000 times greater than carbon dioxide's. Between 1980 and 1990, CFC emissions were responsible for 24% of the total increase in global warming trends.[27] However, CO_2 remains the main contributor despite its inefficiency per added molecule simply because increases in CO_2 releases relative to CFCs are 100 times greater.

The role of second-generation solvent replacement substances in global warming is more complex and difficult to ascertain. Some HCFCs and HFCs can be oxidized in the lower atmosphere. Specifically, the hydrogen bonding sites afforded by these compounds provides an attack point for possible early destruction in the troposphere. For HCFC-22, the hydroxyl radical (HO) attack on its C-H bond can be shown as follows:

$$HO + CHClF_2 \longrightarrow H_2O + CClF_2$$

The resultant species may then be 'rained out' of the atmosphere. The degree of reactivity of the

C-H bond depends on the particular hydrochlorofluorocarbon and hydrofluorocarbon so that HCFC and HFC atmospheric lifetimes can be estimated by measuring their reactivity rates with HO in the laboratory. HCFCs generally have about one-tenth the atmospheric lifetimes of the CFCs (Table 2.2).

Chemical Name	Formula <mol.weight>	Synonyms	CAS # Chem. Abstract	ODP (CFC 11=1)	*GWP (CO_2 = 1)	Atmospheric Life
Chlorodifluoromethane	CHClF2 <86.47>	HCFC-22 Freon 22	75-45-6	0.05	1700	15.3 years
2,2-Dichloro-1,1,1-trifluoroethane	C2HCl2F3 <152.93>	HCFC-123 Freon 123	306-83-2	0.02	93	1.6 years
2-Chloro-1,1,1,2-tetrafluoroethane	C2HClF4 <136.48>	HCFC-124 Freon 124	2837-89-0	0.02	480	6.6 years
1,1-Dichloro-1-fluoroethane	C2H3Cl2F <116.95>	HCFC-141b Freon 141b	1717-00-6	0.12	630	7.8 years
1-Chloro-1,1-difluoroethane	C2H3ClF2 <100.50>	HCFC-142b Freon 142b	75-68-3	0.06	2000	19.1 years
3,3-Dichloro-1,1,1,2,2- & 1,1,2,2,3-pentafluoropropane	C3HCl2F5 <202.94>	HCFC-225ca and HCFC-225cb Isomeric blend	422-56-0 ca isomer 507-55-1 cb isomer	0.03 ca 0.03 cb	170 ca 530 cb	1.6 years ca isomer 5.1 years cb isomer
1,1,2-Trichloro-1,2,2-trifluoroethane	C2Cl3F3 <187.38>	CFC-113	76-13-1	0.80	5000	90 years
1,1,1-Trichloroethane (TCA)	C2H3Cl3 <133.42>	Methyl (MCF) chloroform	71-55-6	0.10	110	6.3 years

*Based on 100-year horizon As of October 1996

Table 2.2 SUMMARY OF RELEVANT HCFC/CFC ENVIRONMENTAL DATA[29]

Acid Rain

Air pollution from the burning of fossil fuels is the major cause of acid rain. Acid rain is defined as the mildly acidic (pH < 5.0) solution falling to the earth's surface in the form of precipitation such as rain, snow and fog. It accounts for approximately 50% of all falling acidity, its corrosive nature intensifying as it concentrates with other acidic gases and dry depositions. Accelerated by sunlight, the formation of acid rain usually occurs in high clouds where water, oxygen and oxidants react with the main pollutants sulfur dioxide (SO_2) and nitrogen oxide (NOx).[30]

Of the two chemicals, NOx is also an emission of supersonic planes flying in the stratosphere and is reactive with the chlorine monomer active in ozone depletion. Whether the processes for ozone depletion and the formation of acid rain are complimentary, competitive or unrelated is presently unknown. The particle emission parameters of the aircraft are not well understood since ground-based tests cannot duplicate the growth and coagulation of reactive gases and particulates for particle number, size and composition of the exhaust plume as it enters the surrounding atmosphere.[31] Further study is urgently needed.

2.5.3 Terrestrial and Aquatic Habitat Impacts

The effects of ozone depletion and global warming are inextricably linked to the welfare of mankind. For instance, it is estimated that a 3-degree rise in global temperature could double the incidence of disease carried by the mosquito.[18] Most communicable diseases could be spread more widely, with a climate-related increase in respiratory ailments and incidents of life-threatening heat stress. Rising sea levels will make many areas uninhabitable by man and other wildlife, destroying entire ecosystems. A summation of these effects is presented in Figure 2.7.

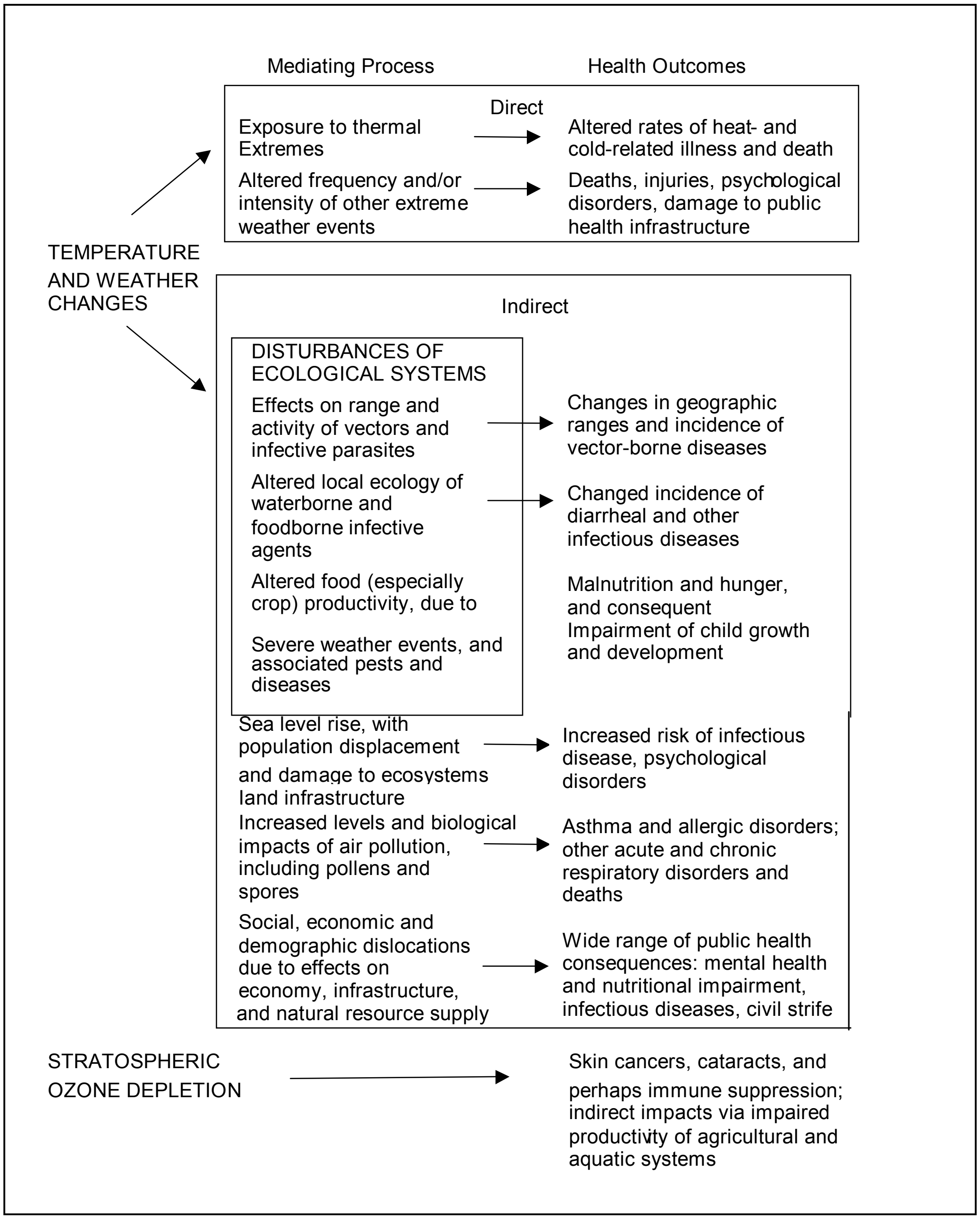


Figure 2.7 POSSIBLE HUMAN-HEALTH IMPACTS FROM CLIMATIC CHANGES[18]

In September of 1992, ozone values over South America were 30%-35% lower than normal. Unconfirmed reports of skin lesions in humans and blindness in animals were filed in Punta Arenas, Chile by 1994. In January of 1993, Australia's Royal Society for the Prevention of Cruelty to Animals advised that pets be kept indoors between 11 a.m. and 3 p.m., when daily solar activity is at its strongest, and Australian farmers were asked to shelter their livestock as incidents of skin cancer were on the rise, ostensibly from increased UV exposure due to ozone depletion. Then in March of 1994 the World Health Organization (WHO) issued a warning that malignant melanoma was "epidemic" in some parts of the globe with occurrences of the disease among fair-skinned people rising 5%-10% annually. Highest levels of the disease were found in Australia, New Zealand and parts of the United States. Canada, the Netherlands, Scandinavian countries, Switzerland and the United Kingdom also reported rapid increases in this type of skin cancer (Figure 2.8).[26]

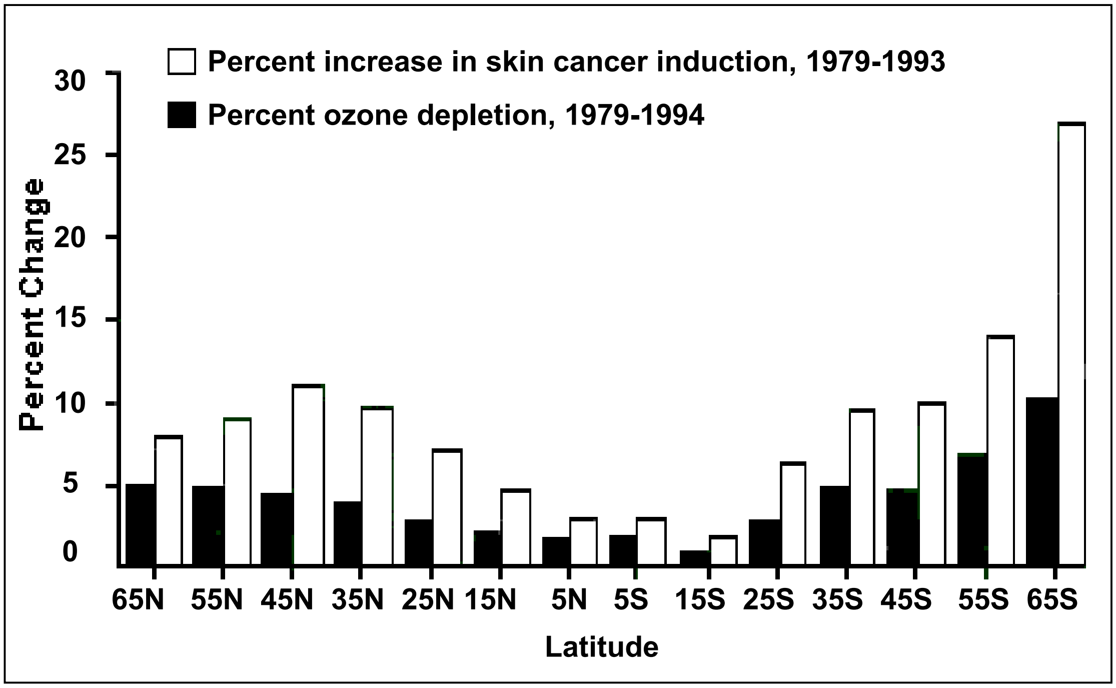


Figure 2.8 STRATOSPHERIC OZONE AND INDUCED SKIN CANCERS, BY LATITUDE[17]

The location, extent and effects of induced climatic changes and global weather shifts, however, are as difficult to predict and to isolate as natural disasters (floods, droughts, monsoons, earthquakes, etc.). These interactive patterns and occurrences, coupled with uncontrolled human population growth and deforestation, are certain to impact food production and man's standard of living and health throughout the world. For example, warmer ocean temperatures, along with increased salination of the world's bodies of water and altered stream flows like the El Nino, are projected to result in an 8% decline in fish catch by the year 2100.[18]

One sophisticated model suggests that plant productivity may even increase by 20% - 26% in response to a Greenhouse climate with a doubling of CO_2 concentrations in tropical and dry temperate zones.[26] Since tropical zones are *currently* at their optimal crop-growing temperatures, dry zones may be *temporary* winners in this newly emerging global climate.

2.5.4 Carcinogenicity, Neurotoxicity and Reproductive Toxicity

The halocarbons carbon tetrachloride and perchloroethylene are hepatotoxic as well as carcinogenic. Studies of dry cleaning workers indicate elevated incidences of leukemia, lymphoma and other cancers in this group.[32] In 1993, the Massachusetts Upper Cape Cancer Study demonstrated an increased risk of leukemia linked to communities' using perchloroethylene-contaminated drinking water, apart from worker exposure.[33] The carcinogenicity of tetrachloroethylene is under investigation.

Other organic cleaning solvents, such as methyl ethyl ketone (MEK), are neurotoxins.[34] They act by depressing the central and peripheral nervous systems and can cause drowsiness, weakness and loss of feeling and dexterity. Because it is a volatile organic compound (VOC), MEK is easily released to the air through evaporation. Volatilization can occur from solvent-containing building materials and consumer products as well. Upon exposure, MEK is readily absorbed via inhalation and skin contact. Its toxicity is low when used alone, but MEK can pose a serious toxic problem when blended with other solvents such as xylene.

Carbon tetrachloride, methyl ethyl ketone, tetrachloroethylene, trichloroethane, trichloroethylene, toluene and xylene are solvents associated with negative reproductive health effects. Current research suggests that exposure to toluene and methyl ethyl ketone of both men and women may cause deleterious effects on reproduction and subsequent offspring.[35] In addition, wives of workers exposed to these solvents have been shown to have a higher risk of spontaneous abortions and their children, an elevated risk of childhood cancers.[36]

A study conducted by Harvard University found increased rates of perinatal deaths, birth defects, lung/respiratory, urinary tract and kidney ailments, as well as eye and ear abnormalities among Woburn, Massachusetts residents associated with using water supplies contaminated with trichloroethylene, tetrachloroethylene and chloroform.[37]

2.5.5 Cardiovascular and Central Nervous System Damage

While considered low in toxicity, the mutagenicity and carcinogenicity of CFCs is not fully elucidated since these chemicals, like the HCFCs and HFCs, accumulate in body fat after repeated exposures over time and are probably dependent on a solvent's chemical stability or persistence and the toxicological profile of its by-products.[38,39] Occupational exposure is normally via the lungs (i.e., inhalation) and absorption is medium to high. Heavy workload and increased physical activity increase the uptake of these and other volatile organic compounds (VOCs). CFCs also carry a risk of asphyxiation at high exposures, particularly in poorly ventilated environs. Under such conditions, cases of severe tremors and fatalities have been cited. Both HCFCs and HFCs exhibit greater potentials for systemic effects than CFCs but are less acutely toxic than either CFCs or halogenated hydrocarbons.

The most important toxicological effects of the CFCs/HCFCs are their influence on the central nervous system (CNS) and the heart (palpitations, arythmias), although little is known about their biological effect mechanisms.[39] The underlying method(s) for CNS damage is similar to those of the general anesthetics whereby the chemical itself, and not its metabolites, is the offender. Of particular concern are the combined effects of azeotropic mixtures of HCFCs. The enhanced potency of combinations of any CFC and HCFC compounds depends on their fat solubility and on the distribution coefficients in air/blood and blood/fat. These responses determine the criteria for the permissible exposure levels (PELs) listed below (Table2.3).

Chemical Name	Formula <mol.weight>	Synonyms	CAS # Chem. Abstract	Exposure Limit (parts per million)
Chlorodifluoro-Methane	$CHClF_2$ <86.47>	HCFC-22 Freon 22	75-45-6	1000 PPM
2,2-Dichloro-1,1,1-trifluoro-ethane	$C_2HCl_2F_3$ <152.93>	HCFC-123 Freon 123	306-83-2	*AEL=30 PPM
2-Chloro-1,1,1,2-tetrafluoroethane	C_2HClF_4 <136.48>	HCFC-124 Freon 124	2837-89-0	500 PPM
1,1-Dichloro-1-fluoroethane	$C_2H_3Cl_2F$ <116.95>	HCFC-141b Freon 141b	1717-00-6	500 PPM
1-Chloro-1,1-difluoroethane	$C_2H_3ClF_2$ <100.50>	HCFC-142b Freon 142b	75-68-3	1000 PPM
3,3-Dichloro-1,1,1,2,2- and 1,1,2,2,3- penta-fluoropropane	$C_3HCl_2F_5$ <202.94>	HCFC-225ca and HCFC-225cb Isomeric blend	422-56-0 ca 507-55-1 cb	Company set at 25 PPM / ca-isomer Manufacturer set at 50 PPM / isomer blend
1,1,2-Trichloro-1,2,2-trifluoro-ethane	$C_2Cl_3F_3$ <187.38>	CFC-113	76-13-1	1000 PPM
1,1,1-Trichloro-ethane (TCA)	$C_2H_3Cl_3$ <133.42>	Methyl (MCF) chloroform	71-55-6	350 PPM

*Allowable Exposure Level

As of October 1996

Table 2.3 SUMMARY OF RELEVANT HCFC/CFC EXPOSURE DATA[8]

To date, almost all toxicity studies are biased towards acute rather than chronic chemical exposure indicators, extrapolating results from the laboratory or on test animals that may not hold true for all species and both genders and for all stages of development.[17,38] Consequently, environmental indicators, an upcoming topic, may offer a more sustainable approach to determining the relative safety of chemical manufacture and use since they more fully encompass a chemistry's life cycle and fate.

These exposures, then, can be categorized in three ways: direct (worker), indirect (consumer) and ambient (population-at-large). Overlaps exist within the groups, especially between consumers and the ambient population where what differs most may be the informed consent for the exposure (re: Right-to-Know laws).

2.6 Legislative Initiatives to Control Atmospheric Chlorine

The United Nations Environment Programme (UNEP) began to address the issue of ozone depletion in 1977. Under the auspices of UNEP, the governments of the world met at the Vienna Convention for the Protection of the Ozone Layer in 1985. Through this Convention, governments “committed themselves to protect the ozone layer and to cooperate with each other in scientific research to improve understanding of the atmospheric process.”[40]

2.6.1 International Efforts: the Montreal Protocol

The governments agreed to the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987. The Protocol “aims to reduce and eventually <to> eliminate the emissions of man-made ozone depleting substances.”[40]

Since its inception, the treaty has been strengthened and amended four times at meetings in: London (1990), Copenhagen (1992), Vienna (1995) and Montreal (1997). The Montreal adjustments were to become effective as of January 1, 1999. The number of countries Party to the Convention, the Protocol and the Amendments to the Protocol as of May 3, 1999 according to the Depositary of the United Nations Office of Legal Affairs, New York, New York are presented in Table 2.4.

Treaty	Vienna Convention	Montreal Protocol	London Amendments	Copenhagen Amendments	Montreal Amendments
Date Treaty Entered into Force	September 9, 1988	January 1, 1989	August 10, 1992	June 14, 1994	Not Yet In Force
(Original Signatories)	(28)	(46)			
*Total Ratified	169	168	129	88	11

Table 2.4 RATIFICATION STATUS OF MONTREAL-PROTOCOL RELATED TREATIES
**Types of ratification include: ratification, accession, acceptance, approval and succession. The ratification totals reflect the summations of all ratification types under each treaty. For example, under the Montreal Amendments: 8 Ratifications + 2 Acceptances + 1 Accession = 11 total countries ratified. For those nations that concluded the treaty after it entered into force, entry into force is ninety days following the date of the nation’s ratification.*

2.6.2 United States Efforts: the Clean Air Act to the Toxics Release Inventory

Environmental problems began to attract more and more attention in the United States (U.S.) during the early 1970s. President Nixon established the U.S. Environmental Protection Agency (EPA) in 1972 with the mission “to protect human health and to safeguard the natural environment - air, water, and land - upon which life depends.”[41]

U.S. EPA Clean Air Act and Amendments
High levels of ozone in the lower atmosphere irritate the eyes and cause breathing problems among the elderly and the sick. Statistics reveal that 40% of the U.S. population lives in ozone non-attainment areas. Because of these facts, early efforts to reduce air pollution focused on decreasing VOC releases since ozone, the primary component of smog, is formed when VOCs are released and react with nitrogen oxides. Section 109 of the Clean Air Act (CAA) of 1990 set

a national ambient air quality standard and federal regulations like the Resource Conservation and Recovery Act (RCRA) govern VOC emissions.

Section 602 of the Clean Air Act Amendments (CAAA) created two classes of ODSs. The Class I list of chemicals contains all fully halogenated CFCs, fire-retardant halons, HCFC-precursor carbon tetrachloride (tetrachloromethane) and methyl chloroform. In general, Class I chemicals possess an ODP of 0.2 or greater. All groups in this class reached their production phaseout date on January 1, 1996.

The Class II list of chemicals contains the HCFCs. Section 605 of the CAAA set accelerated phaseout dates for three HCFCs with relatively high ODPs: HCFC-22, HCFC-141b and HCFC-142b. For cleaning applications, production and importation of HCFC-142b and HCFC-22 will be banned in 2010 and the remaining HCFCs in 2015. As with some of the CFCs, the phaseout schedule for HCFCs may be further accelerated with the development of more and effective non-ozone depleting alternatives.

Significant New Alternatives Policy

Section 612 of the Clean Air Act requires the U.S. EPA to establish a program to identify alternatives to Class I (CFCs, halons, carbon tetrachloride, methyl chloroform, methyl bromide and HBFCs) and Class II (HCFCs) substances. These ODS replacements are governed by the Significant New Alternatives Policy (SNAP). SNAP lists acceptable and unacceptable substitutes for specific uses. For example, HCFC-141b is unacceptable for cleaning as of January 1, 1996. The SNAP list is updated periodically in the U.S. Federal Register.

The CAA also lists the global warming potential (GWP) and atmospheric lifetimes of several chemicals. These values can be used to determine the environmental consequences associated with different halogenated solvents. For instance, hydrofluoroether (HFE), recently listed by the EPA as a substitute for Class I substances such as methyl chloroform and CFC-113 in metal, electronic and precision cleaning, has a GWP of 150-480 and an atmospheric lifetime of 4.1 years.

Many HCFCs used for solvent cleaning are blends or azeotropic mixtures with alcohols and/or ethers. The ODPs and GWPs of these mixtures can be determined by taking the individual characteristics for each chemical, multiplying by their respective weight fractions and summing them together (refer to VOC calculations in section 2.2).

The following is a timetable for the phaseout of the use and manufacture of these federally-regulated chemicals (Table 2.5).

Chemical Name	Formula <mol.weight>	Synonyms	CAS # Chem. Abstract	Cleaning Phaseout Dates[1]
Chlorodifluoro-Methane	$CHClF_2$ <86.47>	HCFC-22 Freon 22	75-45-6	2010[2]
2,2-Dichloro-1,1,1-trifluoro-ethane	$C_2HCl_2F_3$ <152.93>	HCFC-123 Freon 123	306-83-2	2015[2]
2-Chloro-1,1,1,2-tetrafluoroethane	C2HClF4 <136.48>	HCFC-124 Freon 124	2837-89-0	2015[2]
1,1-Dichloro-1-fluoroethane	$C_2H_3Cl_2F$ <116.95>	HCFC-141b Freon 141b	1717-00-6	1996[2,3](1997[4])
1-Chloro-1,1-difluoroethane	$C_2H_3ClF_2$ <100.50>	HCFC-142b Freon 142b	75-68-3	2010[2]
3,3-Dichloro-1,1,1,2,2- and 1,1,2,2,3- penta-fluoropropane	$C_3HCl_2F_5$ <202.94>	HCFC-225ca And HCFC-225cb Isomeric blend	422-56-0 ca 507-55-1 cb	2015[2,5]
1,1,2-Trichloro-1,2,2-trifluoro-ethane	$C_2Cl_3F_3$ <187.38>	CFC-113	76-13-1	January 1, 1996
1,1,1-Trichloro-ethane (TCA)	$C_2H_3Cl_3$ <133.42>	Methyl (MCF) chloroform	71-55-6	January 1, 1996

As of October 1996

Table 2.5 IMPORTANT U.S. DEADLINES FOR CLEANING-RELATED SOLVENTS[8]

1 - These chemicals cannot be produced or imported for cleaning usage after the phaseout date; inventoried or recycled stock available for use.
2 - Phaseout schedules for refrigeration and feedstock uses are different (CAAA Sections 601-607).
3 - Use restricted by EPA SNAP (CAA Significant New Alternatives Policy) list.
4 - Proposed extension by EPA SNAP for existing users in precision cleaning and high performance electronics only.
5 - HCFC-225ca isomer used for electronics and precision cleaning; HCFC-225 isomeric blend not approved for metal cleaning.
6 - Based on 100-year horizon.

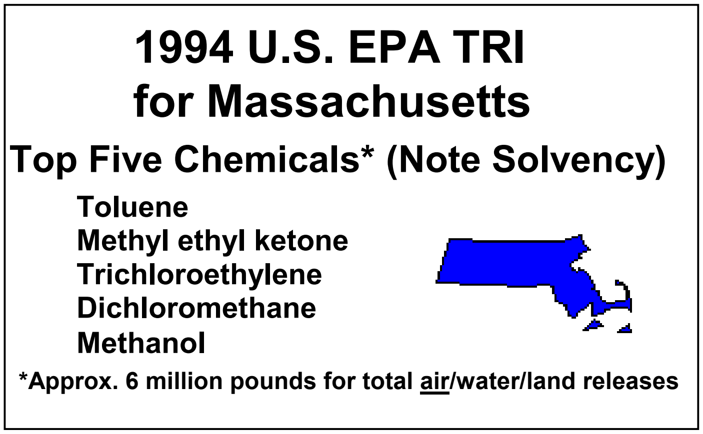
The Toxic Release Inventory: Emergency Planning and Community Right-To-Know Act

The primary purpose of the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986 is to inform communities and citizens of chemical hazards in their areas. Sections 311 and 312 of the Act require businesses to report the locations and quantities of chemicals stored on-site to local governments. This helps communities prepare to respond to chemical spills and similar emergencies.

Section 313 of EPCRA specifically requires manufacturers to report releases of more than 600 designated toxic chemicals to the environment. These individual reports are submitted to the U.S. EPA and state governments. The EPA compiles the data into a yearly report, listing the major pollutants and top industrial emitters for each state. Facilities are also required to report off-site transfers (a transfer of wastes for treatment or disposal at a separate facility), pollution prevention activities and chemical recycling.

Through EPCRA, the U.S. Congress mandates that the annual report, known as the Toxic Release Inventory (TRI) be made public. TRI supplies citizens with data about potentially hazardous chemicals so that companies using them can be held accountable.

TRI is a valuable source of information for states concerning the toxic chemicals that are being employed, manufactured, treated and transported within their borders. For instance, the TRI data for Massachusetts, an older, smaller, well-populated and highly-industrialized state, revealed the significant impact solvent operations were having on total pollutants emitted by its businesses (Figure 2.9). This is particularly important since most if not all of these chemicals are transported, and not manufactured, in the state. Shipping is usually by truck, and potentially effected communities now have the mechanism to become informed of the potential for spills along highways, in addition to accidents within plants.



1994 U.S. EPA TRI
for Massachusetts

Top Five Chemicals* (Note Solvency)

- **Toluene**
- **Methyl ethyl ketone**
- **Trichloroethylene**
- **Dichloromethane**
- **Methanol**

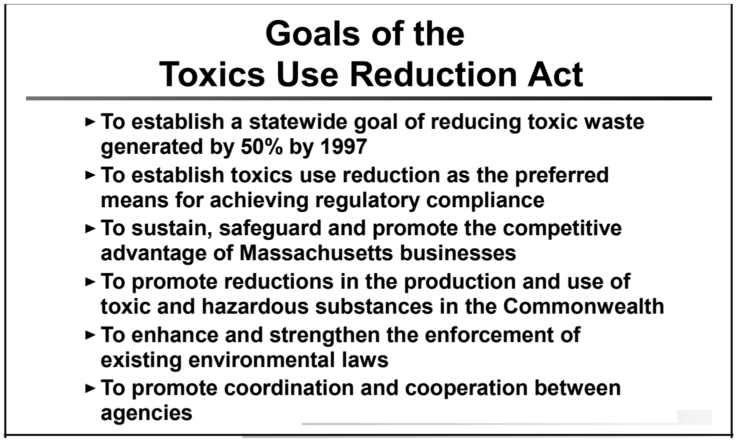
***Approx. 6 million pounds for total air/water/land releases**

Figure 2.9
LEADING INDUSTRIAL POLLUTANTS EMITTED IN MASSACHUSETTS IN 1994[42]

TRI data, however, was not designed to show if chemical releases of any sort pose health or environmental hazards. Pollution prevention measures would be required to achieve that goal.

2.6.3 Massachusetts Efforts: the Toxics Use Reduction Act and Institute

Three years later in 1989, the Commonwealth of Massachusetts passed the Toxics Use Reduction Act (TURA). The goals of this state's legislation are summarized in Figure 2.10.



Goals of the
Toxics Use Reduction Act

- **To establish a statewide goal of reducing toxic waste generated by 50% by 1997**
- **To establish toxics use reduction as the preferred means for achieving regulatory compliance**
- **To sustain, safeguard and promote the competitive advantage of Massachusetts businesses**
- **To promote reductions in the production and use of toxic and hazardous substances in the Commonwealth**
- **To enhance and strengthen the enforcement of existing environmental laws**
- **To promote coordination and cooperation between agencies**

Figure 2.10
MAJOR OBJECTIVES OF MASSACHUSETTS' TOXICS USE REDUCTION ACT[42]
Substantial reductions (approx. 33%), short of the 50% goal, were achieved by Massachusetts in toxic waste generation by 1997.

The Massachusetts Toxics Use Reduction Institute

The Toxics Use Reduction Institute (TURI) was established by TURA with a mission "to promote reduction in the use of toxic chemicals or the generation of toxic by-products in industry and commerce in the state of Massachusetts."[43] Located at the University of Massachusetts in Lowell, TURI is a multi-disciplinary research, education and policy center.

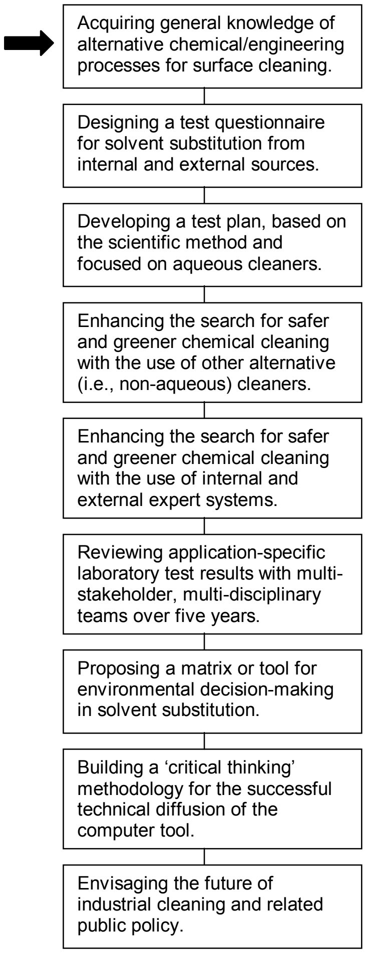
The Institute maintains a Surface Cleaning Laboratory (SCL) with the capability to evaluate the effectiveness of different cleaning chemicals and equipment on a variety of substrates and soils. Operational since 1994, SCL's purpose is to "identify, develop and promote safer alternatives to hazardous materials such as organic and chlorinated solvents."[44] This necessarily involves the supplies and practices of surface preparation, cleaning, rinsing, drying and analysis used within industries.[45] Testing services are provided 'free-of-charge' to Massachusetts' firms.

2.7 Observations

For the purposes of this thesis, a thorough examination of the development and regulation of cleaning solvents was necessary. Accordingly, this chapter reviewed (1) the evolution of cleaning chemicals, both organic solvent- and aqueous-based, (2) the discovery of the negative effects on the environment, and upon workers' health and safety of chlorinated and organic cleaning solvents and (3) the history of international and regional legislation governing these chemical agents.

In conclusion, the acute and chronic toxicological profiles of organic and of the first-alternative CFC cleaners, coupled with the deleterious environmental impacts of some of the second-generation HCFC substitutes, have stimulated the development of new or innovative surface cleaning techniques. The rebirth of primarily aqueous/semi-aqueous cleaning technologies, the topic of the next chapter, has been led by legislative efforts directed towards industries, worldwide.

3 The Search for Safer, Greener Chemical Cleaners: An Introduction



Each of the succeeding chapters contains an explanatory diagram (right) to serve as a topical guide for the reader.

3.1 Overview of the International Community's Response

In 1998, UNEP's Solvent Technical Options Committee (STOC) released a 242-page report on solvents, coatings and adhesives from the Montreal Protocol on substances that deplete the ozone layer. The report assessed a wide range of solvent-related topics from metal, precision, electronics and dry cleaning to adhesive, aerosol, and miscellaneous solvent applications. In addition, targeted areas included (1) small- to medium-sized enterprises (SMEs), "which, when taken collectively, consume the greatest volume of OD solvents", (2) alternatives to ozone-depleting solvents in developing countries, (3) a comparison of military and commercial applications and (4) oxygen systems such as life-support devices requiring special cleaning of component parts.

The document concludes that while many industrial users have made a successful transition to alternative aqueous (i.e., water-based) cleaners, difficulties remain in several applications such as precision cleaning, "where factors such as high reliability, compatibility and short cycle time (e.g., fast, spot-free drying) are required." Reverting to flammable isopropyl alcohol is common, even though alcohol has a very low soil loading (i.e., the ability to retain a soil). In other situations, cleaning practitioners are converting to alternative solvents that are more expensive to use than the original ozone-depleting substances and these compounds may not be as effective.

A speedy phase-out of solvent usage for metal cleaning has also been hampered by the large number of small users, most of which are undercapitalized. Maintenance cleaning is considered a sub-sector of a sort, which is not generally addressed by seminars or other training programs.

Furthermore, the report continues, "the number of new ozone friendly solvents is quite small and the projection for continued research into new solvents is not high. Cost of research, time for governmental approval and user acceptance continue to be major concerns for developers." This is because the market is "made up of many suppliers with numerous alternatives… This dispersed nature of this market has made the economics of scale, realized in the past, impossible today." The STOC concludes, however, that "new solvents that have ODPs and incomplete toxicological assessment <are> being offered in the market. The rush to promote these alternatives has been such that these properties are being overlooked and indeed minimized."

The complete report can be obtained from the Montreal Protocol's Technology and Economic Assessment Panel (TEAP) at http://www.teap.org/.

3.1.1 No-Clean Techniques

STOC's 1998 assessment of the electronics industry confirmed two main uses of OD solvents: developing dry film photoresists and defluxing soldered assemblies (i.e., the removal of flux). Flux (for example, a rosin) is a substance used to promote fusion when it is applied to metal surfaces about to be soldered, brazed or welded. Excess flux frequently adheres to these joints.

Besides the use of aqueous cleaners, a serious attempt was made to eradicate cleaning chemicals altogether with the use of no-clean flux. A no-clean flux is defined as one in which residues do not have to be removed from an electronics assembly and, therefore, no cleaning is necessary. This type of flux is usually characterized by low quantities of residues.

In 1997, the Toxics Use Reduction Research Fellows Program released a study (Technical Report No. 40) on the evaluation and implementation of no-clean alternatives, with a focus on small electronics manufacturers. While the report substantiates the feasibility and benefits of no-clean fluxes, <they> "are not usually a direct drop-in replacement." Concerns associated with no clean-fluxes include, among other things, their lower fluxing activity, demanding "tighter manufacturing process control and incoming material solderability control procedures."

Oftentimes, however, manufacturers simply do not have control on the design of parts received. Environmental management systems like ISO 14000 may help bring no-clean design principles, also referred to as a design-for-the-environment (DfE) initiative into better focus (or, unfortunately, cause additional out-sourcing of cleaning operations to developing nations). The no-clean issue is again underscored in chapter four as the first step in 'topics and criteria under review' (Table 4.1) prior to conducting an investigation into solvent substitution.

3.1.2 Use of Non-Volatile Organic Compounds

Lactate esters, particularly ethyl lactate, are known for their cleaning and solvating properties. This ester will remove silicone oils and greases, machining coolants, tapping oils (sulfur-based), lithium grease, layout inks, and fingerprints and is being tested as a possible substitute for glycol ether used in the semiconductor industry. Rinsing after ethyl lactate cleaning can be accomplished with fresh ethyl lactate, water or alcohol.[49]

Ethyl lactate (ethyl 2-hydroxypropionate) is commercially available as a monobasic ester. It is a clear, colorless liquid with a high vapor pressure of 1.2 mm Hg at 68° F (1.6 mbar at 20° C) and a boiling point of 309° F (154° C). Its classification as a non-volatile organic compound[d] may be dependent on its location, however, and it is combustible (flash point of approximately 120° F or 49° C, depending on its purity). It may be recycled with filtration or vacuum distillation. It should not be flushed down the drain, but may be incinerated at an approved facility. Safety precautions are required, including gloves, eye protection and adequate ventilation. While ethyl lactate is considered biodegradable, a threshold limit value (TLV) has not been established.

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[d] See also, section 9.3.2 for more information on the role VOC-policy plays on solvent selection.

One study conducted by Argonne National Laboratory (Argonne, Illinois) in 1999 revealed ethyl lactate's use for machine-shop parts cleaning and degreasing as well. The NTEC Versol™ version of the chemical was used, along with parts-cleaning machines supplied by Safety Kleen (formerly of Chicago, Illinois). Results of the six-week pilot project conducted at two sites confirmed the cleaner's performance to the satisfaction of the tests' participants.

Ethyl lactate is also packaged as a solvent blend with other hydrocarbons (P-T Technologies, Dynamold), making its selection as an alternative cleaner a more complex decision.

3.1.3 Alternative Cleaning Methods Chosen for this Study

As a result of the limited success of no-clean applications and the less-than-ideal environmental and/or health consequences of non-volatile compounds used for cleaning, this thesis focuses on three alternative processes with chemicals that are based on water, sodium bicarbonate (baking soda) or carbon dioxide, the vast majority of them being better suited for water (i.e., aqueous)-based processes for reasons that are discussed in chapter six. It represents an entirely new body of work since it is a *comparative* study of alternative cleaning methods in different industries involving the development of (1) questionnaires and performance tests, (2) training modules and an interactive computer tool for solvent substitution and (3) a complete methodology, or critical thinking format, to increase a project's chances of success, with a further goal of continuous improvement.

Working Definitions for the Terms Safer, Greener and More Sustainable
Due to the study's comparative nature, the meanings of the terms *safer*, *greener* and *more sustainable* need explanation as they apply to this work. *Safer* refers to any cleaning process that represents an improvement to worker and/or public health and safety, as compared to an existing cleaning practice. Exposure guidelines, supplied by various government organizations, are fairly straightforward unless those compounds are new to the market. The classical definition of green chemistry is supplied in the thesis' forward. The term *greener* applies to a cleaning process that is less polluting than the existing cleaning practice. The phrase *more sustainable* reflects a chemical's diminished dependence as well as impact on natural resources when compared to an existing cleaning practice. The application of this term is to be based upon life cycle assessments of component chemicals, described in chapter eight. It may also refer to a cleaner that is both safer and greener.

These definitions offer a 'moving target' in the search for safer and greener chemical solvents (for example, the same alternative cleaning process may be an improvement in company A but not in company B). Nevertheless, a great deal of progress can be gained by such an application-specific approach. It may even prevent 'risk shifting' among various environmental and health stakeholders.

3.2 Aqueous Cleaners and How They Work

Just as section 2.3 characterized different types of organic solvents to help explain their solvency, the properties of the water molecule and the role of micelles must be examined to understand the chemical properties of aqueous cleaners.

3.2.1 Water Polarity and Surfactant Micelles

Water is a polar solvent suitable for dissolving polar soils, including many inorganic and some organic contaminants. The same unique structure that allows for the molecule's expansion upon freezing, provides for this solvent's ability to arrange other molecules such as dissolved dirt in a more thermodynamically-stable state. This is due to water's *dipole moment* with a net negative directional charge, electrons being associated with the single oxygen atom (M-) versus the positive charges (M+) of the two smaller hydrogen atoms at the molecule's other end as diagramed and presented in Figure 3.1.

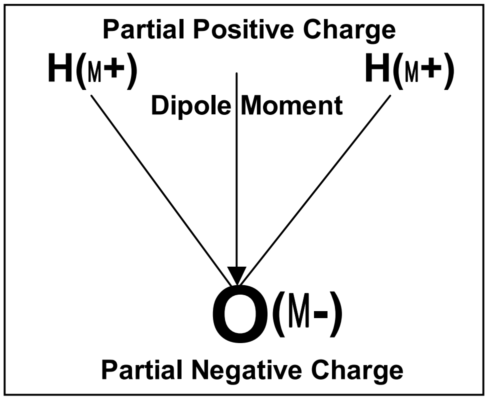


Figure 3.1 THE WATER MOLECULE'S POLARITY AND DIPOLE MOMENT[46]

Unlike many other solvents, the water molecule can undergo *hydrogen bonding*. Hydrogen bonding is primarily an ionic chemical bond that occurs between a highly electronegative atom and a hydrogen atom already attached to another highly electronegative atom. It is a very important reaction in many biochemical processes. In cleaning, it allows the water molecule to bond to a soil to enhance its removal.

Since not all soils are readily dissolvable in water, surface-active chemicals are added to the formulations of aqueous cleaners. Compounds known as surfactants are usually oblong-shaped molecules with a hydrophobic (water-repelling) and a hydrophilic (water-attracting) end. The hydrophilic portion is stable in water while the hydrophobic section orients itself towards the contaminant, creating sphere- or rod-shaped aggregate molecules known as *micelles*. Micelles are able to contain hydrophobic oil internally and create stable emulsions (i.e., suspensions) during the cleaning process illustrated in Figure 3.2. Like water, surfactants are characterized according to their ionic charge(s).

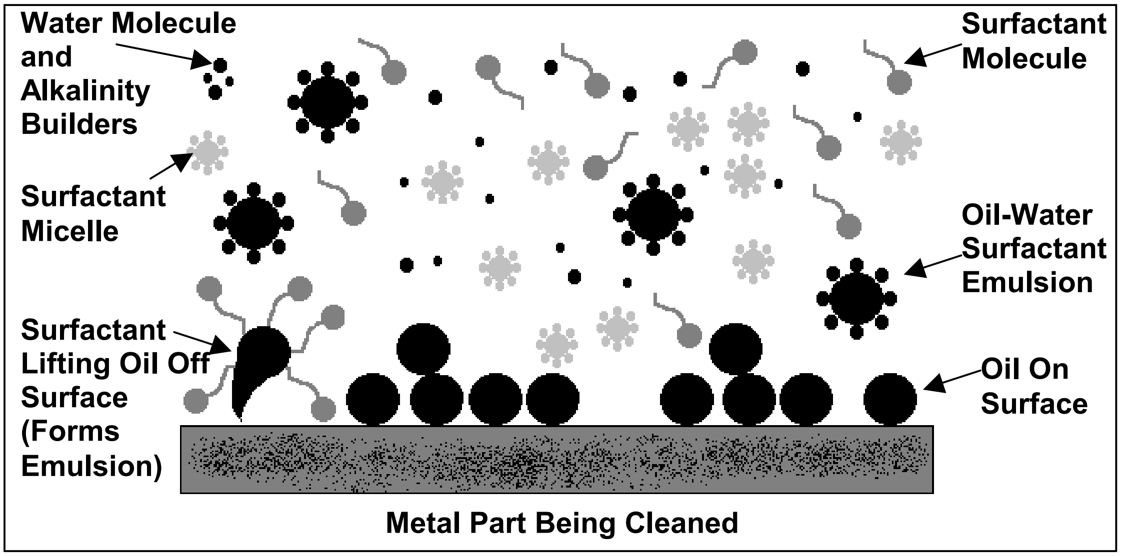


Figure 3.2 MICROSCOPIC DEPICTION OF AQUEOUS CLEANING OF METAL[47]

While surfactant concentrations are well below 10% for most aqueous cleaners as shipped, they constitute the chief active ingredients of the detergent industry and are selected and/or formulated for the final product's targeted application and markets. The major chemical manufacturers are hesitant about the release of specific information concerning these formulas with and without patenting and will frequently list them as, for example, a "nonionic proprietary surfactant" on Material Safety Data Sheets (MSDSs).

Thousands of chemicals with surfactant properties are readily available and a complete discussion of them is beyond the scope of this work. A primary source of information is McCutcheon's Emulsifiers and Detergents (MC Publishing, Glen Rock, New Jersey, USA) published annually. Example entries are provided in Table 3.1.

Trade Name	Company	Class and Formula	Form	Conc. (%)	Type	*HLB	Remarks
Icomeen T-2	BASF Wyandotte	Ethoxylated Amines	Paste		Cationic	5.0	Wetting agent, Penetrant, etc.
Scherco-teric MS-2	Scher Chemicals	Coco imida-zolinium deriv. dicarboxylate	Liquid	42	Ampho-teric (acid or base)		Mild for shampoos, Industrial cleaners
Makon 10	Stephan Company	Alkoxylates	Liquid	100	Nonionic		Detergent, emulsifier in hard surface cleaners
Witconate 1240	Witco Chemical	Linear alkylaryl sodium sulfonate	Slurry	40	Anionic		Hard surface Cleaner, laundry

*The Hydrophylic Lipophylic Balance (HLB) is listed only if the company reports it.

Table 3.1 McCUTCHEON'S EMULSIFIER AND DETERGENT ENTRIES

Some surfactants appear to interfere with the endocrine or hormonal system, but most surfactant molecules are thought to be too big to cross membranes and effect glandular functioning. Additional testing is needed, however, since the same might not be true for their metabolites. Chapter nine continues this discussion of surfactants as suspect endocrine disrupters.

3.2.2 Builders and Alkalinity

After water, the most common ingredient of all aqueous cleaners for metal part cleaning is sodium hydroxide (NaOH) or a comparable alkaline builder. Sodium hydroxide supplies alkalinity ($pH > 7.0$) for most aqueous cleaning processes and acts as a 'builder' to enhance the cleaning ability of surfactants in a number of ways (section 3.1.3). Alkaline aqueous cleaners are typically shipped as concentrates containing 50% NaOH and final volumetric dilutions of 1% - 20% of the cleaner are used, depending on the application, making these cleaners relatively safe, with proper care, for both workers and the environment. As a pure base, however, sodium hydroxide is quite caustic. A complete chemical report on sodium hydroxide is presented in Appendix A of this thesis.

Other alkalis, such as potassium hydroxide (KOH) are being used more frequently in the formulation of aqueous cleaners and may be considered less caustic. Regardless of the buffer/ builder chosen, pH provides a method to group cleaners according to their alkalinity (Table 3.2).

pH of Cleaner	Category
8.5 – 11.0	Mildly Alkaline
11.0 – 12.5	Alkaline
> 12.5	*Highly Alkaline

*Potentially corrosive

Table 3.2 CLASSIFICATION OF AQUEOUS CLEANERS BY ALKALINITY

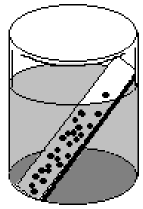
Acidic ($pH < 7.0$) cleaning is also performed under aqueous conditions but with much lower frequency. Acidic cleaners function due to the reaction of hydrogen ions (H^+) with the soil to form a water-soluble molecule via solubilization and/or hydrolysis. The pH for this group of chemical cleaners is typically less than 5.5. In addition, neutral aqueous cleaners range in pH from 5.5 to 8.5.

3.2.3 Aqueous Processes and Chemical Constituents

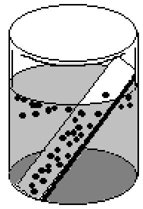
Prior to the search for safer and greener chemical cleaners, solvent cleaning was often performed via single-species vapor degreasing. In addition to immersion, vapor degreasers were employed because the vapors of traditional solvents had superior ability to dissolve organic matter. In vapor phase cleaning, the final 'rinsing' of the surface was accomplished by the condensation of solvent vapors.

Unlike these chlorinated organic solvents, environmentally-friendlier, water-based detergents may not depend on their penetrability for their cleaning efficiencies, especially for the removal of petroleum-based surface debris. They rely instead on the chemical processes of solubilization, wetting, emulsification, deflocculation, sequestration and saponification depicted in Figure 3.3.

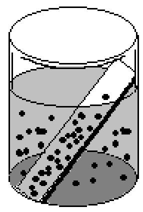
The Cleaning Processes



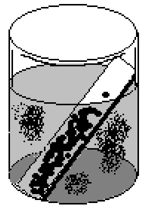
Solubilization



Wetting



Emulsification



Deflocculation

Sequestration

Illustrations courtesy of W.R. Grace & Co.

Solubilization
The process by which the solubility of a substance is increased in a certain medium.

Wetting
The action by surfactants of lowering surface and interfacial tensions so that a cleaner can penetrate small spaces and get under the soil to lift it from the substrate.

Emulsification
After wetting, the process of coating oil droplets (soils that do not dissolve in water) with surfactant to keep them from recombining and migrating to the surface of the cleaning bath.

Deflocculation
The breaking down of soil into fine particles, with the result that they are dispersed throughout the cleaning medium. The soil/liquid matrix is maintained as a dispersion or colloidal suspension, preventing agglomeration.

Sequestration
The chemical deactivation of ions such as calcium, magnesium or heavy metals preventing the formation of insoluble cleaning byproducts such as soap scum.

Saponification (not illustrated)
The alkaline hydrolysis of fat by the reaction of fatty acids with alkalis to form water-soluble soaps. This cleaning method is used for solvent-free defluxing and degreasing.

Figure 3.3 AQUEOUS CLEANERS RELY ON A COMBINATION OF DEPICTED PROCESSES[11]
The illustrations at the left, with the exception of Sequestration, are representations of 'coupon' testing in Pyrex beakers containing a cleaning fluid. Coupon testing is well documented within the industry and is described at length in chapter five.

To complete these sometimes overlapping tasks, aqueous cleaners are often complex mixtures of surfactants, emulsifiers and other additives in an alkaline base. Definitions and explanations of aqueous-cleaner component chemicals are included in the glossary at the end of this thesis.

3.2.4 Parameters: Time, Agitation, Temperature and Concentration, *TACT*

Having defined the processes and types of chemicals important for effective aqueous cleaning, practitioners need to refine the operating conditions to optimize those factors as a consequence of time and economics. This is especially true for water-based cleaners that do not possess the chemical energy relative to chlorinated organic solvents, and so must rely on a number of relatively sophisticated and sensitive mechanisms instead, as depicted in Figure 3.3.

These conditions include: time, agitation, temperature and concentration, collectively known as *TACT*. While other cleaning-related factors exist, these four parameters hearken from the well-developed science of laundry detergency. A complete, experimental test method using *TACT* is presented in chapter five.

In general, all cleaning regimes benefit from increases in cycle time and temperature, provided that they do not damage the parts being cleaned. Loss of product functionality may accompany this type of cleaning-induced surface damage. The form of agitation selected is dependent on the application as well as the volume of product to be cleaned. It is also the most economically-sensitive parameter. Table 3.3 lists the major kinds of equipment available.

Part-Cleaning Equipment	Brief Description
Air Sparging or Activity-Supplying Unit	Immersion/soak tanks fitted with side or bottom aeration; Vibrational and rotational movement also available for agitation
Immersion/Soak Tank	Holding tanks for dipping parts in batch cleaning
Manual Parts Washer/Degreaser	Free-standing sink with pressure at low psi; usually heated storage tank for chemical cleaner recirculation underneath with/without filtration unit
Spray/Cabinet/usually Low-moderate psi	Stationary dishwasher configuration generally in stainless steel; needs low-foaming detergent; may be incompatible with some semi-aqueous cleaners
Spray/Conveyor/usually Low-moderate psi	Spray station with parts moving along on belt for continuous operation; may have integral rinsing and drying stations
Spray/Free-standing, Hand-held units/ Moderate-high psi	Powerwash with hose and nozzle than can be hand-held or automated depending on water pressure (psi); can also be used for removal of some coatings
Ultrasonics	Cavitation of ultrasonically-induced bubbles produces work to clean like a jewelry cleaner; range of KHz and model sizes available for many applications; one of the easier methods to duplicate / scale-up

Table 3.3 CHIEF MECHANISMS USED TO SUPPLY AGITATION FOR AQUEOUS CLEANING

For every type of cleaning mechanism, there are numerous compatible chemical cleaners. Errors in the selection of equipment and chemical cleaner may include excess chemical foaming or etching (i.e., surface degradation) of certain metals such as aluminum.

3.2.5 Rinsing and Drying

Many of the same issues that are relevant to cleaning, apply to rinsing and drying. In particular, rinsing problems can often be traced to inappropriate increases in detergent concentrations or the cross-contamination of cleaning and rinsing baths. Rinsing can be achieved with municipal or treated (deionized) water at ambient or elevated temperatures, in tanks or by spray, depending on the application. A practice known as 'cascade rinsing'[e] is common to many industries.

An innovative alternative or enhancement to cascade rinsing is the 'quick dump' rinser. In this mechanism, a trap door is located in the tank's bottom for quick drainage. At the point in the rinse cycle when the tank is first filled, the drain is automatically opened and the rinse water collected and stored separately, thereby pre-concentrating or minimizing the wastewater stream. Sprayers attached to the sides of the tank and aimed at the parts for better rinsing, accomplish the filling. Subsequent rinse cycles occur normally, i.e., with the drain closed as in cascade rinsing.

Drying utilizes mechanical, evaporative or displacement mechanisms or a combination of these methods. Displacement drying involves the use of other solvents and is not be discussed here since the reintroduction of solvent usage in the drying cycle is counter to the purpose of eliminating them in surface cleaning. Drying is the rate-determining cycle for almost all aqueous cleaning systems, except for parts that are composed of flat, simple (no screw configurations, blind holes, etc.) surfaces. As with cleaning machinery, a range of drying equipment is available and is listed in Table 3.4.

Aqueous-Compatible Drying Equipment	Comments
Air Blower or Knife (Knife = An apparatus supplying a knife-edge source of air for drying or water for rinsing)	High-velocity compressed air dislodges water films by hand-held air gun or automation (may require hearing protection); Knives use less air and are quieter
Centrifuge (Centrifugal Drying)	Rotating system spins parts in a cylindrical compartment about a central axis to remove water; potential to damage some parts
Conventional/Convection Oven	Use of industrial oven temperatures provides heat for drying; convection ovens circulate air better and reduce cycle time
Heat Gun (Portable)	Like a hair dryer, supplies heat as well as air for manual, spot piece drying
Hot Forced Air (Gas Drying)	Large space allocation for commercial equipment; like IR, rather high operational costs for energy
Infrared (IR) Heat Lamp	Light creates heat for evaporation; expensive to scale-up
Tumbler and Absorbents	Heated tumbling like clothes dryer with or without absorbant material such as corncob; not for delicate parts; concurrent use to effect deburring
Vacuum Oven	Decrease in atmospheric pressure lowers the boiling point of water for more efficient evaporation than conventional/convection ovens
Vibrator	Low-frequency (10-100cycles/sec) vibration or gentle shaking augments gravity to accelerate removal of water from the parts

Table 3.4 MAJOR EQUIPMENT USED TO DRY PARTS AFTER AQUEOUS CLEANING

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[e] A cascade rinse consists of a tank supplied with water whose flow rate causes the water to exceed the tank's capacity in such a way that the water 'cascades' over the rim of the tank, in equal proportions on all sides.

It may be easy for the industrial cleaning practitioner to overlook the importance of rinsing and drying cycles; traditional solvent-based degreasing operations simply did not require them and the engineer or plant operator may be too focused on determining the efficiency of the alternative chemical cleaner under review.

Cleaning bath-life, rinsing (in particular, a form of water recycling known as 'closed loop') and drying as it pertains to energy requirements are discussed in more detail in chapter eight.

3.3 Semi-Aqueous Cleaners

Semi-aqueous cleaning incorporates the chemical principles of water-based and solvent-based cleaners in using both surfactant and hydrocarbon, often a terpene, to form a cleaning blend (section 2.2.2). Unlike aqueous cleaners, many manufacturers recommend using these semi-aqueous blends at full-strength and at lower temperatures owing to risk of fire due to relatively low flash points. Ventilation may also be required from an aesthetic as well as health perspective. Part rinsing with water after semi-aqueous cleaning is possible, however.

These chemicals are generally more expensive than aqueous cleaners and, furthermore, difficult to filter for reuse.

3.4 Observations

A summary of key points made in chapter three include:

(1) Water, while the simplest of molecules in terms of its size/molecular weight, elemental components and abundance is by no means easy to understand in terms of its solubilizing behavior. Water's dipole moment and ability to form hydrogen bonds with other chemicals make it a unique solvent.

(2) Surfactants and emulsifiers, in newly-formulated aqueous and semi-aqueous cleaners, may pose unknown risks due to a lack of thorough testing.

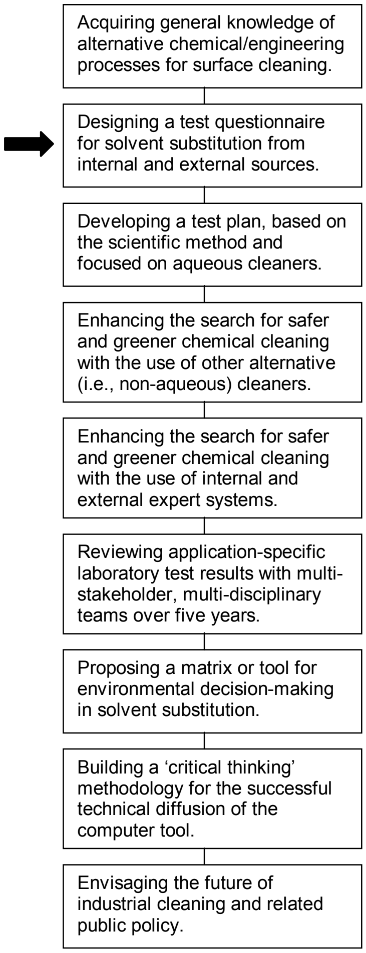
(3) Sodium hydroxide, the cornerstone of the majority of water-based cleaners to date, is itself not free from health and environmental risks; it is merely a compound the use of which is well established with well-documented hazards.

(4) Aqueous cleaning most often requires mechanical agitation that chlorinated organic solvents do not require.

(5) Rinsing and drying cycles, previously unwarranted with solvent-based cleaning, may put an additional strain on meeting production quotas.

Based upon this background, the empirical work for this thesis in the search for proficient, greener cleaning chemicals is addressed in chapters four, five, six and seven.

4 Developing a Test Method for Surface Cleaning, Part I



This chapter begins with a discussion on problem solving that effects all aspects of surface cleaning, regardless of application. Whether a virtually contamination-free part is mandated (as in the computer industry and cleanrooms) or only gross cleaning is required (as in an automotive shop), some meaningful generalizations can and should be made. This rationale will lead to the development of a new test form for solvent substitution. Its purpose is to focus on all those applications that fall somewhere between those two extremes, as do most of the cases at the SCL, where 'something-better-than-visible' clean is desired.

Visual examination is not the only inspection method available to the cleaning practitioner, however. The second part of the chapter describes a variety of surface cleanliness inspection techniques. These analytical tools need no modification, but must be properly selected and applied.

4.1 Designing a Questionnaire for Companies with Cleaning Problems

Consequently, Tables 4.1 and 4.2 outline four basic considerations for any cleaning regime, to be researched prior to and during an investigation, respectively.

Topic	Important Criteria
Knowledge of the Part or Product to Be Cleaned	There is no substitute for expertise in this area. A product's materials of construction will dictate the pH of an aqueous bath and whether or not a rust inhibitor is necessary. Soft plastics can absorb the energy of ultrasonics, leading to poor cleaning quality. Also, some surface finishes are susceptible to damage by certain cleaning chemicals and forms of agitation. Understanding the geometry (simple or complex with inaccessible areas) and size of the parts is critical for devising an effective cleaning process. Blind holes and screw-like configurations, because of moisture retention and increased surface area, are two of the more challenging substrate surfaces. ***With input from the product's designer, it may be possible to critique changes in the blueprint that will not adversely effect functioning but may enhance product cleaning or eliminate cleaning entirely.***
Knowledge of the Contami-nant(s) on the Part	***All pertinent information about what is present on the parts as-supplied should be made readily available. After reviewing this data, suggestions could be made to suppliers to provide cleaner or no-clean parts.*** Using MSDSs, discussions with appropriate staff members could lead to the possibility of trying one cutting oil, for example, where three separate compounds are being used. Switching to an oil that is easier to disperse in water should also facilitate aqueous cleaning. Particulate matter behaves differently than films on surfaces. If more that one source of contamination is present, it may be worthwhile to look at each separately. Moreover, mixtures of contaminants, such as dust and oil, may respond to cleaning regimes unlike the individual soils themselves. For waxy substances, adhesives and stains that tend to smear, formulators frequently recommend significant increases in cleaner concentrations.

These efforts illustrate Design for the Environment (DfE) principles.[f]

Table 4.1 TOPICS AND CRITERIA FOR REVIEW PRIOR TO AN INVESTIGATION

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[f] DfE may be defined as the systematic concern about a product's environmental safety and health issues during its design phase, and throughout its entire life cycle. More information can be found at http://www.pnl.gov/doesustainabledesign/what.htm and http://home.flash/~rcade.

Topic	Important Criteria
Knowledge of the Cleaning Process	Generally speaking, the *TACT* parameters (chapter three) of cleaning, rinsing and drying are augmented at the expense of one another. For instance, needing to *decrease* the temperature of the cleaning bath may necessitate *increasing* the detergent's concentration. The temperature of the bath should be monitored since some cleaners degrade at a high temperature. Adding a low-level fungicide or bactericide may extend the bath's life. If spray wash is the form of agitation, use a low-foaming cleaner. Equally important is the water supply, municipal or de-ionized. Re-circulating water at elevated temperatures can damage expensive carbon filter beds, resulting in contamination. Familiarization with other sources of re-contamination such as cascade versus 'quick dump' rinsing can be helpful in maintaining quality control and better water management (chapter seven). The time allotted to dry parts after aqueous cleaning offers the most reliable means to predict throughputs. To assess scale-up feasibility, work backwards from this final step, accounting for batch sizes and production quotas. Gravimetric analysis of smaller parts before/after cleaning may infer clues (chapter five). The streamlining of processes and the elimination of duplication tends to offset the increased cycle times associated with safer, environmentally-friendlier alternative cleaning systems, as they relate to other manufacturing steps before/after cleaning.
Trouble-shooting	Do not overlook the establishment of a 'baseline clean.' That is, the point at which further contamination interferes with product functioning (or, conversely, but just as important, the point at which further cleaning is not warranted). Know the current part-failure percentages and the reasons for them. Are there expected seasonal fluctuations? Does one production line or shift experience more problems than others? Plant floor personnel may best answer these questions. Having this information beforehand will almost certainly eliminate some suspect causes of failure and save on downtime. It may be impossible to develop cleanliness baselines due to factors such as limited analytical capabilities and staffing. In these cases, compare cleaning efficiencies rather than defining the clean state. If solvent cleaning became integral to a manufacturing routine simply because alternatives were not seriously investigated, it is not surprising to find that aqueous cleaning compares favorably to the solvent technology. Use the product's present 'performance test' to compare solvent- and alternatively-cleaned parts. Age acceleration is one method. In age acceleration, parts are placed in a conventional oven and brought to a previously-determined temperature for a set amount of time. The duration of exposure to heat corresponds to an expected product life (e.g., 50 hours at 100 deg. F before failure is equal to five years' product lifespan). Surface residues after cleaning are not always caused by process soils but by the detergents themselves. Drying parts under infrared heat lamps and noting the resultant fumes can sometimes reveal this phenomenon. Cleaner levels may have to be *decreased*, especially for precision cleaning, where concentrations under 5% are common. The wrap used for storage/shipping can be a source of contamination.

Table 4.2 TOPICS AND CRITERIA FOR REVIEW DURING AN INVESTIGATION

If more information is needed, manufacturers having to clean parts or products should look to their customers and vendors for support, especially in light of new ISO (International Standards Organization) and EMAS (Ecological Management and Auditing System) environmental standards.

With these elements of a hypothetical, generalized view of the industrial cleaning process, a questionnaire can be designed that addresses most, if not all, of the major points identified in the foregoing tables. This will provide the cleaning practitioner with the ability to organize the individual firm's cleaning requirements prior to the scientific testing of any alternative solvents. In this way, efforts can concentrate on the cleaning methods and chemical cleaners that have the most realistic opportunity of being used on the shop floor. In this respect, research at the SCL reflects a focus on applications development, as opposed to research and development.

4.1.1 A Government-Sponsored Test Form

In 1993, the SCL was using the test format developed by the Research Triangle Institute (RTI) for the U.S. Environmental Protection Agency known as SAGE (Solvent Alternative Guide). This program is available on the World Wide Web at http://www.clean.rti.org. SAGE is "a comprehensive guide designed to provide pollution prevention information on solvent and process alternatives for parts cleaning and degreasing."[49]

Currently, SAGE is composed of (1) a Process Advisor, an "Expert System to evaluate…<cleaning> process<es> and generate a ranked list of possible alternative solvents," (2) Alternatives, "descriptions of all the alternatives in SAGE, including case studies, environmental information, references, etc." and (3) a Search Engine to "search the entire SAGE web site."[49]

The Process Advisor Information Input Form is included in Appendix B of this thesis. The Process Conversion Checklist is presented in Table 4.3.

SAGE Process Conversion Checklist
Is the material of the parts compatible with the proposed process/chemistry?
Will the cleaning be batch or continuous?
Will the process be automated?
What are the financial limitations on new equipment purchases?
Is the new process labor intensive relative to the old process?
Will the cleaning process affect the upstream or downstream processes? (for example, will a change in lubricants be needed to be compatible with the new cleanser; will the time required in the drier be compatible with current throughput rate?)
Will the cleaning process harm the surface of the part?
Will additional surface preparation be needed after cleaning?
Is an acceptable and sufficient quantity of the new chemical or equipment available at reasonable cost?
Can current equipment be used as in (drop-in substitution)?
Is retrofit more economical than equipment replacement?
Is the material of your existing equipment compatible with your new chemistry/process? (For example, will there be corrosion, embrittlement, chemical reaction, heat transfer difficulties, or pressure containment?)
Will scale buildup be a problem?
Is sufficient containment available (shielding for spraying, edges to prevent drips)?
Is humidity control adequate?
Are pumps adequate?
Are closed-loop recycle and reuse practical within the process?
Will the wastewater include biocides, foaming agents, or metals?
Will contracts need to be changed to reflect the new cleaning method?
Will the product meet quality specifications including applicable MIL <military> specifications?
Will customer require proof that specifications are met and, if so, what kind?
Is resistance to the changes likely?
What type of training should be set up?
Are incentive programs or monitoring programs appropriate for your facility?

Source: http://clean.rti.org/chklist.cfm

Table 4.3 SOLVENT ALTERNATIVE GUIDE PROCESS CONVERSION CHECKLIST, 1999

By 1994, Massachusetts firms trying to fill out earlier versions of the SAGE Process Advisor Information Input Form were having difficulties running the program and/or not being able to answer all of program's questions, necessary to generate the ranked report.

Those companies that were able to use SAGE found the reports helpful but not application specific, even though case studies were cited. Examples of SAGE 'overview' reports for chemicals and processes are in Appendix B of this thesis.

4.1.2 Industry-Inspired Test Forms

Forms used by industry to conduct applications development proved to be much shorter in length. Two industry models were selected to begin the process of revamping SCL's approach to more effectively fulfill the needs of the Massachusetts companies it serves.

The first model was chosen on the basis of the author's familiarity with its successful use in an entirely different industry (Figure 4.1). The second model was selected because of its connection to the industrial cleaning field (Figure 4.2).

Figure 4.1 originated from Gaulin, Inc. of Everett, Massachusetts, manufacturers of homogenizers, colloid mills and mixers. This thesis' author developed this form in the 1980s for use in the company's Customer Service Laboratory. Firms interested in purchasing Gaulin's equipment were required to complete this form to test the machines under various conditions in order to reveal the proper processing needs of their finished goods. Examples included pharmaceuticals, foodstuffs and chemicals.

Figure 4.2 originated from Sonic Air of Fullerton, California, manufacturers of drying equipment for the cleaning industry. Sonic Air developed a number of questionnaires, based on the applications described to them by their potential clients, and used in a similar fashion as the Gaulin form.

LABORATORY TEST REQUEST
This Form Must Be Returned Before Scheduling a Test
Instructions:

1. Be as thorough as possible (please print).
2. Attach MSDSs (not required for food products) or appropriate clearance for biologicals.
3. Send samples only after testing date has been confirmed and product amounts discussed with our staff.

Company Representative:
Company:
Billing Address: Shipping Address:
Do You Wish to Witness the Test? Yes No
Product Name and Application:
PRODUCT CHARACTERISTICS
Viscosity at ambient temperature
% Oil (for emulsions)
% Solids (for dispersions)
% Surfactant (if any)
Viscosity at processing temperature
Storage temperature
Temperature limitations, if any
Density
Any special concerns:
TESTING PARAMETERS
FEE:
Equipment to run:
Sample size at each condition required for analysis:
Instructions for premix (including temperature):
HANDLING PRECAUTIONS
Recommended solvent for clean-up:
PRODUCT EVALUATION
Equipment now used for manufacture (and settings):
Current product specifications:
Method(s) presently use for evaluation:
Desired product specifications:
ANALYSIS REQUIRES FROM LABORATORY
Viscosity measurement
Light photography
Computer-enhanced particle sizing
Other:
Authorized signature: Date: P.O.#
Please return completed form to:

Figure 4.1 INDUSTRIAL LABORATORY TEST REQUEST, GENERAL

PARTS DRYING EVALUATION GUIDE

FROM

Name:
Company:
Address:

THE PART

1. Describe the part to be dried:
2. Of what material is part constructed? Can a sample be supplied to us? Yes No
   Plastic Metal Elastomer Other
3. What are the physical dimensions of the part? L: W: Ht: Wt:
4. What is the surface of the part?
   Smooth surface Blind holes and crevices Rough Surface
   Other
5. How is material transported?
   Batch Batch size Batches/Day
   Conveyor: Conveyor speed Conveyor width
6. What is your conveyorized production rate for this part?
   Parts per: Minute Hour Day
7. Conveyor type:
   Roller Belt Chain Overhead Hoist

DRYING PARAMETERS

1. Material to be removed from part
   Tap water D.I. water Wash solutions Acids/solvents Coolants/Lubricants Soils
   Other
2. Describe liquid blown off:
   Composition Percentage Temperature Viscosity
3. What happens to the part after it is dried?
   Packaged Stocked on shelf Further processing Assembly
   Other
4. What level of air filtration is needed to maintain part cleanliness?
   Standard 10 micron Cleanroom 1.0 micron Cleanroom 0.3 micron
   Other
5. What quality problems occur as a result of inadequate drying?
   Corrosion Performance failure Poor packaging Aesthetics
   Other
6. What manufacturing problems occur as a result of inadequate drying?
   Increased/additional labor costs Decreased rate of production
7. How do your parts dry now?
   Don't Heater tunnel Oven Comp air Chemicals Air knife Fans
   Other
8. What method do you use to determine dryness of the part?
   None Visual Electrical test Gross wt. Measurement Optical scanner
   Other
9. What utilities area available for your drying system?
   Electricity Cooling H_20 Exhaust air
10. Are you ready to discuss your drying needs with us? Please use reverse side for comments.

Figure 4.2 INDUSTRIAL LABORATORY TEST REQUEST, APPLICATION-SPECIFIC

4.1.3 Creating a New Cleaning Assessment Form

As a consequence of evaluating these forms, this thesis' author believed that a new form was needed. The form presented in Figure 4.3 was designed by the author and adopted by the Massachusetts Toxics Use Reduction (TUR) program's Surface Cleaning Laboratory in 1994.

1. Please print or type. Be as thorough as possible.
2. Attach MSDS of present relevant chemistries.
3. Do not send any samples/parts without first contacting SCL.

Test to be witnessed? No Yes

<u>DESCRIBE THE PART/PRODUCT TO BE CLEANED</u>

Materials of construction: Metal Plastic Other:
Please specify type:
List percentages cleaned (if more than one substrate):
(for example, 60% of parts are aluminum; 40% are 304 stainless steel)
Surface (circle two): Rough or Smooth Hard or Soft
Approx. size (dimensions in inches):
Geometry: Simple (e.g., flat) OR Complex (contains inaccessible areas)
Gram weight: Min. Max.
What is this part/product used for?

<u>DESCRIBE THE CURRENT CLEANING PROCESS</u>

Contaminants to reduce or eliminate (circle all that apply): Oil Grease Wax Flux Dirt Salt
Combination (describe): Other:
Are samples of contaminants available? No Yes (if available, attach MSDS)
Manufacturing step immediately <u>before</u> cleaning:
Manufacturing step immediately <u>after</u> cleaning:
Number of parts cleaned **per week** (or shift, etc.): **per batch**:
Equipment in use (circle all that apply): Vapor degreaser Agitation/air sparging unit
Immersion/soak/dip tank Ultrasonics Pressure spray washer (approx. psi)
Other: Specify vendor, if possible:
Cleaning Chemical(s): (attach MSDS) Concentration: %
Time: min. Temp. deg.F Water source, if applicable: DI (deionized)/Tap
Rinse Cycle, if any: Time: min. Temp.: deg.F Water source: DI (deionized)/Tap
Drying Cycle, if any: Method Time: min. Temp: deg.F
Any problems with present cleaning system?
After cleaning, parts are (circle one): Used Immediately OR Stored
If stored, How: How long:
What is the purpose of cleaning (i.e., desired product specifications)?
Methods employed for evaluating cleanliness: None Visual Microscopic UV
Other performance test, if any (please describe):
Comments or Areas of Concern:
Return any samples/parts? No Yes

Figure 4.3 TOXICS USE REDUCTION INSTITUTE'S SURFACE CLEANING TEST REQUEST FORM

4.1.4 Results, Conclusions and Recommendation

Results
After substituting the SAGE form with the form in Figure 4.3, *requests for testing at the SCL increased ten-fold during the first year of its implementation*. Because there had been no other significant changes in the solvent substitution program, the apparent success in the laboratory can be attributed to this form. Its effectiveness is primarily due to the fact that it is shorter and therefore easier to use than the form previously used in Appendix B.

Since 1994, this facility has provided technical assistance to over two hundred companies. Half of those firms required application-specific testing to replace diverse solvents used for cleaning and degreasing (Figure 4.4).

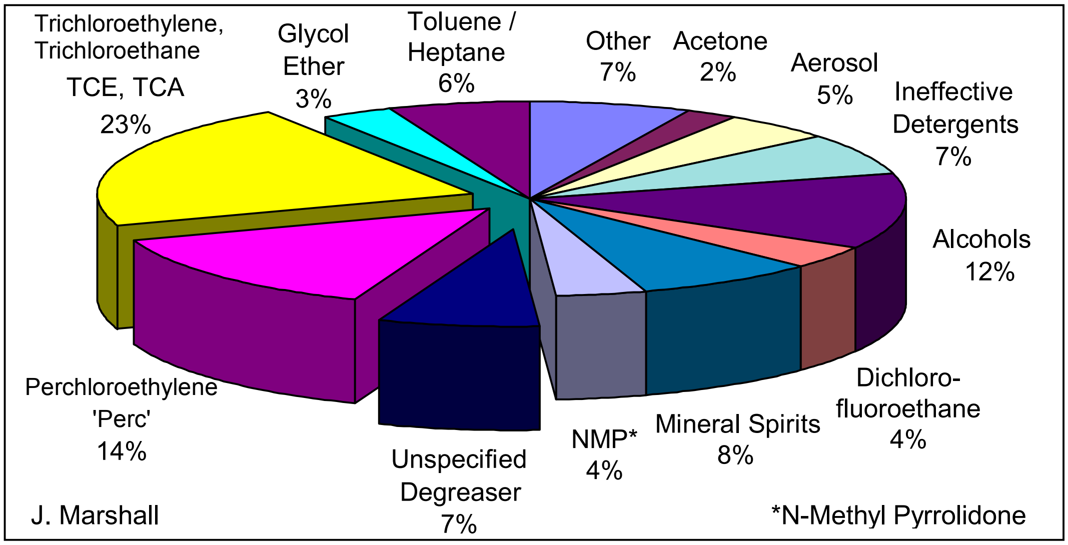


Figure 4.4 METAL-CLEANING SOLVENTS ASSESSED FOR REPLACEMENT BY SCL, 1994-1999

SCL clients represent a variety of product manufacture and service activities (Figure 4.5).

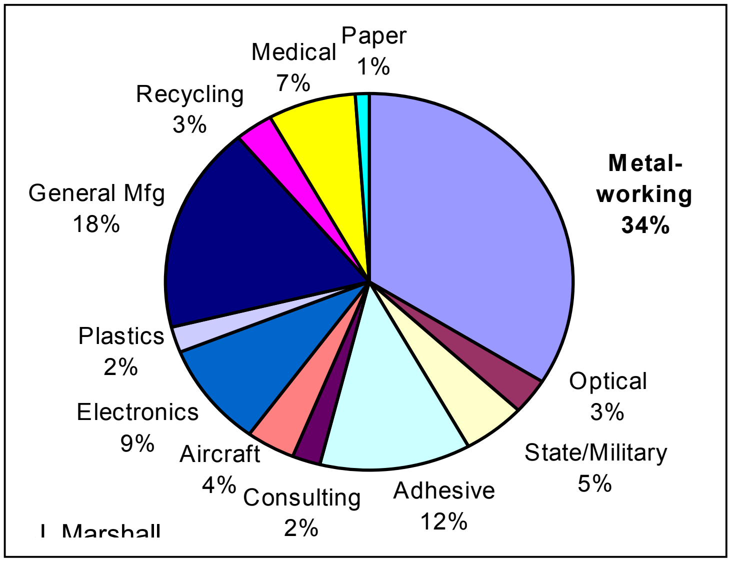


Figure 4.5
INDUSTRIES SERVED BY SCL, 1994-1999

Based on Massachusetts' Annual Report on the TUR program for fiscal years 1998 and 1999, these companies can be further categorized by geographical location. Figure 4.6 presents this data in calendar years.

A preliminary report commissioned by this author on implementation rates for the Worcester area, completed by a Clark University undergraduate student, suggests that one in seven companies is successful in carrying out solvent substitution at the plant without additional assistance from the SCL. This is similar to the performance rates of industrial laboratories tied to applications development and marketing, and slightly better than most other technical assistance programs *not providing hands-on engineering at the plant*. The majority (60%) of companies using SCL's facilities are not TURA filers, that is, those Massachusetts companies using sufficient amounts of TURA-controlled substances (not unlike the U.S. TRI-substances) that require filing and fees for usage. It can be assumed that these firms are trying to avoid coming under this regulation since many are using only slightly less than regulated amounts. Using the minimum amount required for TUR chemical reporting and the number of companies conducting trials at the SCL from 1994-1999, a decrease of 100,000 pounds in the use of toxic organic/chlorinated solvents can be extrapolated.[g]

---

[g] An estimated one-third of the companies are piloting some aspect of the cleaning recommendations made by the SCL after testing.

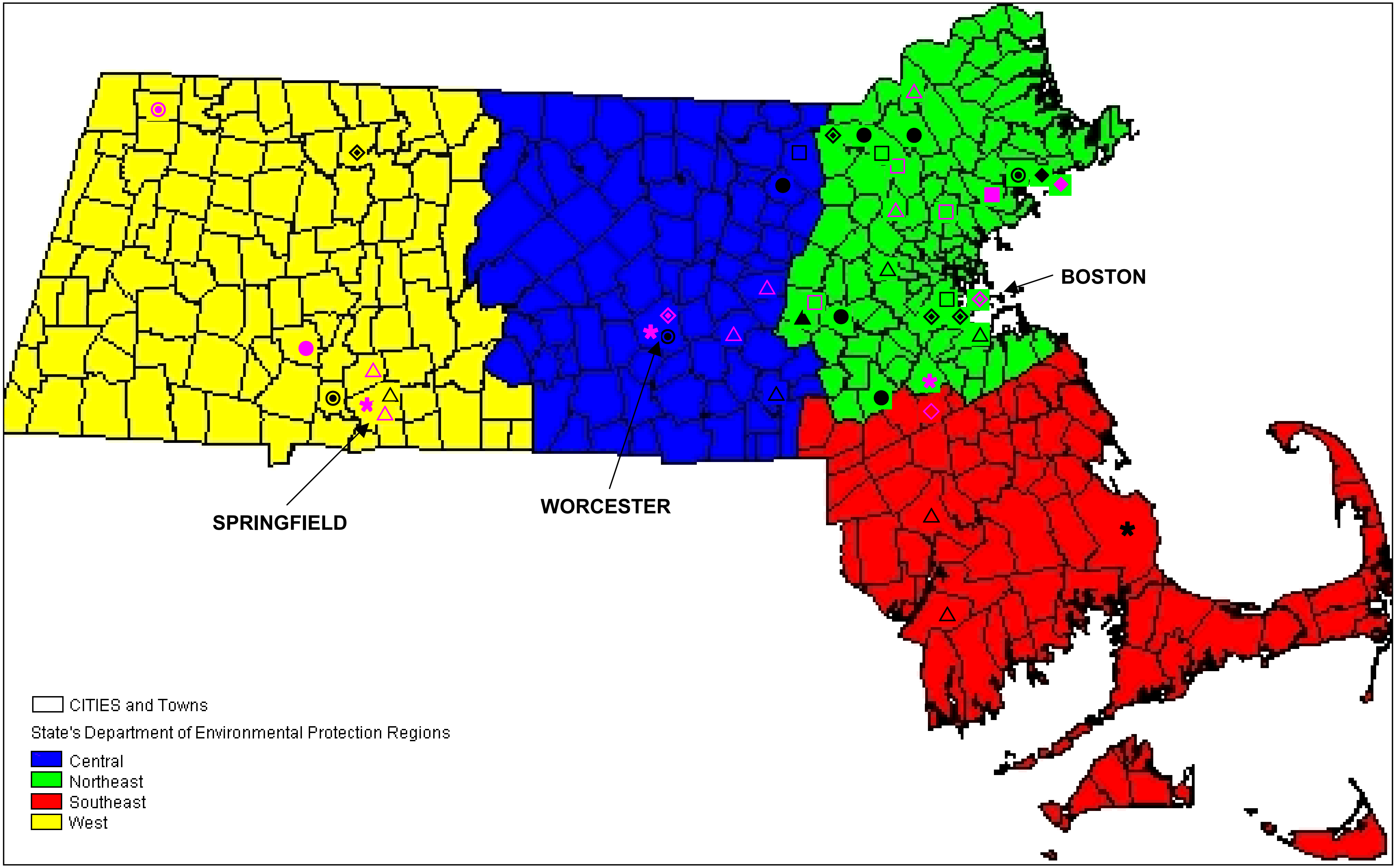


Figure 4.6 LOCATIONS OF MASSACHUSETTS INDUSTRIES CONDUCTING TESTS AT SCL, 1998 AND 1999

	Aircraft	Chemical (Adhesives, etc.)	Consulting	Electronics	General Manufacture	Medical	Metalworking	Optical	Recycling	Government (State / Military)		*Number of Companies*
1998	■ *1*	□ *3*	● *1*	⊙ *1*	✱ *3*	▲ *0*	△ *6*	◆ *1*	◇ *1*	◈ *2*	=	*19*
1999	■ *0*	□ *3*	● *5*	⊙ *3*	✱ *1*	▲ *1*	△ *6*	◆ *1*	◇ *0*	◈ *4*	=	*24*

Further information derived from the SCL Test Request Forms completed by businesses reveal the distribution of surface substrates and the types of contaminants that were to be removed. From data included in Figures 4.7 and 4.8, it is clear that steel and non-steel metals were 86% of the substrates studied and oil, adhesives and grease were the dominant contaminants present.

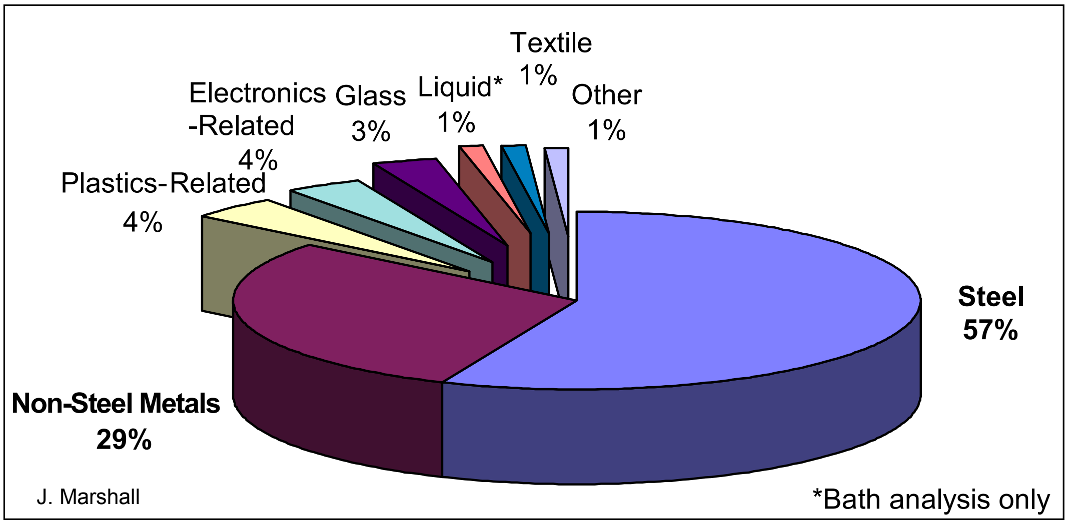


Figure 4.7 SURFACE SUBSTRATES CLEANED BY SCL, 1994-1999

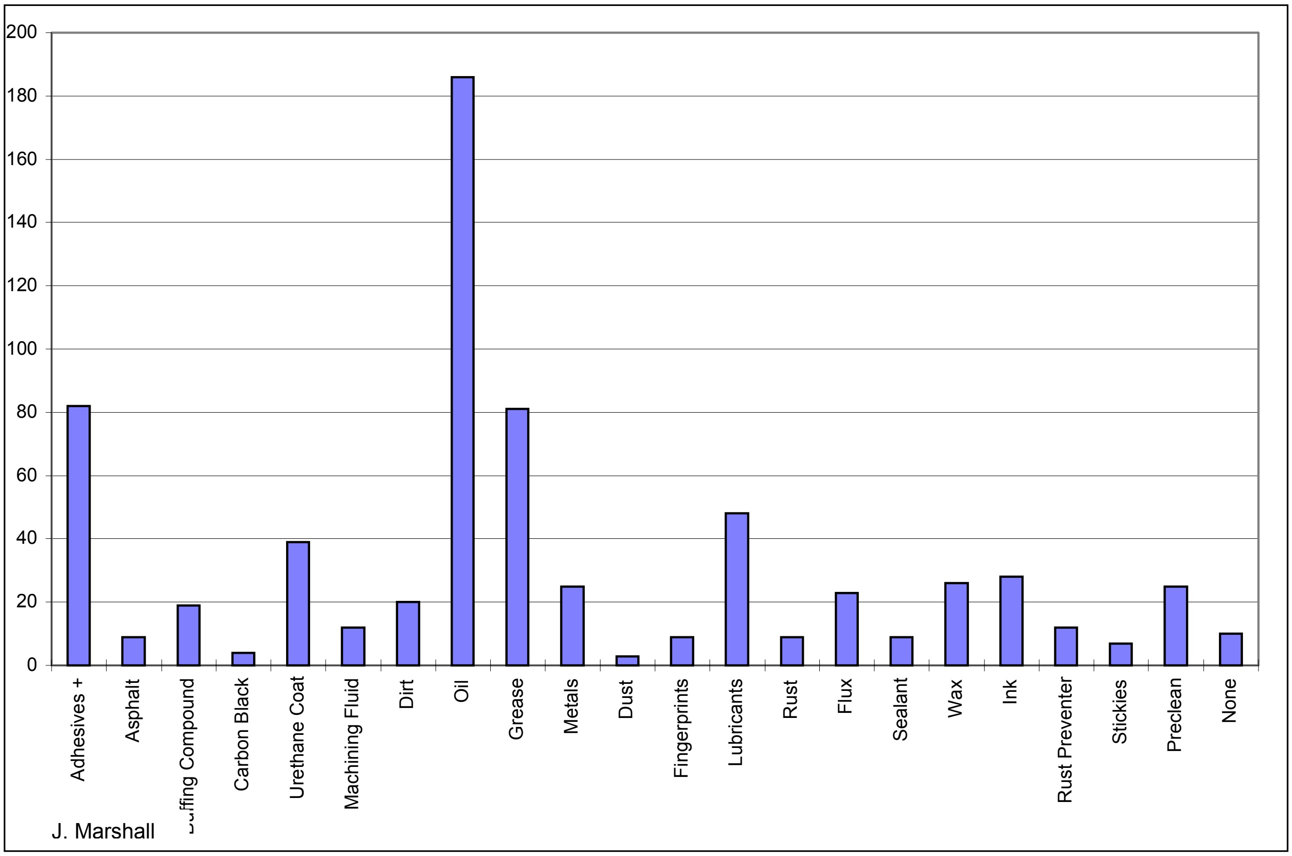


Figure 4.8 NUMBER OF TESTS CONDUCTED vs. CONTAMINANTS STUDIED AT SCL, 1994-1999

Conclusions
A substantial number (>100) of companies have requested testing at the SCL from 1994-1999 via submission of a special Test Request Sheet. Conclusions from these studies reveal:

(1) The use of a single, abbreviated test form, tailored to industrial cleaning assisted companies in the pursuit of solvent substitution. In some cases, filling out the sheet revealed opportunities for improvements in procedures or chemicals that were accomplished *without* testing, as plant personnel used the form to become familiar with all aspects of the cleaning process and the related manufacturing steps.

(2) Approximately one-third (37%) of all tests conducted at the SCL were performed for the replacement of chlorinated organic solvents TCE, TCA and 'perc.' Though the substantial hazards associated with these chemicals have been well known for some time and not disputed, the science of solvent substitution lags behind.

(3) The metalworking industry is the most visible (34%) sector in Massachusetts to use SCL's services. Yet over one-half (57%) of all tests were performed on various steel substrates. This means that not all of the metal examined at the SCL was in traditional metalworking fields, but in other trades such as electronics and is reflective of the more robust, high-tech industries which entered the state's economy during this interval.

(4) Oil is the most common (2:1) industrial contaminant found in the applications studied thus far. Tribologists, the scientists whose job it is to formulate oils, should develop products that are easier to remove during the cleaning process, without jeopardizing the oils' lubricating properties.

Recommendations
While the current SCL Test Request Form works well with industries performing parts cleaning, improvements could be made in its format to include maintenance cleaning. This would encourage municipalities (town departments), communities (hospitals and schools) and other industries (hotels and restaurants) to explore solvent substitution opportunities.

An increase in the types of substrates cleaned by the SCL (floor tile, bathroom ceramics, etc.) would be expected. Although some of the same surface contaminants would be present, new contaminants under investigation could include microbes, mold and mildew.

4.2 Analytical Techniques Used to Determine Surface Cleanliness

If the purpose of solvent substitution testing is to identify a safer, greener cleaning process that is at least as effective as its solvent-based counterpart, then *benchmarking* becomes necessary. Benchmarking is achieved by conducting scientific comparisons of variously treated surfaces via standardized and reproducible analytical methods.

Depending on the application, the American Society for Testing and Materials (ASTM) and other standards such as military specifications may be employed (chapter seven). While there is a host of other possibilities (section 4.2.7), this chapter focuses on the six major surface analysis techniques used by the SCL that are acceptable to the scientific community and cover the widest range of applications.

4.2.1 Gravimetry

Direct Method

Properly employed, gravimetric analysis can be the most inexpensive and revealing of all surface measurement techniques. The importance of this method is noted in the aqueous cleaning test method described in chapter five.

Ideally, the part or test coupon is weighed a total of three times with the same analytical balance and under the same atmospheric conditions. Weights are taken (1) before artificial contamination, (2) after artificial contamination and (3) after cleaning. Cleaning trials conducted under such conditions should be repeated a minimum of three times to ensure reproducibility of results. Percent soil removal rates and standard deviations can then be calculated. Some difficulty may arise in arriving at a pre-contamination weight under actual plant/production settings, though estimates may be possible, provided that the parts are relatively small and a significant volume of parts are examined. Care must be taken in selecting near-identical substrate pieces and applying the contaminant in a consistent manner. These problems are mostly avoidable by using test coupons instead of actual parts in preliminary tests. Standard Operation Procedures (SOPs) are followed for both balances used by the SCL and an example SOP from the laboratory's experimental log is found in Figure 4.9.

DATE:
EXPERIMENTER:
SUBSTRATE MATERIAL:
COMPANY NAME:
DESCRIPTION OF EXPERIMENT AND TREATMENT OF COUPONS:

GRAVIMETRIC ANALYSIS:

Coupon Number	Weight of Pre-cleaned Coupon	Weight With Contamination	Weight After Cleaning

OBSERVATIONS:

Figure 4.9 EXPERIMENTAL PARAMETER LOG FOR GRAVIMETRIC ANALYSIS

In addition to cleanliness, gravimetric analysis can reveal surface conditions such as etching. Etching is surface damage caused by chemical or other means of perturbation. An etched substrate will typically weigh less than its undamaged counterpart. This effect can also be verified microscopically. Chapter seven contains a specific example of gravimetry used to detect etching (Table 7.8).

Indirect Method

Non-volatile residue (NVR) may be collected by a solvent extraction/flush of the part. The rinse solution is run through a filter paper of known weight and the filter subsequently dried and weighed as well as visually inspected. This method is not routinely employed by the SCL since it (1) assumes that the solvent extraction will remove contaminants that the cleaning process did not, (2) is more time consuming that the direct use of gravimetric analysis and (3) is not as reliable as a direct measurement of surface cleanliness.

4.2.2 Microscopy

Microscopy is a well-established method for evaluating cleanliness, but is not widely used in manufacturing for quality control. This is because only a select number of parts from any one production line can be viewed microscopically in a timely fashion. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) offer magnifications as high as several thousand that can detect the minutest detail of surface morphologies. As opposed to these microscopic techniques associated with precision cleaning, other types of parts cleaning may be monitored with a stereoscope at magnifications well under 1000X. A variety of camera attachments are available for most light microscopes as are computer software packages that 'count' the soil load per photographic frame and store the information on disks for a permanent record. Some of these programs can be downloaded from the World Wide Web at minimal cost from quasi-governmental sites. There are microscopes with photographic capabilities (Polaroid of Massachusetts and Olympus of New York) to suit almost every surface cleanliness application.

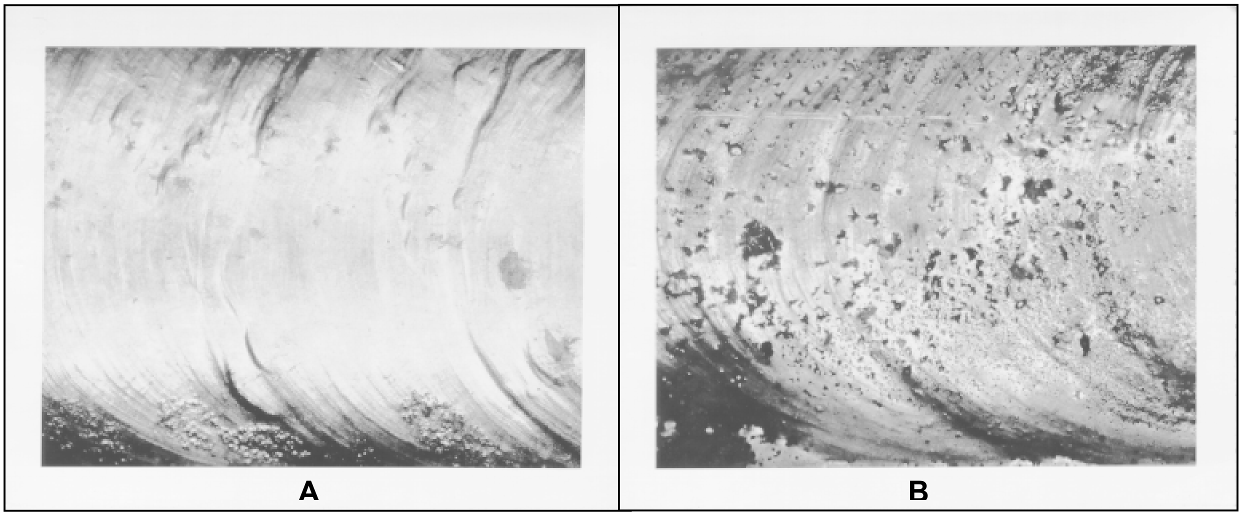


Figure 4.10 PHOTOMICROGRAPHS OF SUCCESSFUL (A) AND FAILED (B) CLEANING OF ALUMINUM PLATES

The pictures in Figure 4.10 dramatically illustrate the effects of poor and successful cleaning tests of aluminum plates from a Massachusetts forging company. The black-and-white instant photos were taken with a Polaroid MicroCam (magnification: 10X) at the SCL.

4.2.3 Goniometry and Other Secondary Surface-Effect Phenomena

Laser or optical contact angle goniometry is the measurement of a secondary surface-effect to extrapolate cleanliness. In this method, a small drop of solvent, usually deionized (DI) water is placed on the substrate by a needle suspended over the part. A light is shown to reflect the droplet's interface with the surface. Usually, the higher the contact angle (that is, the height of the bubble), the greater the contamination. Conversely, water dropped on a clean surface generates a much smaller, flatter contact angle. An example of this effect is noticeable after waxing and then washing a car; the remaining wax acts as a contaminant and the residual water on the surface of the car 'bubbles up.' Contact angle goniometry is a limited technique in that only the cleanliness under the tiny drop is measured. Consequently, several readings must be taken at different points along the part or test coupon. The potential exists for automation, however. Interferences in obtaining correct readings can arise due to differences in surface porosities and evaporative rates of the liquid solvent being used. Flat surfaces are more conducive to accuracy with this method.

Figure 4.11 presents contact angle readings for before-and-after cleaning trials on behalf of a major U.S. defense department contractor.

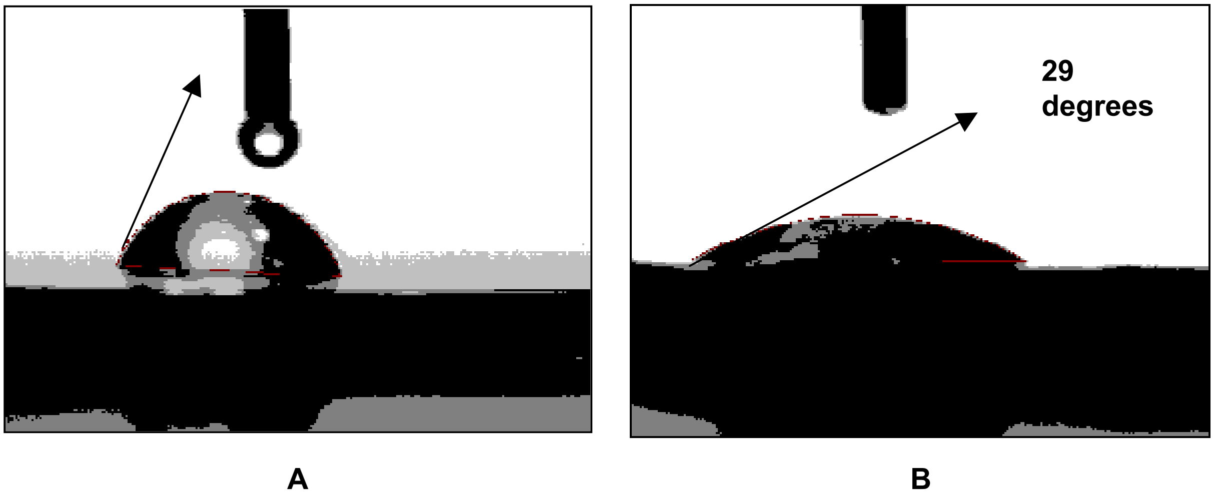


Figure 4.11 CONTACT ANGLE MEASUREMENTS FOR A SURFACE PRIOR TO (A) AND AFTER (B) CLEANING

Water Break Test

Another qualitative method to measure the ability of water to 'wet' a surface is the water break test. A test coupon or part is placed in a beaker of water or a stream of water is allowed to flow gently against it. The behavior of the water while the item is slowly withdrawn from the container or runs off the surface of the part is noted. The water will wet (spread out on) a clean substrate such as metal or ceramic, whereas the presence of an oil film on these surfaces will cause the water to 'break' or bead up.

Tensiometry

Tensiometry is the study of the surface tension of liquids. A graded set of solutions of known surface tension is used to establish the surface energy of the part which is proportional to surface cleanliness. Similar to goniometry and the water break test, this is accomplished by comparing the behavior of a drop of each of the solutions on the surface.

Functionality Tests

Functionality, performance or characteristic tests measure whether the surface is clean enough for subsequent processes by examining the outcome of those processes (e.g., quality of plated finish, failure rate). It is cited in the SCL's request for information on cleaning applications found in Figure 4.3. These tests are product-specific and are usually generated by manufacturers irrespective of cleaning. With the companies' aid, the tests are occasionally duplicated at the SCL.

4.2.4 Fluorescence and Other Visual Aids

Some contaminants, in particular lubricants, naturally fluoresce. Examination under black light reveals the location and extent of this type of surface contamination. Artificial fluorescence is possible with the addition of chemical tags, similar to those used in forensics. The SCL uses a Spectronics Corporation (Westbury, New York) tagger known as Ar-Glo® 1. This technique is limited to oily contaminants, however. Fluorescence/black light examination is a user-friendly, inexpensive procedure that is also highly effective.

White Glove or Wipe Test

In addition to fluorescence, a clean white glove or new wipe/swab can be used to manually check for residual contamination.

4.2.5 Optically Stimulated Electron Emission

Optically Stimulated Electron Emission (OSEE) or Photo Electron Emission (PEE) is based on the principle that metals and certain surfaces emit electrons upon illumination with ultraviolet (UV) light. These electrons can be collected, measured as current, converted to a voltage and digitally displayed. A surface contaminant will either enhance or attenuate this signal, depending on its photoemissive nature. While OSEE will not identify a contaminant, it is a good comparative tool to determine the degree of contamination. The method is best suited for thin films (oils, etc.) and not particulate matter (dust, for example).

Figure 4.12 (A and B) illustrates the operational particulars of OSEE.

1

► WHAT IS OSEE ?

OSEE is defined as the process by which UV photons interact with a surface to produce electrons

- Optically Stimulated Electron Emission (also known as PEE, Photo Electron Emission)
- Principle discovered by Einstein, circa 1917
- Electrons are emitted from certain (i.e., metal) surfaces when exposed to UV (ultraviolet) light at the proper nm (nanometer) wavelength

2

► FURTHER DEFINITIONS & CLARIFICATIONS

- Photoemitters - Materials/surfaces or contaminants that emit electrons when exposed to UV light
- Surfaces with no contamination *usually* give a high signal; a contaminant, depending on its own emissive characteristics, either attenuates OR enhances the signal from the substrate

3

► OSEE RESPONSE DETERMINED BY:

- Photoemissive nature of contaminant
- For example,
  Clean surface = Current (I) generator and
  Non-photoemitting contaminant = Resistance
- Therefore,
  the heavier the contaminant,
  the higher the resistance *and*
  the greater the decrease in measured signal

4

► OSEE METHODOLOGY

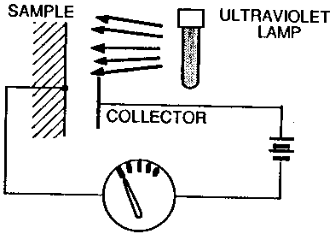
Emitted and scattered electrons are:

- Collected across an air gap by a biased collector, located on a sensor using a lamp at 185 nm and 254 nm (6.6 and 5.0 ev*, respectively)
- Measured as current (amps)
- Converted to a digitally-displayed voltage

****ev = electron volts***

5

< SCHEMATIC DIAGRAM OF OSEE SYSTEM



6

► FACTORS EFFECTING OSEE RESULTS

- **Long-term (instrument condition):**
  - UV light intensity
  - Collector bias voltage

Refer generally to calibration (direct and indirect) and proper maintenance.

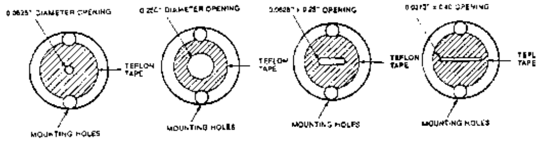
7

► FACTORS EFFECTING OSEE RESULTS

- **Short-term (sample condition):**
  - Specimen must be properly grounded
  - Surface finish (lapped, milled, etc.)
  - Thickness of coating/contaminant
    normal range: 2 to 7500 angstroms
  - Sample size and shape / aperture setting

8

< TYPICAL APERTURE SET



Special resolution is approx. 10% of the sensor opening.

Figure 4.12A PRINCIPLES OF OPTICALLY STIMULATED ELECTRON EMISSION (OSEE)

9

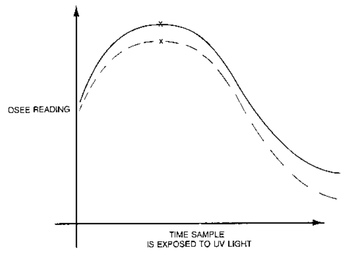
- *FACTORS EFFECTING OSEE RESULTS*
- **Short-term (experimental condition):**
  - **Duration of UV exposure on surface (peak detect)**
  - **Line voltage**
  - **Temperature and pressure**
  - **Air flow/turbulence at sensor**
  - **Humidity and static charge**
  - **Distance of sensor to surface - readings directly proportional**

10

- *IMPORTANT OSEE PARAMETERS*
- **UV light *flux* provides energy needed by substrate to emit electrons**
- **Changes in the recorded photocurrent = changes in the specimen's surface when surface-to-collector distance = constant**
- **Repeated measurements of the same spot to show repeatability and reproducibility are not appropriate (use constant-speed scan)**

11

< ***OSEE READINGS VS TIME***



12

- *OSEE CHARACTERISTICS*
- **Non-destructive and non-invasive**
- **In-process as well as lab scale**
- **Economical and rapid (scan to 7500 ft./min.)**
- **Quantitative (not qualitative)**
- **Applicable to a variety of surfaces (excluding teflon) and film contamination to a molecular level (not particulates)**

13

- *OSEE USES*
  - **Surface preparation monitoring -** ***intermediate products***
  - **Quality control -** ***finished products***
  - **Measuring thickness of** ***thin films and coatings ****

The attenuation of an OSEE signal is inversely proportional to a contaminant's thickness, within its material-specific range.

Figure 4.12 B PRINCIPLES OF OSEE (Cont.)

4.2.6 Spectroscopy

Fourier Transform Infrared spectroscopy (FT-IR) correlates vibrational energy to a compound's molecular signature. Similar to other high-tech methods such as gas chromatography (GC), the curves generated in this analytical technique are both qualitative for species identification (the placement of the curve on the electromagnetic spectrum) and quantitative for amounts (the area under the curve). Not all contaminants can be identified in this way (for example, inorganic materials not possessing the necessary atomic bonding) and interpretation of graphs can be difficult due to the presence of interfering peaks. It may be used in cleanrooms for disk drive manufacture where the source of contamination may be entirely unknown and the amounts of contamination very low. A relatively expensive instrument, an FT-IR spectrometer requires special training and care in sample preparation. While spectroscopy is an excellent analytical tool, it is too costly for routine product inspection for most companies involved in parts cleaning.

The SCL operates a Nicolet Magna IR™ Spectrometer Model 550. Figure 4.13 is a spectrograph of contaminants found on the surface of boiler parts manufactured in Massachusetts.

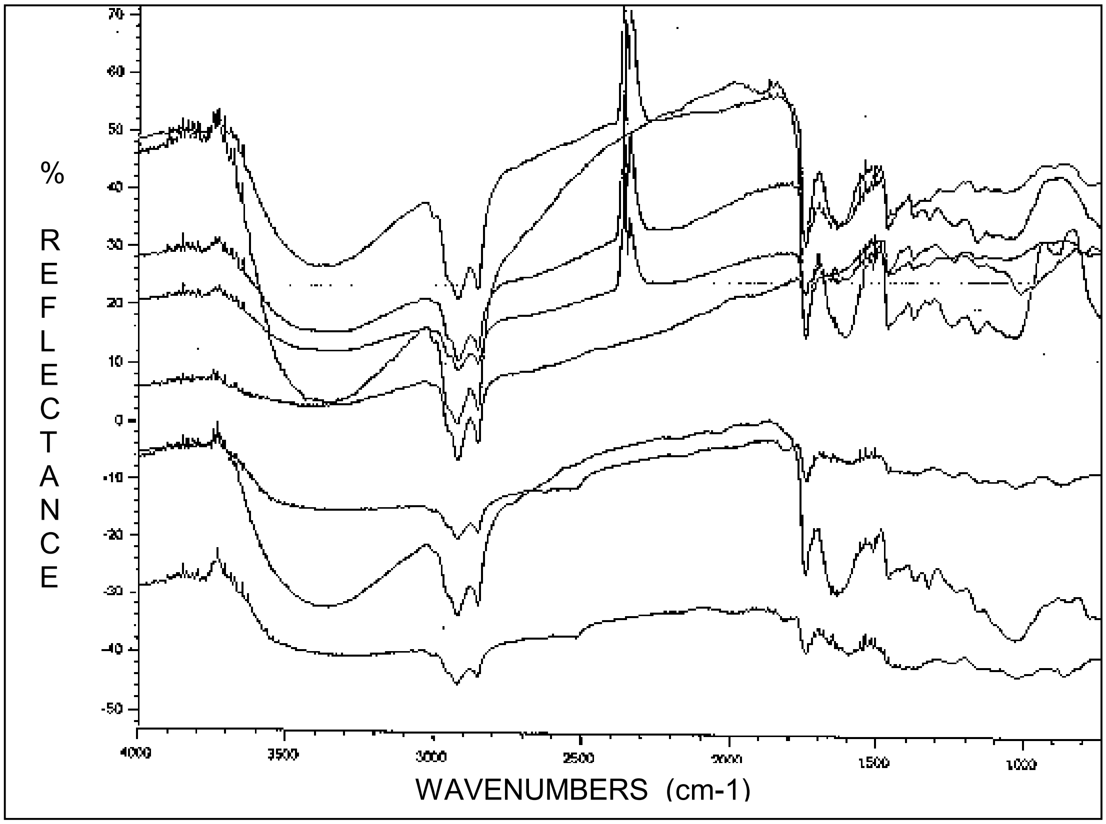


Figure 4.13 FT-IR SPECTRA OF BROWN PARTICLES ON BOILER FIN

4.2.7 Other Techniques

Direct Measurement of Surface Cleanliness

The major spectroscopic techniques not under investigation at the SCL are listed in Table 4.4. These methods have not been selected primarily because of their high capital cost and the low incidence of requests for associated applications from the Massachusetts business community.

Acronym	Spectroscopic Technique	Characteristics of Test
AES	Auger Electron Spectroscopy	Sensitivity 2-5nm; Detection Limit 10^3 Solids, organic species only Quantitative Method
ESCA	Electron Spectroscopy for Chemical Analysis	Detection Limit 10^4 Most materials
ISS/SIMS	Ion Scattering / Secondary Ion Mass Spectroscopy	Detection Limit 10^6 Solids only ISS Quantitative Method, SIMS Not
XPS	X-ray Photoelectron Spectroscopy	Sensitivity 2-5nm Quantitative Method

Table 4.4 OTHER METHODS OF SPECTROSCOPY [48, 51]

Dozens of other surface characterization tests (desorption studies, diffraction, ellipsometry and radiation as well as other forms of spectroscopy) may be appropriate for the determination of cleanliness. They are beyond the scope of the present work.

Indirect Measurement of Surface Cleanliness

Residual contaminants may also be removed by solvent extraction by exposing the part to an organic solvent flush. The solvent is then analyzed via traditional methods for the presence of contaminants. This technique assumes that the extraction will remove residuals that the original cleaning process did not.

If the purpose of the SCL is to reduce or eliminate the use of toxic substances in industrial cleaning practices, then their re-introduction in the analytical stages refutes the lab's primary objective. Solvent extraction is, therefore, not an option in the pursuit of greener laboratory practices.

More Methods

Like NVR measurement, particle counting, turbidity and conductivity are indirect methods, the use of which is typically limited to the analysis/monitoring of cleaning and rinsing baths. This topic will be addressed in chapter eight.

4.2.8 Results, Conclusions and Recommendations

Results

Figure 4.14 confirms a trend towards more scientific surface evaluation. As the number of tests for which the SCL was able to conduct gravimetric analysis increased, visual inspection as the sole means to measure surface cleanliness, decreased. All other analytical techniques were used to a much lesser extent.

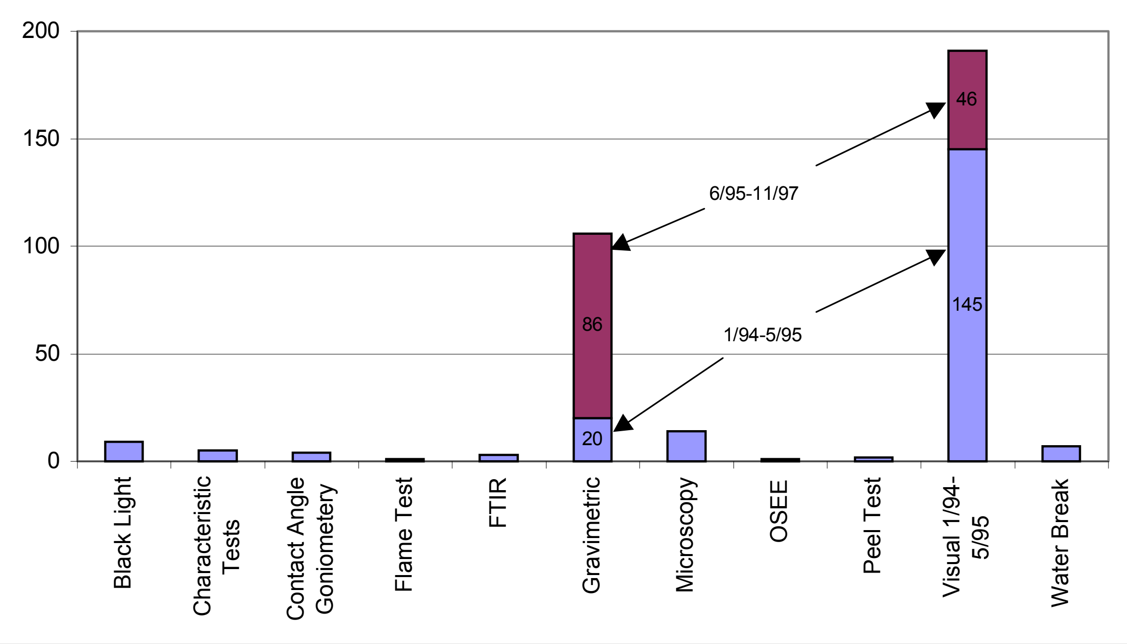


Figure 4.14 NUMBER OF TESTS PERFORMED vs. ANALYTICAL METHODS USED AT SCL, 1994-1999

Conclusions

Following a complete review of analytical methodologies, conclusions from the SCL data reveal:

(1) For the first 16 months of surface cleanliness determination by the SCL, the ratio of gravimetric (objective) vs. visual (subjective) analyses was 1:7. Over the subsequent 17 months, the ratio was 2:1. Subjective evaluation methods, for example white glove and water break tests, should be considered to be incomplete and insufficiently accurate for most modern metal-cleaning applications. This is important, since many industrial as well as military cleaning operations are still maintained to these inadequate standards, where personnel are not trained to any degree of sophistication.

(2) The number of spectral analyses conducted by the SCL for 1994-1999 was less than expected. For applications in which FT-IR was an appropriate choice, the SCL oftentimes lacked a necessary accessory costing hundreds of dollars. On some occasions, arrangements were made with the spectrometer's manufacturer to evaluate samples at their facility. This method, then, cannot be seen as user-friendly enough to be of significant value to the vast majority of metalworking applications, in or out of the SCL.

(3) On the basis of instrument capabilities at the SCL, very little attention was given to particulate matter in the analysis of contamination. While this is justifiable from an application point of view (Figure 4.7), it is also true that industrial contaminants such as greases and oils tend to capture dirt, dust and other solid debris to the surfaces on which they are present.

(4) Surface treatments such as buffing compounds are almost never cleaned from parts alone; they are usually entrained with particulates after the buffing process.

(5) Consequently, analytical errors could be made since (1) cleanliness testing might vary from one contaminant to another, even on the same substrate and (2) mixtures of contaminants, such as dust and oil, might respond to cleanliness testing differently from the way the individual contaminants responded.

(6) Surface analysis devices and methodologies for cleanliness inspection need further development. The testing performed at the SCL thus far is really a comparative study of available, practical (i.e., economically feasible) cleaning technologies. The search for the latest innovations in industrial cleaning will evolve as sustainability factors such as life cycle assessment (LCA) become better scientific tools for incorporation into other multi-disciplinary endeavors like total cost accounting (TCA). This effort will be enhanced as more companies seek ISO 14000-series certification or its European counterpart, EMAS. These topics are discussed in chapter eight.

Recommendations

Two analytical techniques for surface cleanliness should be utilized for each cleaning application: a primary and a secondary method, based on entirely different scientific principles, to verify the results. This should account for differences in detection methods and contaminant mixtures.

The purchase of FT-IR accessories is not worthwhile from a cost/usage perspective at the SCL. Acquiring a computer-based spectral library similar to those used in the petrochemical industry, however, would enhance peak identification for those cleaning processes, for example, in the semiconductor industry, where FT-IR application is feasible. This would enhance the SCL's services to high-tech clients.

Future acquisitions of analytical equipment should focus on the evaluation of solid particles. This would be especially helpful for locating and identifying entrained matter such as metal fines (for example, in buffing compounds). Their presence and numbers impact the choice and performance of cleaning processes. Particulates may also contribute to air-borne pollutants that exacerbate health conditions such as asthma if aerosoled during the any manufacturing step, including surface cleaning.

Although not reflected in Figure 4.14, OSEE and new advances in contact angle goniometry offer the most comprehensive approach to satisfying the upcoming needs of many diverse industries for surface quality monitoring. Plans are underway to use this method more frequently, in conjunction with instrument research and development at the SCL.

5 Developing a Test Method for Surface Cleaning, Part II

Once this thesis' author had devised a form to obtain meaningful background information from client companies in advance of solvent substitution testing at SCL, it became necessary to develop a test method or experimental design to perform the actual trials. This protocol had to be in a format that was applicable for a variety of aqueous/semi-aqueous cleaners to be tested, *regardless of the solvent to be replaced or the industry under investigation.*

- Acquiring general knowledge of alternative chemical/engineering processes for surface cleaning.
- Designing a test questionnaire for solvent substitution from internal and external sources.
- ➡ Developing a test plan, based on the scientific method and focused on aqueous cleaners.
- Enhancing the search for safer and greener chemical cleaning with the use of other alternative (i.e., non-aqueous) cleaners.
- Enhancing the search for safer and greener chemical cleaning with the use of internal and external expert systems.
- Reviewing application-specific laboratory test results with multi-stakeholder, multi-disciplinary teams over five years.
- Proposing a matrix or tool for environmental decision-making in solvent substitution.
- Building a 'critical thinking' methodology for the successful technical diffusion of the computer tool.
- Envisaging the future of industrial cleaning and related public policy.

5.1 Determining the Stages of an Aqueous Cleaning Trial for this Study

Section 3.1.4 introduced the parameters of time, agitation, temperature and concentration in testing water-based cleaners. The test phases outlined in this chapter judiciously utilize these variables, as do other standard methods (listed in chapter seven and reviewed in section 8.2) that did not meet the above universal-application needs.

5.1.1 Phase I: MSDSs, Cleaning Coupons and Subjective Analysis

Material Safety Data Sheets: Brainstorming and Shortcomings
The first duty of any cleaning practitioner is to clean the parts without damaging them. This often translates into understanding the impact that cleaning has on other manufacturing processes and can only be accomplished by being well informed by the same team of professionals who completed the Test Request Form (Figure 5.1). Likewise, team members should be kept informed as testing proceeds.

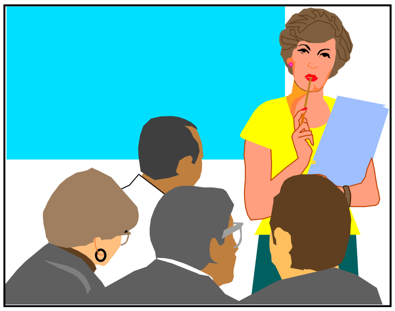


Figure 5.1
LISTENING TO COLLEAGUES' CONCERNS INCREASES CHANCES FOR SUCCESS

Also required for successful solvent replacement is a thorough understanding of the parts' materials of construction and the chemical constituents of the contaminant and the prospective substitute cleaners. These points were introduced in chapter four (Tables 4.1 and 4.2). Initially, this entails the collection of all pertinent product information, usually in the form of MSDSs and technical data sheets. Nevertheless, at least one study by the Canadian government, appearing in Applied Occupational and Environmental Hygiene (Volume 15, 2000) has revealed major flaws in MSDSs, mandated to reveal important health and handling risks, "where hazardous ingredients, present in significant concentrations in a controlled product, are not listed." Technical data sheets, if any, indicate the applications for which a product is best suited. The following examples depict an MSDS (Figure 5.2) for an aqueous cleaner and its corresponding technical data sheet (Figure 5.3).

GRACE CONTAINER PRODUCTS
W.R.Grace & Co. - Conn.
55 Hayden Avenue
Lexington, MA 02421-7999
EMERGENCY PHONE NO. (781) 861-6600

SECTION I – IDENTIFICATION

PRODUCT (TRADE) NAME: DARACLEAN~ 203X
General Chemical Description: Waterbased high alkaline cleaner

SECTION II - INGREDIENTS

Maximum Exposure Value (ppm)
(8 hour time-weighted average)

Hazardous Ingredients	% by Weight	OSHA PEL*	ACGIH TLV**
potassium hydroxide (CAS# 1310-58-3)	10 approx.	2 mg/m3 (ceiling)	2 mg/m3 (ceiling)

* 29 CFR Section 1910.1000, July 1, 1992
** 1997 recommendation, American Conference of Governmental Industrial Hygienists

SECTION III - PHYSICAL DATA

Solubility in Water: Complete
pH 14.0
Appearance: Colorless to pale yellow liquid
Specific Gravitv (water=]): 1 approx.
Boiling Point: 212°F approx.
Odor: Mild

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flash Point: None to boiling
Extinguishing Media: Carbon dioxide, dry chemical, foam. Avoid water if possible, as water may cause spattering of hot material and may spread burning.
Combustion will result in the release of the usual decomposition products including oxides of carbon and nitrogen. May also include sulfur.

SECTION V - REACTIVITY DATA

Product is stable; hazardous polymerization will not occur.
Incompatible with strong oxidizers.
Do not mix with strong acids.

SECTION VI - SPILL OR LEAK PROCEDURES

Handling Precautions: See Section VIII.
For Small Spills: Wipe up, or absorb with sand or other absorbent material. Collect waste in sealed containers.
For Large Spills: Dike area to prevent spreading. Absorb residual material with sand, or other absorbent material. Wash area with soapy water and rinse. Area will be slippery until cleaned.
Material is defined as a hazardous waste with EPA Waste Number D002.
Dispose of all product wastes and water rinses in accordance with current local, state, and Federal regulations.

SECTION VII - HEALTH HAZARD DATA

Threshold Limit Values: See Section II.

Signs & Symptoms of Acute Exposure	Emergency First Aid Procedures
Inhalation: Airborne concentrations of mist or spray may cause damage to the upper respiratory tract.	Remove to fresh air; get medical attention.
Corrosive upon direct contact.	Immediately flush eyes with water for at least 15 minutes; get medical attention
Corrosive upon direct contact.	Wash affected area with water; if irritation persists, get medical attention. Remove contaminated clothing.
Ingestion: Harmful if swallowed.	Dilute with water or milk; do not induce vomiting; get medical attention.

CHRONIC EFFECTS: None known.
Medical Conditions Aggravated By Overexposure: None known.
GET MEDICAL ATTENTION IF SYMPTOMS PERSIST

SECTION VIII - SPECIAL PRECAUTIONS

Handling and Storing:
- Does not normally become airborne; in operations where it does, if general ventilation or local exhaust is inadequate, persons exposed to mists should wear approved breathing devices. - Wear neoprene gloves if direct contact likely; wear eye protection. - Store product at 40-100°F in a well-ventilated area.

PREPARED 01/11/99

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Figure 5.2 MSDS OF AN AQUEOUS CLEANER

GRACE Metalworking Fluids

DARACLEAN 203X: Aqueous Low Foam Caustic Cleaner Data Sheet

DARACLEAN 203X is a high pH waterbased cleaner containing caustic alkali inhibitors chelator and a blend of surfactants in a water base. It is specially formulated for high pressure and immersion cleaning applications where tough soils are involved. DARACLEAN 203X contains strong caustic alkalies. **Do not use with aluminum alloys.**

- No SARA reportables
- No fragrances
- No phosphates
- Recyclable
- Free rinsing
- No silicates
- No glycol ethers
- No nitrites
- No foam

Applications/Starling Dilution

Method	Concentration	Temperature	Typical Duration
Soak	5 - 30%	Ambient - 160°F	0.5 - 30 Minutes
Agitation	5 - 30%	Ambient - 160°F	0.5 - 30 Minutes
Spray	3 - 30%	Ambient - 200°F	0.5 - 30 Minutes
Steam	1 - 10%	130 - 200°F	0.5 - 30 Minutes
Ultrasonic	5 - 30%	Ambient - 180°F	0.5 - 30 Minutes
Inhibitor/Rinse Aid	Not recommended		

Concentration temperature and duration may be adjusted for optimum performance.

Concentration Check Procedure

Test Kit Titration Method

Sample Size: 1 ml

Titrant: Indicator: 0.5 N Acid

Concentration (%|:Phenolpthalein

Drops titrant x 1.0

Conductivity Method

Conductivity reading (mS) . 4.4 =

% DARACLEAN 203X

Refractometer Method

Reading (°Brix) x 3.0 = % DARACLEAN 203X

Typical Readings	5% = 1.5°Brix
	10% = 3.3°Brix
	25% = 8.3°Brix

DARACLEAN 203X has been found effective at removing a variety of soils including heavy oils, greases, carbonized oil and some light rust.

Typical Physical	
Alkaline	1.9- 2.1 (MEQ to pH 8.3)
Equivalent	2.2-2.5 (MEQtopH4.0~
Appearance	Clear, colorless to pale yellow
Cloud Point	<80 °F 110% in DI
Conductivity,	244 mS
Foam	Very low
Odor	Mild
pH, 10% Diluted in DI Water,	13.0
pH, Concentrate, 25°C	14.2
Refractive Index,	30 - 35°Brix (undiluted at
Specific Gravity	1.12
Surface Tension, 10%	34 dynes/cm
Vapor Pressure	1 ~ mmHG @ 20°C
VOC,10% {EPA Method 24	0.0 lbs/U.S. gallon (0.0
VOC, Concentrate {EPA Method 24	0.0 lbs/U.S. gallon ~ 0.0
Weight/U.S. Gallon	9.35 lbs

Immersion Corrosion,	100%,10%, 1% Excellent
Copper Corrosion,	100%,10%, 1% Excellent
Cast Iron Chip Corrosion,	100%,10%, 1% Excellent

Disposal: DARACLEAN 203X can be pretreated via skimming and/or filtering. Final sewerability is determined by the municipal sewer district covering the plant location.

Availability' Storage, and Handling: DARACLEAN 203X is available in 5 gallon pails, 55 gallon drums, 330 gallon totes, and tank truck quantities. It is recommended that DARACLEAN 203X be stored in well-ventilated areas at temperatures between 40°F and 100°F. The recommended shelf life of this product is one year.

Do not freeze or heat concentrate above 140 oF; contents may separate.

We hope that the Information given here will be helpful. It Is based on our best knowledge. and we believe it to be true and accurate please read all statements, recommendations or suggestions herein in conjunction with our, conditions of sale which apply to all goods supplied by us. We assume no responsibility for the use of these statements recommendations or suggestions nor do we intend them as a recommendation for any use which would infringe any patent or copyright.

DARACLEAN. is a registered trade name of W.R. Grace & Co. - Conn.Rev. 3/98 DCN203X

Figure 5.3 TECHNICAL DATA SHEET FOR THE SAME AQUEOUS CLEANER DESCRIBED IN FIGURE 5.2

Both forms should be used if both are available, since the information provided is different. In the above example, it would not be appropriate to test this cleaner on aluminum parts. This processing information was obtained from the technical data sheet (fifth line, Figure 5.3), not from the MSDS. Having determined what is *not* appropriate for this application, the brainstorming session should include as many chemical-cleaner types as is practical (usually, no more than six) to test and monitor. Two categories might be (1) an aqueous cleaner based on sodium hydroxide with a nonionic surfactant (typically proprietary) and (2) an aqueous cleaner with a potassium hydroxide base and a different kind of surfactant. *If the tests are to be conducted by one researcher during the same time interval*, the selection should be limited to one soil per substrate since all experiments should be conducted in triplicate, at the very least. The resultant 18 sets of data can be used to access negative cleaning capacity of diverse cleaners. The best sources of information in making choices for Phase I testing, then, are vendors and specialty databases (sections 6.2 and 7.1).

Cleaning Coupons

Test coupons or panels are pieces of flat, rectangular substrate surfaces matched to a part's materials. No one is sure how the term 'coupon' became associated with the cleaning industry, but the term, along with their use, is widespread. Coupons are artificially contaminated with the soil of interest, usually by a hand-held swab, prior to conducting cleaning tests in the laboratory. Care must be taken not to over-contaminate any one coupon, or the test results will not be accurate. Coupons are used to conserve parts for testing under more optimal conditions in later phases. Figures 5.4 and 5.5 picture coupons from the SCL.

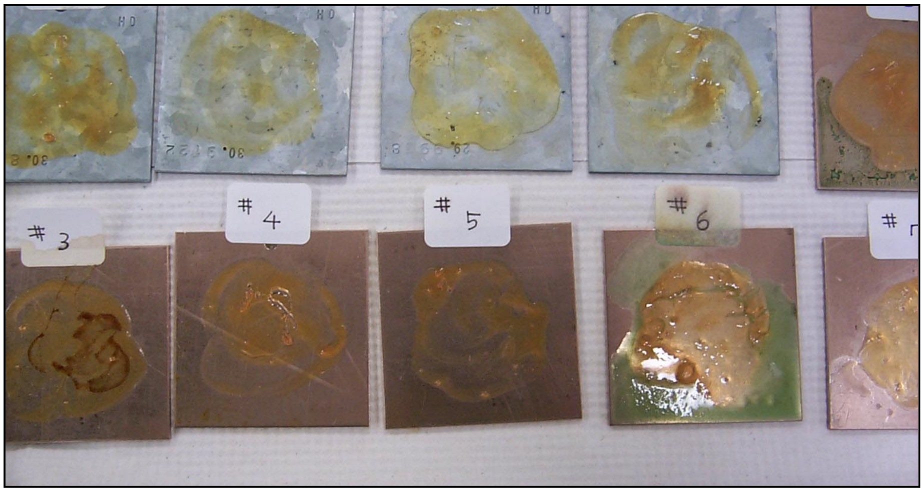
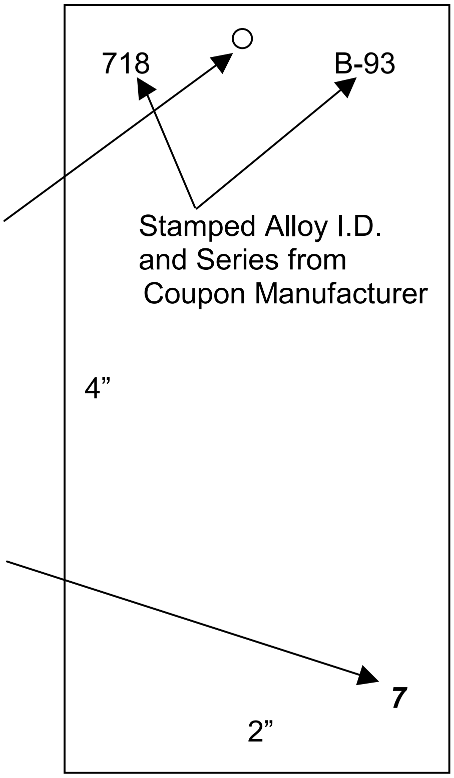


Figure 5.4 COUPONS ARTIFICIALLY-CONTAMINATED BY HAND-HELD SWABS



Hole for suspension in cleaning fluids.

Figure 5.5
EXAMPLE OF INCONEL METAL COUPON
(Shown actual size and 0.06" thick)
Coupons should be labeled or etched for identification. It is convenient if they are fabricated with tabs or holes for suspending in cleaning fluids during other stages of testing.

Sample number etched for identification during tests.

Some suppliers of test coupons and panels are listed in Table 5.1.

Company	Contact Information
Metal Samples Co., Inc.	P.O. Box B 152 Metal Samples Road Munford, AL 36268 Tel. (205) 358-4204 Fax (205) 358-4515
Metaspec	P.O. Box 27707 San Antonio, TX 78227-0707 Tel. (512) 923-5999
The Q-Panel Company	26200 First Street Cleveland, OH 44145 Tel. (216) 835-8700 Fax (216) 835-8738

Table 5.1 MANUFACTURERS OF TEST COUPONS

Subjective Analysis
In this very preliminary step at ambient (room) temperature, drops of cleaners at full-strength are placed on grossly contaminated coupons and any signs of soil 'lift' or dissolution are noted. If no visible differences can be ascertained, then nothing has been gained by completing this step. But if, upon visual inspection, the soil is being dissolving by some of the cleaners with no form of agitation supplied, then subsequent tests should concentrate on those cleaning formulas.

5.1.2 Phase II: *TACT*, Cleaning Coupons and Objective Analysis

This phase uses the cleaning parameters of time, agitation, concentration and temperature, collectively known as *TACT*. Additional test coupons are required. The first round of scientific (i.e., objective) surface cleaning analysis is conducted by measuring the weight of the artificially-applied contaminant before and after cleaning (Figure 5.4). In addition, the source of agitation is minimized to focus the test on chemical activity. Cleaning time is kept constant to ensure accurate comparisons among the cleaners.

TACT
For the purposes of demonstrating this technique, suppose that six (6) aqueous cleaners were selected in Phase I and all but one (1) exhibited some signs of activity on the contaminated coupon. In Phase II, the five (5) chemical cleaners that provided some cleaning are tested at the vendor-recommended temperatures and concentrations on artificially-contaminated coupons.

Cleaning Coupons
Figure 5.6 illustrates the coupon/beaker testing method mentioned in chapter three (Figure 3.3). Since all experiments must be in triplicate, 5 cleaners = 5 beakers with cleaning fluid containing 3 contaminated coupons each = 15 coupons (total). As many as three (3) coupons can be safely tested per beaker of cleaning solution. For these experiments, temperatures are maintained by a hot plate and magnetic stir bar agitation. Cleaning cycle times remain constant for all cleaners tested.

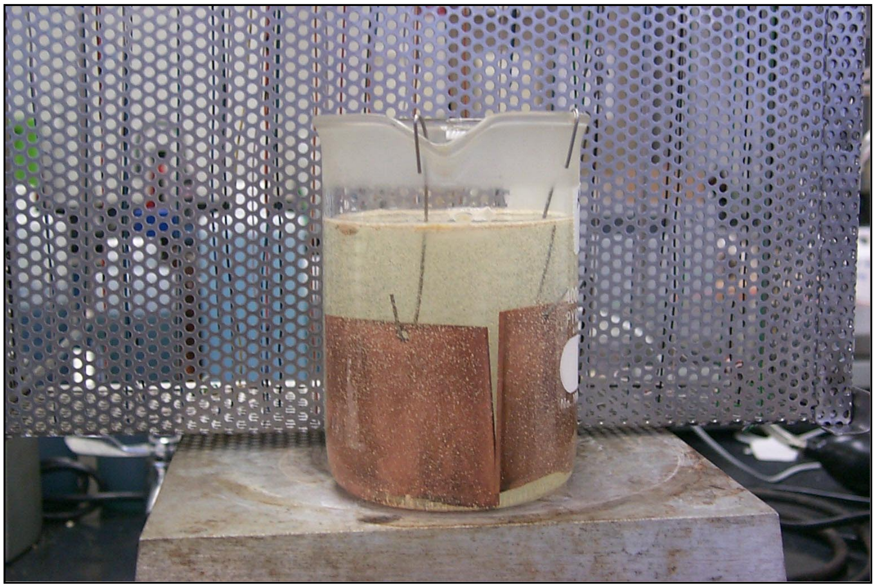


Figure 5.6 CLEANING COUPONS IN A PYREX BEAKER ON A HOT PLATE WITH STIR-BAR AGITATION

Objective Analysis

Before the coupons were cleaned, a measurement of the contaminant applied by a hand-held swab was taken. This was accomplished by weighing fresh, pre-cleaned[h] coupons on an analytical balance *before* and *after* artificial contamination to obtain a gram weight of the soil. A *third* weight was taken of each coupon after cleaning to arrive at the amount of soil removed. Percent soil removal rates can then be calculated. For most tests, the SCL used Denver Instrument Company Model A-250 analytical balance with an accuracy of up to +/-0.0005 grams. Table 5.2 illustrates an actual SCL case using gravimetric analysis, discussed in section 4.2.1.

Coupon Number	Initial Coupon Weight (g) A	Contaminated Coupon Weight (g) B	Cleaned Coupon Weight (g) C	Initial Contaminant Weight (g) D	Remaining Contaminant Weight (g) E	Percent Contaminant Removal (%) F
1	78.9991	79.0568	79.0124	0.0577	0.0133	76.94974
2	77.4751	77.4965	77.4798	0.0214	0.0047	78.03738
3	78.7441	78.8078	78.7660	0.0637	0.0219	65.62009
4	77.5015	77.5676	77.5085	0.0661	0.0070	89.40998
5	77.4578	77.4896	77.4643	0.0318	0.0065	79.55975
6	78.8838	78.9352	78.8863	0.0514	0.0025	95.13619
7	78.8273	78.8800	78.8308	0.0527	0.0035	93.35863
8	77.6145	77.6621	77.6153	0.0476	0.0008	98.31933
9	77.4630	77.5031	77.4638	0.0401	0.0008	98.00499

Where D = B-A, E = C-A and F = (D-E)/D x 100

TABLE 5.2 GRAVIMETRIC ANALYSIS OF PRE-CLEANED, CONTAMINATED AND CLEANED COUPONS

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[h] Pre-cleaned coupons are coupons that have been cleaned, prior to a test, with a hard surface cleaner that is not under investigation (in this case, Dawn dishwashing liquid), rinsed by hand, and allowed to air-dry. The process is repeated until identical weight readings of the coupons are obtained to ensure surface cleanliness prior to applying a contaminant.

5.1.3 Phase III: *TACT*, Cleaning Coupons and Application-Specific Analysis

In the above case, 3 of the 5 cleaners performed satisfactorily. In Phase III, one then explores the various forms of agitation depicted in Table 5.3, so that the company can scale-up the cleaning process once the project leaves the SCL. Typically, these remaining 3 cleaners are tested in an ultrasonic unit, readily available in most laboratories. Fresh coupons (9) will be needed. A review of the success/failure of gravimetric analysis is conducted and the appropriateness of other analytical techniques is examined.

TACT

Ultrasonics provides a mechanical source of agitation that is accepted by many industries because of the availability of different equipment and appropriate frequency (KHz) ranges for a wide array of applications. Refer to Table 5.3.

Frequency	Ultrasonic Energy	Types of Cleaning	Examples
25 KHz	Large Bubbles, Most Aggressive	Gross Cleaning Applications	Motor parts, Heavy contamination
40 KHz	Medium Bubbles, Aggressive	Most Industrial Cleaning Applications	Metalworking, Moderate contamination
68 KHz	Small Bubbles, Less Aggressive	Precision Cleaning Applications	Computer-related products, Light contamination
*Megasonics	Smallest Bubbles, Least Aggressive	Still Experimental, Relatively Expensive	Delicate parts, Light contamination

*Transducer frequency in the thousands-KHz range

Table 5.3 RELATIONSHIP BETWEEN ULTRASONIC CAVITATION AND CLEANING PERFORMANCE

Ultrasonic cleaning is based on the principle that high-frequency sound waves produce microscopic voids ('bubbles') in fluids. When these bubbles collapse or implode on parts, they strip contaminants away from the surface. The intensity of this stationary-tank cavitation is primarily dependent on the power supply/generator (i.e., wattage) and the temperature and gas absorption properties of the liquid. In most instances, bottom-mounted transducers produce the most efficient transmittance of sound waves as diagramed in Figure 5.7.

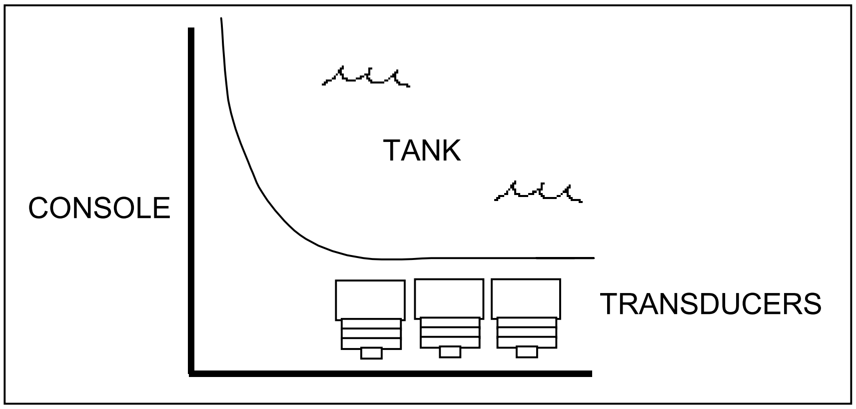


Figure 5.7 TRANSDUCER PLACEMENT IN ULTRASONIC CLEANING TANK (Not drawn to scale)

The transducers in Figure 5.7 are constructed of piezoelectric crystals that may crack and dislodge from the bottom of the tank. The magnetorestrictive transducer illustrated in Figure 5.8 is nickel laminated and silver-brazed to a stainless steel plate, which becomes the tank bottom and is more durable than the former type.

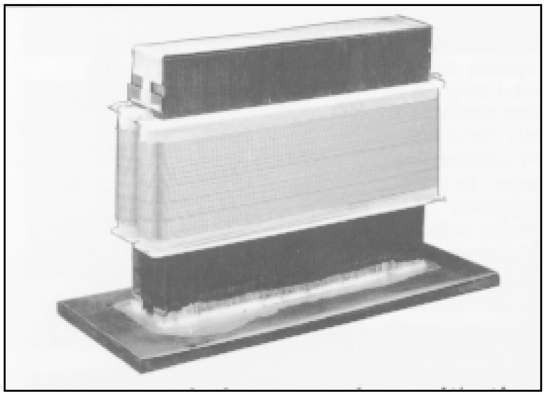


Figure 5.8 MAGNETORESTRICTIVE TRANDUCER

Other factors such as the number and distance between transducers are also important. Better energy distribution in the cleaning tank is maintained with sweep frequency whereas conventional, single (i.e., fixed) frequency produces a standing wave containing nodes and antinodes (hot spots and dead zones) resulting in stratified cleaning.[50] Sweep frequency may be defined as a unique waveform developed for uniform cavitation and copyrighted by Ney Ultrasonics of Bloomfield, Connecticut, USA. For most Phase III trials at SCL, a Crest (Trenton, New Jersey, USA) Model 4HT, 40 KHz, 10-gallon tabletop unit was used.

Cleaning Coupons

Figure 5.9 illustrates a beaker containing a properly-diluted cleaner and artificially-contaminated coupons suspended in an ultrasonic tank filled with water. This method allows testing of the 3 cleaners in one trial since more than one beaker can be suspended at once, eliminating the wasteful volumes of chemical solutions that would be needed to fill the tank with each cleaner. The presence of the beakers (or any holder) *does* effect cleaning results, so it is important to compare these findings to other cleaners tested in a similar fashion (and not to coupons cleaned without the use of beakers).

Figure 5.9
LAB ULTRASONIC TANK FILLED WITH WATER AND SUSPENDED TEST BEAKER

Application-Specific Analysis

Perhaps gravimetric analysis (Phase II) works well for this cleaning project. If not, Phase III could include examination of other types of surface evaluation discussed in chapter five in preparation for actual parts cleaning.

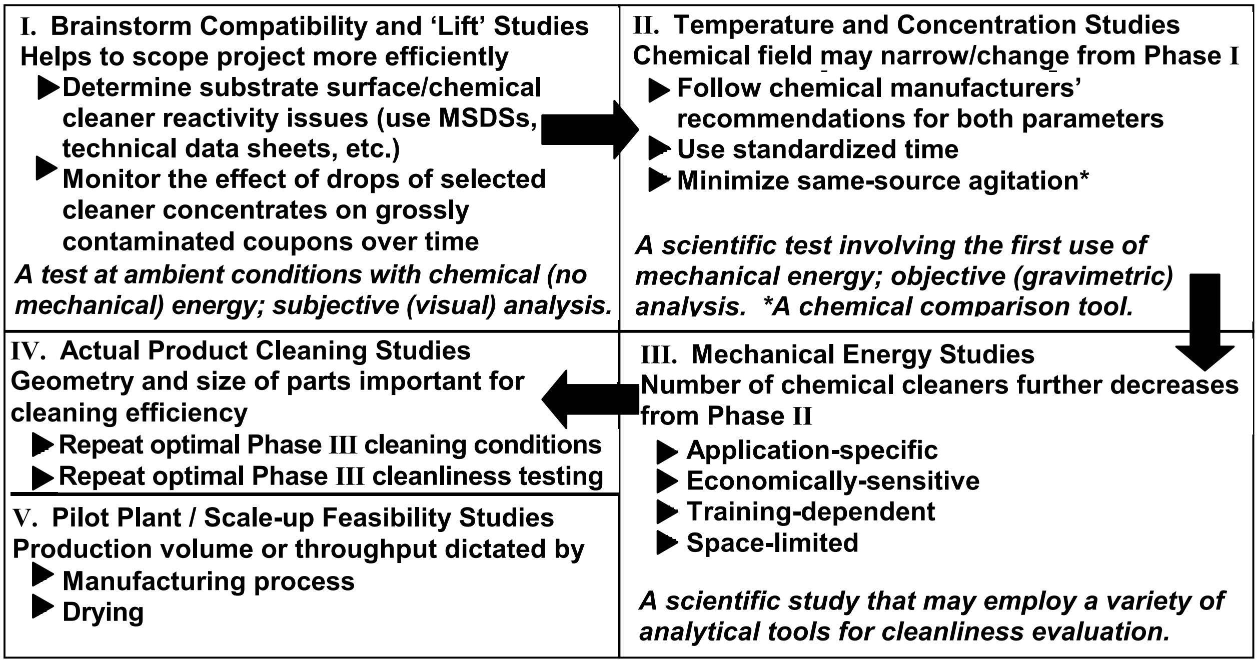
5.1.4 Phase IV: *T<u>A</u>C<u>T</u>*, Cleaning and Evaluating Parts

Assuming that 2 of the cleaners successfully removed the majority of the contaminants on the coupons in Phase III, these cleaners will be tested *in an identical fashion* on actual parts in Phase IV. If an attempt was made to arrive at a surface cleanliness technique matched to the application *on coupons*, applying this method *on the parts* before and after cleaning will reveal any analytical problems suspected upon scale-up. Refer to section 4.2.

5.1.5 Phase V: Piloting and Scaling Up the Process

The application leaves the laboratory and is piloted either by the equipment or chemical vendors for the company, or by the company in-house. Hundreds or thousands of parts may be cleaned to duplicate batch sizes and production quotas, depending on the dimensions of the parts. Cycle times must therefore be introduced in keeping with the application and equipment limitations.

It is appropriate to test more than one chemical cleaner due to (1) unforeseen supply problems, (2) differences in technical services among vendors and (3) downstream negative impacts yet to be determined. In summation, Figure 5.10 illustrates the entire testing process for aqueous and semi-aqueous cleaners.



I. Brainstorm Compatibility and 'Lift' Studies
Helps to scope project more efficiently
- **Determine substrate surface/chemical cleaner reactivity issues (use MSDSs, technical data sheets, etc.)**
- **Monitor the effect of drops of selected cleaner concentrates on grossly contaminated coupons over time**

A test at ambient conditions with chemical (no mechanical) energy; subjective (visual) analysis.

II. Temperature and Concentration Studies
Chemical field may narrow/change from Phase I
- **Follow chemical manufacturers' recommendations for both parameters**
- **Use standardized time**
- **Minimize same-source agitation***

A scientific test involving the first use of mechanical energy; objective (gravimetric) analysis. *A chemical comparison tool.

III. Mechanical Energy Studies
Number of chemical cleaners further decreases from Phase II
- **Application-specific**
- **Economically-sensitive**
- **Training-dependent**
- **Space-limited**

A scientific study that may employ a variety of analytical tools for cleanliness evaluation.

IV. Actual Product Cleaning Studies
Geometry and size of parts important for cleaning efficiency
- **Repeat optimal Phase III cleaning conditions**
- **Repeat optimal Phase III cleanliness testing**

V. Pilot Plant / Scale-up Feasibility Studies
Production volume or throughput dictated by
- **Manufacturing process**
- **Drying**

Figure 5.10 PHASES OF AN AQUEOUS-BASED SURFACE CLEANING TEST METHOD

The same principles apply to rinsing and drying cycles as well (see also, section 3.1.5). Note that in this model, mechanical energies, that is, forms of agitation (Phase III), are critically examined only after the proper cleaners, concentrations and temperatures (Phases I and II) are ascertained. Phase IV is concerned with the significance of part shape (screw configurations and blind holes, etc.) on metal cleaning. Although other test protocols may be as effective, it is essential that the experimental design be logical, consistent and reproducible.

5.1.6 Results, Conclusions and Recommendations

Results

An examination of the SCL test data following Phases III and IV confirmed the increased dependence on mechanical energy of replacement cleaners mentioned in chapters two and three. Figure 5.11 specifies the types and percentages of agitation for all applications under investigation from 1994 to 1999.

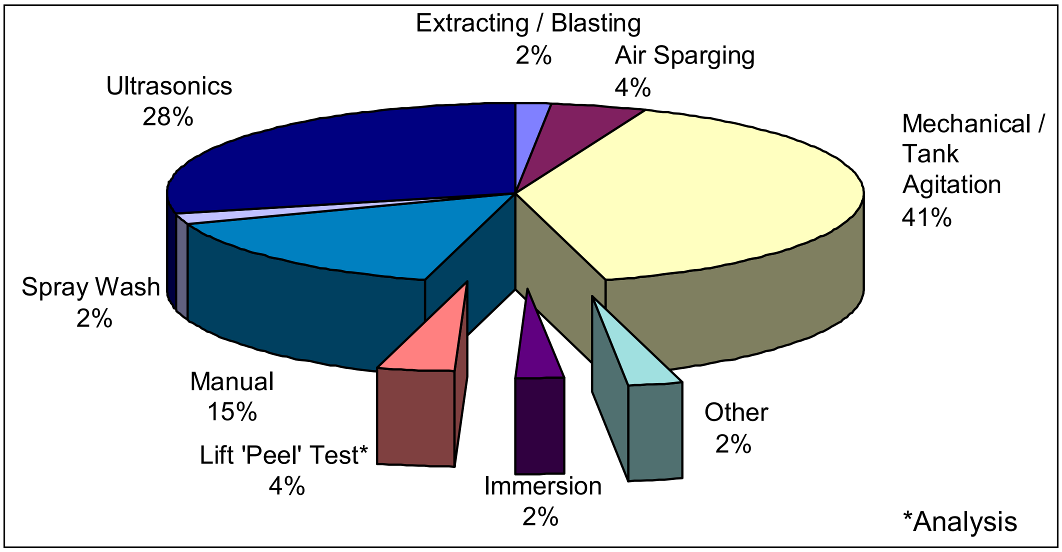


Figure 5.11 ALTERNATIVE CLEANING METHODS USED AT SCL, 1994-1999

Figure 5.12 portrays the same information for drying, plus additional statistics on rinse cycles.

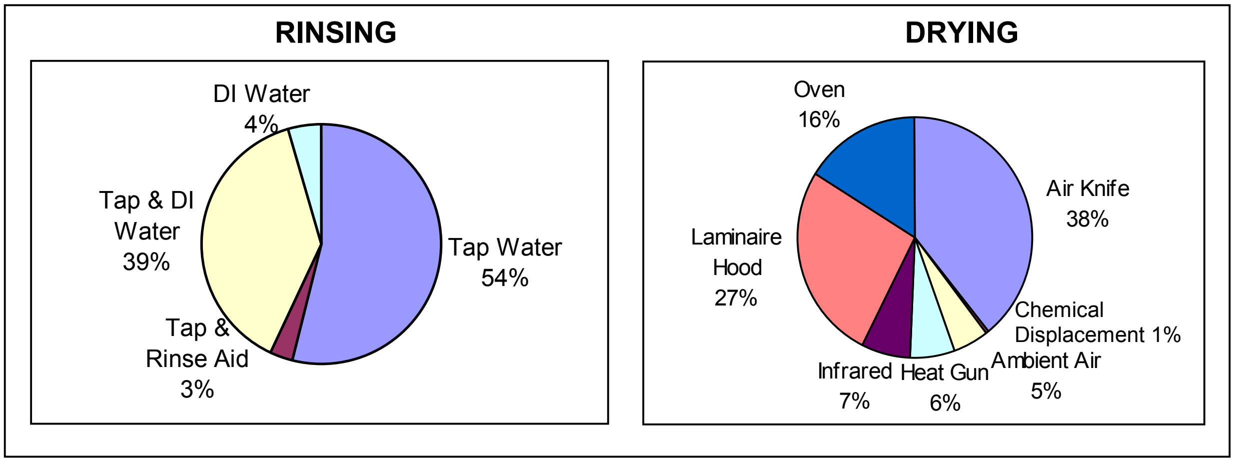


Figure 5.12 RINSING AND DRYING METHODS USED AT SCL, 1994-1999

Conclusions

Several conclusions can be drawn from devising a test method for aqueous cleaners, including:

(1) *Brainstorming* is an important first-step to solving a cleaning problem. As the design of the SCL assessment form illustrated, it is critical to have key players (i.e., stakeholders) identified and at the table for these sessions.

(2) Effective brainstorming sessions sometimes lead to the identification of a successful cleaner that was not recommended by the chemical manufacturer for a particular application.

(3) Technical data sheets offer product usage tips that are not required on government-mandated MSDSs. Process errors, especially in compatibility, can be avoided with their employment. Nevertheless, very few vendors make use of this application-friendly way of communicating important information to end-users.

(4) The practice of coupon testing saves cleaning researchers both time and resources. In assessing chemicals on reusable, easy-to-handle and simple surfaces, more time can be allocated to finding the *best* cleaner to use on the client-supplied parts that may be cumbersome, expensive and/or not readily available.

(5) While mechanical agitation (41%) represents the most commonly employed source of energy in lab cleaning trials, including stir bar agitation in beakers, ultrasonics (28%) provides a test method with superior reproducibility and predictability, even for projects that will eventually use other types of cleaning equipment. This is because chemical corrections to cleaner formulations can be made later on (for example, an anti-foam agent may be added for spray washing).

(6) Microsoft® Excel analyses of Figure 5.11 (cleaning methods) along with Figures 4.5 (industries), 4.7 (contaminants) and 4.13 (analytical methods) reveals that an average of 3 tests per client company were conducted by the SCL to arrive at meaningful data for the tests performed during 1994-1999. Each test involved experimentation with as many as 6 chemical cleaners.

Recommendations

Continuous improvements are needed in the first and final stages (Phases I, IV and V) of the cleaning test plan.

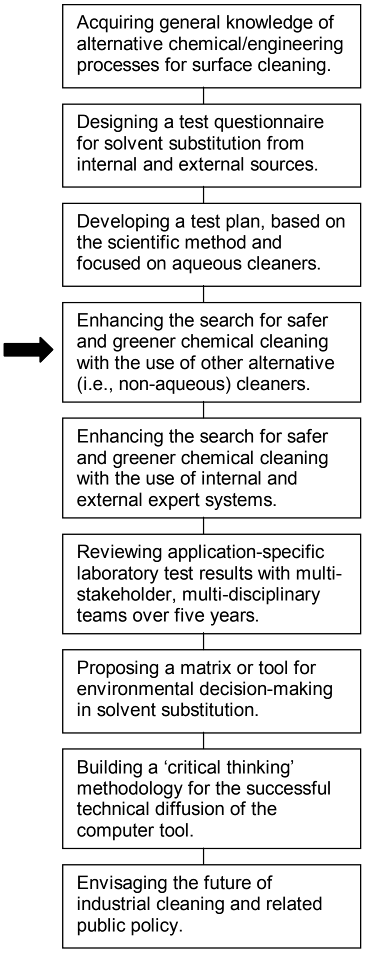
The initial choice of candidate cleaners (along with the method “drop concentrates…on grossly contaminated coupons”) is too subjective and may not include the newest formulations on the market. The temptation exists for technicians to over-select certain cleaners based on past performance, familiarity and time constraints. The only defense for this situation is the wise utilization of the brainstorming team.

The absence of a pilot plant facility negatively impacts the timely scale-up of most alternative cleaning projects under investigation at the SCL. Companies must rely on vendors for servicing which is not forthcoming and technical expertise, which is often lacking. To overcome these obstacles, TURI initiated an Implementation Intern Program staffed by the University of Massachusetts Lowell science and engineering students. Firms may apply for a partially-funded Intern with industrial experience to complete the scale-up versions of their cleaning processes in-house. More funds should be sought to support this program since at current levels only one (1) firm in 25 is able to participate. Tentative plans are underway to house a pilot plant at the SCL to showcase the latest advances and innovations in cleaning technologies at the Institute.

6 Enhancing the Search for Safer, Greener Chemical Cleaners, Part I

The overall risks of a chemical cleaner at the SCL are assessed on the basis of its health and environmental indicators, namely: (1) global warming potential, (2) ozone depletion potential, (3) volatile organic content, (4) flammability/reactivity and (5) toxicity/carcinogenicity.[42] These factors were introduced in chapter two and are listed in Figure 6.1. Stakeholders at the Toxics Use Reduction Institute identified them prior to this research and before surfactants were suspected as endocrine disrupters (chapter nine). The indicators do not, however, automatically point to aqueous cleaners as the sole source of alternatives to solvents.

This chapter begins with an explanation of the limits of aqueous cleaners as the reasons for testing those non-aqueous substitutes that are also prospective safer and greener solvents. The chapter's second part focuses on the collection of vendor information to ensure that as many different kinds of cleaners (and related equipment) as possible are represented in the vendor database.



Acquiring general knowledge of alternative chemical/engineering processes for surface cleaning.

Designing a test questionnaire for solvent substitution from internal and external sources.

Developing a test plan, based on the scientific method and focused on aqueous cleaners.

Enhancing the search for safer and greener chemical cleaning with the use of other alternative (i.e., non-aqueous) cleaners.

Enhancing the search for safer and greener chemical cleaning with the use of internal and external expert systems.

Reviewing application-specific laboratory test results with multi-stakeholder, multi-disciplinary teams over five years.

Proposing a matrix or tool for environmental decision-making in solvent substitution.

Building a 'critical thinking' methodology for the successful technical diffusion of the computer tool.

Envisaging the future of industrial cleaning and related public policy.

- ***WHAT ARE "SAFER" ALTERNATIVES?***
  - **Non-Ozone Depleting Substances (non-ODSs)**
  - **Non-Volatile Organic Compounds (non-VOCs)**
  - **Zero Global Warming Potential (GWP = 0)**
  - **Low or No Toxicity**
  - **Non-Flammable**

Figure 6.1
INDICATORS USED TO DETERMINE THE RELATIVE SAFETY OF CHEMICAL CLEANERS[42]

6.1 End Users: Testing Non-Aqueous Alternative Cleaners and Cleaning Mechanisms

Over 90% of the SCL's tests for safer, environmentally-friendlier cleaners are performed with aqueous cleaners. This is due to their relatively low cost, the availability of companion cleaning equipment and the reproducibility of results in production for most industrial cleaning processes.[52]

Most aqueous cleaners are alkaline and are based upon hydroxides such as sodium hydroxide (NaOH). They are typically shipped as a liquid concentrate of 50% NaOH, with final concentrations of 1% - 20% hydroxide when used as cleaners, depending on the application. Nevertheless, the U.S. Occupational Safety and Health Administration (OSHA) and the U.S. Environmental Protection Agency (EPA) list NaOH as a hazardous material. Its use is further monitored by other agencies such as the National Institute for Occupational Safety and Health (NIOSH) and the National Fire Protection Association (NFPA). It is highly soluble in water

(1000mg/1000mL) and generates considerable heat upon dissolving. As a hazardous liquid waste, volumes of it must be disposed of in accordance with all local, state and federal regulations, even though it can be neutralized with acid.

Table 6.1 outlines the key hazards associated with sodium hydroxide as a caustic (that is, pure) substance. Much of this information is not relevant if one starts with the 50% NaOH solution, unless a process temperature is inadvertently spiked by faulty temperature control. More specifics on NaOH can be found in Appendix A of this thesis.

Sodium Hydroxide (NaOH), conc.		
Potential Health Effects	Inhalation of dust or droplets can irritate or damage lungs.	Direct contact with corrosive solid or liquid can burn skin or blindness.
Potential Environmental Effects	High levels in ecosystem can cause death of animals and death or low growth of plants.	Depending on mineral content and alkalinity of water, NaOH can be acutely toxic to aquatic life.

Table 6.1 POTENTIAL HAZARDS ASSOCIATED WITH SODIUM HYDROXIDE EXPOSURE[53]

Mechanical energy is almost always required to improve the efficiency of aqueous cleaners. This is usually accomplished by providing agitation (ultrasonics et al) and by heating the bath and rinse waters as discussed in chapters three and four. Poorly managed aqueous cleaning can also use copious amounts of water, both for immersion (tank) and spray cleaning and rinsing. The use of water and electricity can cause the operating costs of an aqueous cleaning system to be prohibitive in some cases.

While aqueous parts cleaning may be well established in some industrial settings, it may have reached its technological zenith for the removal of hazardous contaminants and coatings, the recovery of precious metals, the reduction of process wastes, and the completion of precision deburring and component demarking.[54] Other chemical procedures need to be developed to continually improve the efficacy of these and other commonly performed industrial practices. Furthermore, recent efforts by state and federal governments to deregulate the energy industry and the growing need to conserve water as a natural resource have increased the need to evaluate other cleaning options. These replacement cleaners should have a decreased dependency on fossil fuel burning and further minimize or eliminate industrial wastewater streams (chapter eight). Two such techniques were examined especially for this dissertation: media blasting with sodium bicarbonate ($NaHCO_3$) and supercritical extraction with carbon dioxide (CO_2).

6.1.1 Blasting with Crystalline Sodium Bicarbonate

Sodium bicarbonate blasting uses $NaHCO_3$, an odorless, white crystal with no significant health or environmental effects. It is not an eye or skin irritant and it is practically non-toxic. This innovative cleaning method is non-flammable, non-sparking, water-soluble and free from virtually all of the worker and environmental hazards associated with solvents, caustic chemicals and toxic fumes. The blasting medium poses no special disposal problems, provided that the contaminants are removed from the waste stream. It may even be beneficial as a buffering agent during wastewater treatment.

Because most sodium bicarbonate blasting operations involve wide-area, relatively-flat surface cleaning, it cannot be used for removing the contaminants present on parts in most of the SCL tests. Microblasting, a form of blasting developed for these smaller parts, can be performed in an enclosed, computer-controlled chamber with a movable parts-positioner, however.

Sodium bicarbonate blasting consists of specially crystallized baking soda crystals impinging on the parts to be cleaned via a spraying apparatus (Figure 6.2). Examples include paint stripping and graffiti removal. In addition, a number of formulations are available for different cleaning applications, varying by particle size and configuration so that the $NaHCO_3$ system can be used to remove coatings as well.

Figure 6.2
ACCUSTRIP™ DELIVERY DEVICE
FOR SODIUM BICARBONATE BLASTING

Water usage is minimized since the apparatus requires only a spray of water surrounding the stream of sodium bicarbonate, directing the granules to the location to be cleaned. Compressed air for pumping is supplied low enough at the nozzle site, approximately 60 psi, so that the hose can be hand-held a distance of several inches from the surface (Figure 6.3).

Figure 6.3
EXAMPLE OF
CLEANING OPERATION
WITH ARMEX® BLAST MEDIUM

6.1.2 Extracting with Supercritical Carbon Dioxide

Another alternative cleaning method that uses non-toxic as well as fewer chemical components (and thus places a lower drain on natural resources) is carbon dioxide in its supercritical form. By manipulating temperature and pressure, CO_2 gas behaves like a liquid.[55] It is also readily available and relatively inexpensive.

Figure 6.4 illustrates a typical phase diagram for a single component in its solid, liquid and gas forms. Points entirely within each domain represent temperatures and pressures at which only one phase exists. Lines intersecting the domains represent temperatures and pressures at which two phases are in equilibrium: gas/liquid, liquid/solid and solid/gas. The point at which all three lines intersect is called the *triple point* (T), occurring at only one temperature and pressure. The gas/liquid line terminates at the *critical point* (CP), corresponding to the critical temperature (T_c) and critical pressure (P_c) for the component.[56]

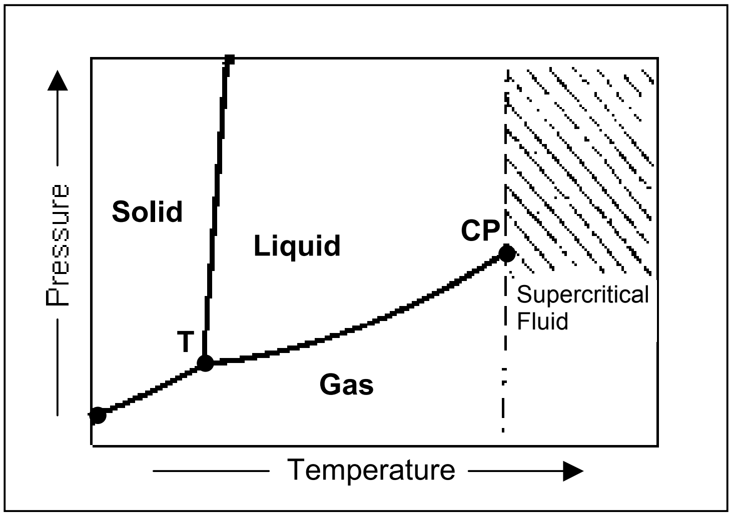


Figure 6.4 PHASE DIAGRAM ILLUSTRATING SUPERCRITICAL AREA FOR A SINGLE COMPONENT[55]

The densities of the gas and liquid become equivalent at the critical point. Only the *supercritical fluid* (SF) exists above the critical temperature, regardless of pressure but generally $P > P_c$ supplies adequate compression for the gas to become solvent-like. This is because the molecules of a dense gas or so-called supercritical fluid are compacted closely together, leading to attractive interactions similar to those that occur in liquids. The compression must be carried out at $T > T_c$ to avoid condensation back to the lower enthalpy and chemical potential of the liquid state. But unlike their liquid counterparts, SFs are highly sensitive to changes in pressure. Most solutes, once dissolved, can be rapidly precipitated from them by simply dropping the pressure to one atmosphere where little, if any, SF solvency remains.[57] This controlled solubility and improved transport mechanism relative to liquids have made SFs popular for a number of years in analytical separation techniques such as chromatography and the solvent extraction of pesticide residues from foodstuffs and soil matrixes. Decaffeinated coffee is produced in much the same way, in large-scaled processes.[55]

The choice of a supercritical solvent is governed by the equation:

$$* = *_{\text{liq}} (D/D_{\text{liq}})$$

Where $*$ is the solubility parameter for the dense gas and D/D_{liq} is the ratio of dense gas density to liquid density. The equation reveals two factors governing the solvent power of an SF: the critical role of gas density, D, already discussed and the liquid value of $*_{\text{liq}}$, which reflects the polarity, and other molecular chemical properties of the parent liquid. The problem in choosing or needing a polar SF is that its boiling and critical points are elevated by its polarity. Since $T > T_c$ for supercritical operations, difficult high temperatures would be mandated. The selection of CO_2 as an SF offers a compromise between polar substances with high values of T_c and nonpolar substances with low values of $*_{\text{liq}}$,, with $T_c = 31^{\circ}C$ and $*_{\text{liq}} = 8.9$.[57]

While special equipment and expertise are necessary to perform supercritical extraction with carbon dioxide, the operating conditions are well understood and common to many other industries. Pressure and temperature settings used in the homogenization of milk exceed those employed in supercritical CO_2 extraction for the removal of contamination, so that the apparent reluctance to use this technology based on inherent workplace hazards is unfounded.[58] Furthermore, the system uses and generates no toxins. It requires virtually no water. Most importantly, the penetrability of the supercritical gas is superior to water-borne cleaners, making it suitable for cleaning small parts with surface areas difficult to reach.

6.1.3 Laboratory and Pilot Tests of Blasting and Extracting Methods

After completing the SCL Test Request Form (Figure 4.3), the author selected seven client companies from 1996-1998 for testing their materials with media blasting and supercritical extraction, cleaning methods not currently available at the SCL. These are listed in Table 6.2.

Company	Present Cleaner	Substrate	Contaminant/Coating
Fluorescent light Re-manufacturer	No cleaning performed; Copper wire discarded	Copper wire	*PCB-containing asphalt coating
Tire Manufacturer	*Glass bead blasting*	*Steel molds*	*Oil, silicone, dirt, rubber*
Gas Supplier	N/A-new system needed	Steel parts	Salts, corrosives
Furniture Maker	Methylene chloride	Steel fixtures	Urethane coatings
Recycling Center	No cleaning performed; Cassette tape discarded	Cassette tape	Petroleum-based cutting oil
Desiccant Manufacturer	*Manual scraping*	*Teflon-coated Steel screens*	*Baked Kaolin clay, Silicon dioxide*
Tank Truck Cleaner/ Materials Transporter	*Methylene chloride in aerosol cans*	*Steel tanks/ vessels*	*Adhesive-backed labels*

Initial aqueous/semi-aqueous cleaning tests failed at the SCL.
*PCB = polychlorinated biphynols, a well-known class of carcinogens.

Table 6.2 CLEANING PROJECTS CHOSEN FOR BLASTING AND EXTRACTION STUDY

The choice for using medium blasting and/or supercritical extraction was based on (1) previous aqueous/semi-aqueous SCL trials for these and similar applications, (2) discussions with SCL and company staff, (3) the specific cleaning requirements and (4) vendor recommendations.[59]

Bicarbonate medium blasting was conducted under the auspices of Church & Dwight, makers of Arm & Hammer's Armex® and Accustrip™ systems. Authorized distributor Mr. Fred Schneider of Falmouth, Massachusetts, supplied a Model 12X unit. On other occasions, SCL staff transported parts to the vendor's testing facility in Woburn, Massachusetts. At both locations, the patented $NaHCO_3$ spray was applied by a hand-held hose, the properly-attired operator observing results from comfortable distances. Applied Separations, Inc. of Allentown, Pennsylvania performed CO_2 supercritical extraction with the company's laboratory model. Mr. Yale West arranged for two products, Teflon shavings and cylinder valves, to be shipped to their facility, cleaned and returned to the SCL for further analysis.

6.1.4 Results, Conclusions and Recommendations

Results

Test surfaces were visually inspected before and after cleaning under ambient (white) or fluorescent (black) light. In Table 6.3, the cleaning regime was considered (1) completely successful if 0% of the original contaminant remained, (2) mostly successful if less than 25% of the original contaminant remained, (3) partially successful if less than 50% of the original contaminant remained and (4) not successful if more than 50% of the original contaminant remained.

Cleaning Rank: Completely > Mostly > Partially > Not successful

Application	Alternative Method	Surface Analyses	Cleaning Results
Asphalt coating removal from fluorescent light ballast	Media Blasting	Visual inspection and Gravimetric weight	Completely successful
Tire mold cleaning of various contaminants	Media Blasting	Visual inspection	Completely successful
Gas cylinder valves Clean-in-Place (CIP)	Media Blasting and Supercritical Extraction	Visual inspection Visual inspection	Completely successful; Not successful
4-foot metal hooks cleaning (hold furniture pieces for coating)	Media Blasting	Visual inspection	Completely successful
*Magnetic tape degreasing to reclaim Teflon shavings	Supercritical Extraction	Fluorescence	Mostly successful
*Clay removal from PTFE-coated metal screens	Media Blasting	Visual inspection	Partially successful
Adhesive label removal from outside tank vessels	Media Blasting	Visual inspection	Completely successful

*Both of these projects involved Teflon also known as polytetrafluoroethylene (PTFE). In one case, Teflon was the substrate and in the other, a coating that was to be preserved.

Table 6.3 RESULTS OF BLASTING AND EXTRACTION CLEANING

All but one of the thirteen aqueous cleaners tested in the above projects failed to perform satisfactorily. The W.R. Grace alkaline formulation was only partially successful under ultrasonic conditions (40KHz) with a Crest 10-gallon Model 4HT. This cleaner was successful in removing the oil, silicone and dirt but not the rubber contaminant from the steel molds of the tire manufacturer molds.[52] Medium blasting and supercritical extraction were trialed as a result of these isolated aqueous-cleaning failures, according to the selection protocol of the Toxics Use Reduction Institute's SCL.

Accurate gravimetric analysis is the sequential recording of three weights of parts (1) before artificial contamination, if possible (2) before cleaning and (3) after cleaning. Results of gravimetric analysis suggest that cleaning is completely successful if the original weights are achieved after the cleaning regime. This evaluation was feasible for only one application: the removal of the asphalt coating from the fluorescent light ballasts due to the asphalt's density. Other parts were received 'as is' contaminated and original, clean weights could not be estimated and/or the parts' size was beyond the range of the SCL balance scales, Mettler Toledo SB16001 and Denver Instruments Company Model A-250. This made surface evaluation other than visual inspection difficult, if not impossible. Other analytical methods (chapter five) were investigated without success. An application-specific method would have to be developed for each of the seven case studies, which is beyond the scope of this work.

Conclusions

The conclusions to the non-aqueous cleaning tests performed for this thesis are:

(1) Since extensive information is already available about the exposure effects and environmental fates of food grade products, the U.S. EPA advocates the industrial use of substances like sodium bicarbonate. Unlike aqueous cleaners that contain a number of specialty chemicals such as surfactants and emulsifiers, some of which may have their own environmental effects,[48] this blasting medium's chief chemical ingredients are baking soda and water. The same can be said for the manipulation of a naturally-occurring gas such as carbon dioxide that results in the generation of no toxic by-products.

(2) **Tests conducted with sodium bicarbonate revealed:**
Parts best suited for $NaCHO_3$ medium blasting were found to have outer diameters of several inches and/or to be heavier, than most of the products that can be cleaned in a bench-top aqueous station. Whereas smaller products can be totally immersed in an aqueous cleaning tank, parts exposed to a blasting spray must be physically attached or held down so that they remain stationary. Experimental nozzle pressures were 20 psi - 45 psi due to poor air compressor performance, resulting in sporadic plugging of nozzle valves. Higher pressures, 35 psi - 90 psi, are recommended by the vendor.[60] Though modified from its household version, baking soda is still a soft-blast medium with a heavier specific gravity and less hardness than most plastic abrasives used in blasting. Consequently, no scratching or etching of parts was apparent and metal surfaces, in particular, stainless steel appeared polished after cleaning.

The baking soda blasting cycle for all *successful* tests required no more than 2-3 minutes for completion, except for cleaning the tightly-wound copper wire of the fluorescent light ballasts and the stainless steel molds used in the tire industry. Under the less-than-ideal conditions described above, media blasting took five minutes to remove the asphalt coating from the heavy, 2"(w) x 4"(l) x 0.75"(h) ballasts. Although sodium bicarbonate spray removed the oil, silicone and dirt from the tire molds within two minutes, complete removal of the rubber residue increased the cycle time to as much as 10 minutes pre mold. Additionally, some of the protective Teflon coating was stripped from the metal screens of the desiccant manufacturer as a consequence of clay removal.[61]

(3) **Tests conducted with carbon dioxide revealed:**
Supercritical CO_2 extraction was successful in removing the majority of the contaminant oil from the recycling center's Teflon shavings, as evidenced by examination of the naturally-fluorescent cutting oil on the substrate surface under black light before and after cleaning (Table 6.3). Supercritical extraction was not successful in cleaning the gas cylinder valves under existing laboratory conditions, making clean-in-place (CIP) unlikely. It is not clear, however, whether appropriate experimental settings were attained. More testing is needed, especially since its ability to remove particulate matter well (dirt, dust, etc.) has not been adequately documented.

(4) **Tests conducted with both methods revealed:**
Of the 250 cleaning trials conducted by the SCL since 1994, only 1.6% of those tests were conducted using baking soda blasting and less than 1% involved carbon dioxide extraction. Even though these cleaning methods were not investigated until recently, a review of materials tested throughout the five-year period did not reveal any new applications for these non-aqueous cleaning technologies due to (1) part size, (2) part configuration and (3) processing costs.

(5) In summary, while bicarbonate media blasting and supercritical CO_2 extraction have clear environmental benefits, they cannot be utilized for every cleaning process. Unlike the chlorinated and organic solvents that can be used to clean a wide range of contaminants from many substrates, all alternative technologies, including the aqueous, semi-aqueous, media blasting and supercritical extracting techniques are more restricted in their usage. Nevertheless, water-based cleaners cover a far broader range of industrial cleaning applications than blasting with pelletized sodium bicarbonate and extraction with supercritical carbon dioxide.

Recommendations

Aqueous chemical cleaning solutions can be recycled, both for water reclamation and cleaner reuse.[62] In sodium bicarbonate blasting, the sharp edges of the blasting medium responsible for the cleaning action are worn-off during first contact with the surface which prevents the product from being reused. While $NaCHO_3$ can be reprocessed or used as a buffering or pH adjustment agent, formulators should focus on improving the hardness of the $NaCHO_3$ crystal to compare more favorably to other blasting media such as wheat germ which is reusable for more than one cleaning cycle.

Both aqueous cleaning and sodium bicarbonate medium blasting require proper occupational protection. Earplugs are recommended during sodium bicarbonate blasting due to the noise levels generated by the compressor. A mask should be worn by the operator to prevent inhalation of particulate matter as well. For these reasons, blasting should be restricted to certain areas within a facility. Aqueous systems demand eye protection (safety glasses) from potential splashing as well as protective apparel (gloves) to prevent possible skin reactions like dermatitis. The bath temperatures of these systems are often maintained below 160° F to avoid burns and chemical degradation.

Sodium bicarbonate pellet blasting may require subsequent parts rinsing due to the minimally-abrasive residue left behind on surfaces after treatment.[52] Because of this characteristic, most electrical components cannot be exposed to this cleaning procedure. Material compatibility is also a concern. In its natural state, sodium bicarbonate may corrode some substrates. In one U.S. Air Force study, aluminum cladding suffered excessive corrosion when an ordinary baking soda slurry was applied, although a slurry can be viewed as being very different from particulate blasting.[63] Vendors have suggested that they have/can correct this tendency chemically.

6.2 Suppliers: Redesigning Questionnaires for Vendors of the Cleaning Industry

It is not only companies as end users that must respond to regulatory demands and the constraints of toxicity and energy and water consumption for the materials that they use; the companies that are vendors of cleaning-related items must also supply the manufacturing world with the appropriate products to meet these technical challenges. What was needed, then, was an understanding of the interactive roles between end users and vendors.

6.2.1 Massachusetts Guidebook of Parts' Cleaning Alternatives

In 1997, the author contributed to the collaboratively published *Guidebook of Part Cleaning Alternatives: Making Cleaning Greener in Massachusetts* between the Massachusetts Office of Technical Assistance (OTA) and TURI. The idea for a guidebook originated at the agencies' stakeholder meetings of the "Cleaning Is Greener" team in discussions concerning end-users needs and the distribution of vendor information. In addition to listing important references and appendices, the book is divided into the sections described in Table 6.4.

Guidebook Section Titles
Section 1: Nine Steps to a New Cleaning System
Section 2: Alternative Cleaning Technologies
Section 3: Post Cleaning: Rinsing, Drying and Quality Examination
Section 4: Useful Tools for Financial Analysis
Section 5: Useful Tools for Regulatory Compliance

Table 6.4 MASSACHUSETTS GUIDEBOOK OF PARTS' CLEANING ALTERNATIVES

The *Guidebook* also reports the results of a solvent replacement survey conducted with Massachusetts businesses. Participating firms (168) were asked a series of questions about their industrial cleaning practices and needs. A summary of the data obtained as of November 1, 1995, the most recent data collected, is presented in Table 6.5.

Current Cleaning Chemicals Used	*No. of Firms: 83* Aqueous	*52* Alcohol	*36* Petroleum Naphtha	*22* TCE	*17* Methylene Chloride	*14* TCA	*9* HCFC	*5* PERC	*4* CFC
Current Cleaning Methods Used	*77* Cold Cleaning	*67* Hand Wiping	*43* Vapor Degreasing		*43* Heated Tank	*35* Spray Washing			
Substrate Surfaces Cleaned	*137* Metal	*20* Plastic	*18* Printed Circuit Boards		*11* Glass				
Surface Contaminants	*117* Oil	*86* Grease	*82* Dirt		*45* Fingerprints	*28* Flux		*27* Chips	
Already Tested Alternatives	*116* Yes	*52* No							
Top Four Requests for Content	*175* Testing and Evaluation	*174* Vendor Info.	*136* Regulatory Information		*123* Recycling Info.				
Top Four Requests for Format	*574* Written Materials	*168* Workshops	*106* On-site Tech. Assistance		*102* Off-site Demo.				

Table 6.5 RESULTS OF SOLVENT REPLACEMENT SURVEY CONDUCTED BY TURA PROGRAM

These findings are further broken down for companies using aqueous cleaners in Table 6.6.

Aqueously-Cleaned Substrate Surfaces	*68* Metal	*14* Plastic		*10* PCBs	*8* Glass	
Aqueously-Cleaned Surface Contaminants	*65* Oil	*50* Grease	*47* Dirt	*31* Fingerprints	*20* Chips	*19* Flux

Table 6.6 SURVEY RESULTS: AQUEOUSLY-CLEANED SUBSTRATES AND CONTAMINANTS

Since the total number of answers to some questions exceeded the number of respondents, it was apparent that a number of firms were completing more than one cleaning operation at their facilities. It is also interesting to note that in the final portion of the survey, companies responded negatively to teleconferencing by a margin of 2:1 as a means for solving cleaning problems.

Other trends revealed as a result of the solvent replacement survey conducted with end-users of cleaning chemicals and equipment in Massachusetts:

(1) Vendors/consultants are presently the most common sources of information for cleaning applications;
(2) Financial analysis is an important consideration for the majority of applications cited;
(3) Regulatory requirements are the primary drivers for process change;
(4) Responding firms needed up to 6 months to conduct a complete process conversion;
(5) Worker resistance-to-change was the most frequently mentioned unexpected barrier to solvent substitution.

6.2.2 TURI Vendor Survey Database and the Questionnaires

In 1993, the Toxics Use Reduction Institute published its first *Vendor Survey Database for Industrial Cleaning* (Technical Report No. 15). International in scope, its purpose is to serve as a source of information on cleaning chemicals and equipment suppliers to Massachusetts' businesses, specifically those firms performing cleaning at some point in their part/product manufacturing processes. Two other editions were published in 1995 and 1997 with some alterations.

In order to participate in the database, vendors were sent forms to complete about their product lines. While the vendor questionnaires originate from TURI's Surface Cleaning Laboratory, the vendors are solely responsible for the information submitted in them. The Institute does not verify the accuracy of this information or any claims made by the vendors.

The 1999 version of the TURI vendor database needed to respond to the newly observed trends in the *Guidebook of Part Cleaning Alternatives* as well as to the rapidly changing cleaning industry. As a consequence, the author completed major renovations to the questionnaires for this thesis.

Cleaning Chemicals

Figure 6.5 contains the redesigned cleaning chemical questionnaire for 1999. The original questionnaire from 1995 can be found in Appendix C of this thesis.

Cleaning Equipment

Figure 6.6 contains the redesigned cleaning equipment questionnaire for 1999. The original questionnaire from 1995 can be found in Appendix C of this thesis.

Recycling Equipment

Figure 6.7 contains the redesigned recycling equipment questionnaire for 1999. The original questionnaire from 1997 can be found in Appendix C of this thesis.

CLEANING CHEMICAL
Questionnaire

Material Safety Data Sheet (MSDS)
MUST Be Attached
(and Technical Data Sheet if available)

1. Product/Tradename (Use **separate** questionnaire for each cleaning chemical you want listed)
____ Generic Chemical Family:
Meets Specified Standard(s): ASTM: __________ Mil Spec: __________ FDA: __________ Other:
Primary Cleaner Classification (Check only one):
9 Acidic Aqueous
9 Neutral Aqueous
9 Alkaline Aqueous
9 Caustic
9 Semi-Aqueous
9 Terpene
9 Petroleum distillate
9 Organic
9 Powder detergent
9 Enzymatic/ Microbial
9 Blasting
9 Extracting
9 HCFC
9 Alcohol
9 Other: _______________

2. Chemical Constituents (Check all that apply & specify) : Builder: *Sodium Hydroxide 50% (as Concentrate)*
Cleaner Containing: At Least Some Water (_____%) OR No/Minimal Water
9 Builder: ______________
9 Surfactant: ______________
9 Emulsifier: ______________
9 Saponifier: ______________
9 Other: ______________
9 Rinse aid/Silicate: ____
9 Water conditioner/Sequestering/ Chelating agent: ___________________
9 Corrosion inhibitor/Rust prohibitor: ________________________
9 Anti-microbial: ______________________
9 Supercritical fluid:
9 Blasting medium:
9 Other: ______________________

3. Industrial Applications (Check all that apply and Circle Primary
9 Aerospace/Military
9 Cleanrooms
9 Basic Electronics
9 Medical
9 Metal Finishing
9 Metal Fabrication
9 Optics
9 Painting
9 PCBs
9 Plastics
9 Precision Instruments
9 Printing
9 Semicondoctors
9 General Cleaning (floors, etc.
9 Maint./Repair (engines, etc.)
9 Other: _______________

4. Contaminant Removal (Check all that apply & specify, if possible) : Example Coatings *Conformal*
9 Adhesives
9 Buffing/polishing compounds
9 Carbon deposits
9 Coatings
9 Cutting/tapping fluids
9 Fluxes
9 Greases
9 Inks
9 Lubricating/ lapping oils
9 Mold releases/ Silicones
9 Paints
9 Resins/Rosins
9 Rust/Scale
9 Waxes
9 Other: ________________

5. Substrate Compatibility (Check all that apply)
9 Aluminum
9 Alloys (Specify): _____________
9 Brass
9 Carbon steel
9 Ceramics
9 Copper
9 Galvinized steel
9 Glass/quartz
9 Gold
9 Plastic (Specify): _____________
9 Rubber
9 Stainless steel
9 Steel
9 Sterling/silver
9 Nickel
9 Tin
9 Other: ________________

6. Equipment Compatibility (Check all that apply & specify, if applicable)
9 Cold Solvent
9 Vapor Degreasing
9 Manual Wipe
9 Immersion/Soak
9 Mechanical Agitation
9 Ultrasonics
9 Media Blasting
9 Supercritical Extract
9 Low Pressure Spray ___________ psi-range
9 High Pressure Spray ___________ psi-range
9 Other: __________________________

7. Recommended Concentrations: ___________________ Percent Volume (range)
Recommended Temperatures: ___________________ Deg. F (range)

8. Important Physical and Chemical Properties
Maximum theoretical VOC content: ____________
GWP: _______________ Surface Tension: _______________ Density: _______________
ODP: _______________ Kb value: _______________ Other: _______________

9. Cost per pound/gallon: Smallest-unit price: _______________ Large-volume price: **US$**

10. Additional pertinent information not found elsewhere on this form or MSDS:

Figure 6.5 REDESIGNED QUESTIONNAIRE FOR VENDORS OF CLEANING CHEMICALS, 1999

CLEANING EQUIPMENT
Questionnaire

Attach Technical Data Sheet
If Available

1. Model/Description (Use a **separate** questionnaire for each piece of equipment to be listed in the Directory)
Meets Standard(s): ASTM: _______ Mil Spec: _______ FDA: _______ EPA: _______ Other: ________
Primary category (Check one): ☐ Cleaning ☐ Rinsing ☐ Drying Type (Check one): ☐ Stand-alone (conveyor, cabinet, etc.) ☐ Accessory (nozzle, air knife, etc.)
Cleaning Mechanism:
- ☐ Cold Solvent
- ☐ Vapor Degreasing
- ☐ Manual Wipe
- ☐ Immersion/Soak
- ☐ Mechanical Agitation
- ☐ Ultrasonics
- ☐ Media Blasting
- ☐ Supercritical Extraction
- ☐ Low Pressure __________ psi-range
- ☐ High Pressure __________ psi-range
- ☐ N/A (Does Not Apply)
- ☐ Other: ______________________

2. Cleaning Chemicals (used in conjunction with this product)
- ☐ Acidic Aqueous
- ☐ Neutral Aqueous
- ☐ Alkaline Aqueous
- ☐ Caustic
- ☐ Semi-Aqueous
- ☐ Terpene
- ☐ Petroleum distillate
- ☐ Organic solvents
- ☐ Powder detergent
- ☐ Enzymatic/ Microbial
- ☐ Blasting media
- ☐ Extracting solvents
- ☐ HCFC
- ☐ Alcohol
- ☐ Other: ____________

3. Machine Parameters (Write N/A to questions that do not apply to this piece of equipment)
Footprint, in feet/inches: _________ Length (L) x __________ Height (H) x __________ Width (W)
Weight, in pounds:
☐ Batch and/or ☐ Continuous ☐ Standard and/or ☐ Custom

4. Also Available (with this unit):

	Oil Skimmer	Filtration	Recycling	Rinsing	Drying	
Included	☐	☐	☐	☐	☐	☐
Optional	☐	☐	☐	☐	☐	☐
N/A	☐	☐	☐	☐	☐	☐

5. Industrial Applications (Check all that apply and Circle Primary
- ☐ Aerospace/Military
- ☐ Cleanrooms
- ☐ Basic Electronics
- ☐ Medical
- ☐ Metal Finishing
- ☐ Metal Fabrication
- ☐ Optics
- ☐ Painting
- ☐ PCBs
- ☐ Plastics
- ☐ Precision Instruments
- ☐ Printing
- ☐ Semiconductors
- ☐ General Cleaning (floors, etc.)
- ☐ Maint./Repair (engines, etc.)
- ☐ Other: _____________

6. Contaminant Removal (Check all that apply & specify, if possible) Example : Coatings *Conformal*
- ☐ Adhesives
- ☐ Buffing/polishing compounds
- ☐ Carbon deposits
- ☐ Coatings
- ☐ Cutting/tapping fluids
- ☐ Fluxes
- ☐ Greases
- ☐ Inks
- ☐ Lubricating/ lapping oils
- ☐ Mold releases/ Silicones
- ☐ Paints
- ☐ Resins/Rosins
- ☐ Rust/Scale
- ☐ Waxes
- ☐ Other: ______________

7. Substrate Compatibility (Check all that apply)
- ☐ Aluminum
- ☐ Alloys (Specify): ____________
- ☐ Brass
- ☐ Carbon steel
- ☐ Ceramics
- ☐ Copper
- ☐ Galvanized steel
- ☐ Glass/quartz
- ☐ Gold
- ☐ Plastic (Specify): ____________
- ☐ Rubber
- ☐ Stainless steel
- ☐ Steel
- ☐ Sterling/silver
- ☐ Nickel
- ☐ Tin
- ☐ Other: _______________

8. Recommended Temperatures: ____________ Deg. F (range)
Cycle time, if applicable: ____________ Minutes

9. Price Range: ____________________ Shipping Costs: ____________ Installation Costs: ___________ **US$**
Shipping Method(s): _____________ Territory: _________________
Order-to-Delivery Turnaround: ________________________ ~ Weeks

10. Additional pertinent information not found elsewhere on this form or Technical Data
(for example, non-compatibility issues or closed-loop

Figure 6.6 REDESIGNED QUESTIONNAIRE FOR VENDORS OF CLEANING EQUIPMENT, 1999

RECYCLING EQUIPMENT
Questionnaire

Attach Technical Data Sheet
If Available

1. Model/Description (Use a **separate** questionnaire for each piece of equipment to be listed in the Directory)
Meets Standard(s): ASTM: Mil Spec: FDA: EPA: Other:
Primary category (Check one): ☐ Cleaning and/or ☐ Rinsing Type (Check one): ☐ Stand-alone ☐ Accessory
(conveyor, cabinet, etc.) (nozzle, air knife, etc.)
Mechanism:
☐ Oil Skimmer
☐ Ultrafiltration
☐ Microfiltration
☐ Bag filter
☐ Ion exchange/resin bed
☐ Reverse Osmosis
☐ Evaporator/Condenser
☐ Biological
☐ N/A (Does Not Apply)
☐ Centrifuge
☐ Other: ____________

2. Cleaning Chemicals (used in conjunction with this product)
☐ Acidic Aqueous
☐ Neutral Aqueous
☐ Alkaline Aqueous
☐ Caustic
☐ Semi-Aqueous
☐ Terpene
☐ Petroleum distillate
☐ Organic solvents
☐ Powder detergent
☐ Enzymatic/ Microbial
☐ Blasting media
☐ Extracting solvents
☐ HCFC
☐ Alcohol
☐ Other: ____________

3. Machine Parameters (Write N/A to questions that do not apply to this piece of equipment)
Footprint, in feet/inches: ____________ Length (L) x ____________ Height (H) x ____________ Width (W)
Weight, in pounds: ________________
☐ Batch and/or ☐ Continuous ☐ Standard and/or ☐ Custom ☐ Automation

4. Industrial Applications (Check all that apply AND Circle Primary Application)
☐ Aerospace/Military
☐ Cleanrooms
☐ Basic Electronics
☐ Medical
☐ Metal Finishing
☐ Metal Fabrication
☐ Optics
☐ Painting
☐ PCBs
☐ Plastics
☐ Precision Instruments
☐ Printing
☐ Semiconductors
☐ General Cleaning (floors, etc.)
☐ Maint./Repair (engines, etc.)
☐ Other: ______________

5. Contaminant Compatibility (Check all that apply & specify, if possible) Example ☑ Coatings *Conformal*
☐ Adhesives
☐ Buffing/polishing compounds
☐ Carbon deposits
☐ Coatings
☐ Cutting/tapping fluids
☐ Fluxes
☐ Greases
☐ Inks
☐ Lubricating/ lapping oils
☐ Mold releases/ Silicones
☐ Paints
☐ Resins/Rosins
☐ Rust/Scale
☐ Waxes
☐ Other: ______________

6. Substrate Compatibility (Check all that apply)
☐ Aluminum
☐ Alloys (Specify): ____________
☐ Brass
☐ Carbon steel
☐ Ceramics
☐ Copper
☐ Galvanized steel
☐ Glass/quartz
☐ Gold
☐ Plastic (Specify): _____________
☐ Rubber
☐ Stainless steel
☐ Steel
☐ Sterling/silver
☐ Nickel
☐ Tin
☐ Other: ______________

7. Recommended Temperatures: ________________Deg. F (range)
Cycle time, if applicable: ________________Minutes
pH range: ________________

8. Price Range: _______________ Shipping Costs: _______________ Installation Costs: ______________ **US$**
Shipping Method(s): ______________________ Territory: ______________________
Order-to-Delivery Turnaround: _______________________ ~ Weeks

9. Additional pertinent information not found elsewhere on this form or Technical Data Sheet:
(for example, closed-loop capabilities)

Figure 6.7 REDESIGNED QUESTIONNAIRE FOR VENDORS OF RECYCLING EQUIPMENT, 1999

6.2.3 Results, Conclusions and Recommendations

Results

Three sections were added to the *Vendor Survey Database for Industrial Cleaning*, known by 1999 as the *Industrial Cleaning Survey: Directory of Vendors* (the name change was necessary to avoid confusion with other SCL products such as the Effective Test Conditions Database, section 7.2). These additions to the *Directory* were made as a result of the trends noted in surveying Massachusetts businesses' requests for technical assistance (Table 6.10). They include:

(1) A listing of toxics use reduction (TUR) planners as well as consultants to the cleaning trades;
(2) Important cleaning standards and specifications;
(3) Relevant periodicals, conferences and publications.

In order to accomplish these improvements in technical diffusion, major renovations to the questionnaires for cleaning chemical and equipment vendors were undertaken, as a consequence of this thesis' research.

Examples of the 1999 vendor entries for cleaning chemicals are given in Figure 6.8. Representative entries for the years 1995 and 1997 are listed in Appendix C of this thesis.

Examples of the 1999 vendor entries for cleaning equipment are given in Figure 6.9. Representative entries for the years 1995 and 1997 are listed in Appendix C of this thesis.

Examples of the 1999 vendor entries for recycling equipment are given in Figure 6.10. Representative entries for the year 1997 are listed in Appendix C of this thesis.

Company Product Trade Name Approx. Cost Small/Large Unit Additional Info:	Standards ASTM Mil Specs FDA Other	Cleaner Classification		Industrial Uses		Contaminants Removed		Compatible Substrates		Other Characteristics	Compatible Equipment Lab Testing	Kb Value	VOC GWP pH Surface Tension Density	ODP	Cleaner Constituents
AG Environmental Products, LLC Soy Gold 1000		☐ AAQ	☐ PD	AM	PC 6	☐ AD	☑ LL	☑ AL	☐ RB	☐ Alloys	☑ CS	☐ HP	64g/L		BD
		☐ NAQ	☐ EM	CR	PL	☑ BP	☑ MR	☑ BR	☑ SS		☐ VD	☐ LP	-400%	0	SF
		☐ AKAQ	☐ BLT	BE	PI	☐ CD	☐ PT	☑ CS	☑ Steel		☑ MW		58		EF
		☐ CST	☐ EX	MD	PR 5	☐ CO	☐ RR	☑ CR	☑ AG		☑ IM	P-Range:	58		SP
		☐ SAQ	☐ HCF	MF	SC	☑ CT	☐ RS	☑ CU	☑ NI	☐ Plastic	☑ MA		7.33lb/gal		RAS
		☐ TRP	☐ AOH	MB 3	GC 2	☐ FX	☑ WX	☑ GS	☑ Tin		☐ UL			H F R	WSC
		☐ PD	☑ Other	OP 4	MR 1	☑ GR		☑ GQ			☐ MB		HMIS	0 1 0	CR
		☑ OR	Ester	PT		☐ IN		☑ AU			☐ SE		NFPA		AM
											TESTING PROFILE ☑				Other No Water
AG Environmental Products, LLC Soy Gold 2000		☐ AAQ	☐ PD	AM	PC 6	☐ AD	☑ LL	☑ AL	☐ RB	☐ Alloys	☑ CS	☐ HP	43.1 g/L		BD
		☐ NAQ	☐ EM	CR	PL	☑ BP	☑ MR	☑ BR	☑ SS		☐ VD	☐ LP	-400	0	SF NP – 6 (3%)
		☐ AKAQ	☐ BLT	BE	PI	☐ CD	☐ PT	☑ CS	☑ Steel		☑ MW		58		EF
		☐ CST	☐ EX	MD	PR 5	☐ CO	☐ RR	☑ CR	☑ AG		☑ IM	P-Range:			SP
		☐ SAQ	☐ HCF	MF	SC	☑ CT	☐ RS	☑ CU	☑ NI	☐ Plastic	☑ MA		7.36 lb/gal		RAS
		☐ TRP	☐ AOH	MB 3	GC 2	☐ FX	☑ WX	☑ GS	☑ Tin		☐ UL			H F R	WSC
		☐ PD	☑ Other	OP 4	MR 1	☑ GR		☑ GQ			☐ MB		HMIS	0 1 0	CR
		☑ OR	Ester	PT		☐ IN		☑ AU			☐ SE		NFPA		AM
											TESTING PROFILE ☑				Other No Water
AJ Associates Dynajet		☐ AAQ	☐ PD	AM 1	PC	☑ AD	☑ LL	☐ AL	☐ RB	☐ Alloys	☐ CS	☐ HP	0		BD Sodium Hydroxide
		☐ NAQ	☐ EM	CR 1	PL	☑ BP	☑ MR	☑ BR	☑ SS		☐ VD	☑ LP	NE	NE	SF Y
		☑ AKAQ	☐ BLT	BE	PI 1	☐ CD	☐ PT	☑ CS	☑ Steel		☐ MW		NE	<13	EF
		☑ CST	☐ EX	MD 1	PR	☐ CO	☐ RR	☐ CR	☐ AG		☑ IM	P-Range:	NE		SP
		☐ SAQ	☐ HCF	MF 1	SC	☑ CT	☐ RS	☑ CU	☑ NI	☐ Plastic	☑ MA	50psi	NE		RAS
		☐ TRP	☐ AOH	MB 1	GC 1	☐ FX	☐ WX	☐ GS	☐ Tin		☑ UL			H F R	WSC
		☐ PD	☐ Other	OP	MR	☑ GR		☐ GQ			☐ MB		HMIS		CR
		☐ OR		PT		☑ IN		☐ AU			☐ SE		NFPA		AM
											TESTING PROFILE ☐				Other
AJ Associates Gardoclean A5502		☐ AAQ	☐ PD	AM 1	PC	☐ AD	☑ LL	☑ AL	☐ RB	☐ Alloys	☐ CS	☐ HP	0		BD Sodium Alkanoate 1-5%
		☐ NAQ	☐ EM	CR 1	PL	☑ BP	☑ MR	☐ BR	☐ SS		☐ VD	☑ LP	NE	NE	SF Y
		☑ AKAQ	☐ BLT	BE	PI 1	☑ CD	☐ PT	☐ CS	☑ Steel		☐ MW		NE	8.5-9.5	EF Y
		☐ CST	☐ EX	MD 1	PR	☐ CO	☐ RR	☐ CR	☐ AG		☑ IM	P-Range:	NE		SP
		☐ SAQ	☐ HCF	MF 1	SC	☑ CT	☐ RS	☐ CU	☐ NI	☐ Plastic	☑ MA	50psi	NE		RAS
		☐ TRP	☐ AOH	MB 1	GC	☑ FX	☑ WX	☐ GS	☐ Tin		☑ UL			H F R	WSC
		☐ PD	☐ Other	OP 1	MR 1	☑ GR		☐ GQ			☐ MB		HMIS		CR Y
		☐ OR		PT		☐ IN		☐ AU			☐ SE		NFPA		AM
											TESTING PROFILE ☐				Other Trade Secret (TS
AJ Associates Gardoclean A5503		☐ AAQ	☐ PD	AM 1	PC	☐ AD	☑ LL	☑ AL	☐ RB	☐ Alloys	☑ CS	☑ HP	0		BD
		☐ NAQ	☐ EM	CR 1	PL	☑ BP	☑ MR	☑ BR	☑ SS		☑ VD	☑ LP	NE	NE	SF Y
		☑ AKAQ	☐ BLT	BE	PI 1	☐ CD	☐ PT	☑ CS	☑ Steel		☑ MW		NE	~7	EF
		☐ CST	☐ EX	MD 1	PR	☐ CO	☐ RR	☐ CR	☑ AG		☑ IM	P-Range:	NE		SP
		☐ SAQ	☐ HCF	MF 1	SC	☑ CT	☐ RS	☑ CU	☑ NI	☐ Plastic	☑ MA		NE		RAS
		☐ TRP	☐ AOH	MB 1	GC	☐ FX	☐ WX	☑ GS	☐ Tin		☑ UL			H F R	WSC
		☐ PD	☐ Other	OP	MR 1	☑ GR		☐ GQ			☑ MB		HMIS		CR
		☐ OR	Ester	PT		☐ IN		☑ AU			☑ SE		NFPA		AM
											TESTING PROFILE ☐				Other Monoethanolamine; TS
Albemarle Corp. Abzol Cleaners	6368	☐ AAQ	☐ PD	AM 1	PC 1	☑ AD	☑ LL	☑ AL	☐ RB	☐ Alloys	☑ CS	☑ HP	100		BD
		☐ NAQ	☐ EM	CR	PL	☑ BP	☑ MR	☑ BR	☑ SS		☑ VD	☑ LP	0.31	0.006-0.02	SF
		☐ AKAQ	☐ BLT	BE 1	PI 1	☑ CD	☐ PT	☑ CS	☑ Steel		☑ MW		125		EF
		☐ CST	☐ EX	MD 1	PR	☑ CO	☑ RR	☑ CR	☑ AG		☑ IM	P-Range:	25.9 dyne/cm		SP
		☐ SAQ	☐ HCF	MF 1	SC 1	☑ CT	☐ RS	☑ CU	☑ NI	☐ Plastic	☐ MA		1.35		RAS
		☐ TRP	☐ AOH	MB 1	GC	☑ FX	☑ WX	☑ GS	☑ Tin		☑ UL			H F R	WSC
		☐ PD	☑ Other	OP 1	MR 1	☑ GR		☑ GQ			☐ MB		HMIS		CR
		☑ OR	n-propyl bromide	PT		☑ IN		☑ AU			☐ SE		NFPA		AM

Figure 6.8 DIRECTORY ENTRIES OF CLEANING CHEMICAL VENDORS, 1999

Company Name Product Name Description	Meets: ASTM Mil Spec FDA EPA Other	Machine Parameters	Oil Skimmer Filtration Recycling Rinse Dry Automation Footprint Weight	Cleaning Mechanism	Cleaning Chemicals	Industrial Applications	Contaminant Removal	Substrate Compatibility	Temp. Range Price Range Shipping Costs Installation Costs Shipping Method Delivery Time Additional Info (Cycle Time, etc.)
ADF Systems, Ltd. Model 10		☑ Cleaning ☐ Rinsing ☐ Drying ☑ Stand Alone ☐ Accessory ☑ Batch ☐ Continuous ☐ Standard ☐ Custom	Optional 37”x39.5x20” 110	☐ CS ☐ VD ☐ MW ☐ MA ☐ IM ☐ UL ☐ MB ☐ SE ☐ N/A ☑ LP ☐ HP PRange 3-10 Other	☑ AAQ ☑ NAQ ☑ AKAQ ☐ CST ☐ SAQ ☐ TRP ☐ PD ☐ OR ☐ PDG ☐ EM ☐ BM ☐ EX ☐ HCFC ☐ AOH Other	☑ AM ☐ CR ☐ BE ☐ MD ☑ MF ☑ MB ☐ OP ☐ PT ☐ PCB ☐ PL ☐ PI ☐ PR ☐ SC ☐ GC ☑ MR Other	☐ AD ☐ BP ☐ CD ☐ CO ☑ CT ☐ FX ☑ GR ☐ IN ☑ LL ☑ MR ☐ PT ☐ RR ☐ RS ☐ WX Other	☑ AL ☐ BR ☑ CS ☑ CR ☑ CU ☑ GS ☑ GQ ☐ AU ☑ RB ☑ SS ☑ Steel ☐ AG ☐ NI ☑ Tin ☐ Alloys Plastic Other	110°-140° F $1200-2000 US TRUCK N/A
ADF Systems, Ltd. Model 800		☐ Cleaning ☐ Rinsing ☐ Drying ☐ Stand Alone ☐ Accessory ☐ Batch ☐ Continuous ☐ Standard ☐ Custom	Optional Included/Optional Included/Optional Optional Depends on mode 	☐ CS ☐ VD ☐ MW ☐ MA ☐ IM ☐ UL ☐ MB ☐ SE ☐ N/A ☐ LP ☑ HP PRange 700 Other	☑ AAQ ☑ NAQ ☑ AKAQ ☐ CST ☐ SAQ ☐ TRP ☐ PD ☐ OR ☐ PDG ☐ EM ☐ BM ☐ EX ☐ HCFC ☐ AOH Other	☑ AM ☑ CR ☐ BE ☑ MD ☑ MF ☑ MB ☑ OP ☐ PT ☐ PCB ☑ PL ☑ PI ☑ PR ☐ SC ☐ GC ☐ MR Other	☐ AD ☑ BP ☑ CD ☐ CO ☑ CT ☐ FX ☑ GR ☑ IN ☑ LL ☑ MR ☐ PT ☑ RR ☐ RS ☐ WX Other	☑ AL ☑ BR ☑ CS ☑ CR ☑ CU ☑ GS ☑ GQ ☑ AU ☑ RB ☑ SS ☑ Steel ☑ AG ☐ NI ☐ Tin ☐ Alloys Plastic Other	160° F Depends on Accessories TRUCK
ADF Systems, Ltd. Model 900		☐ Cleaning ☐ Rinsing ☐ Drying ☐ Stand Alone ☐ Accessory ☐ Batch ☐ Continuous ☐ Standard ☐ Custom	Optional Included/Optional Optional Optional Depends on mode 	☐ CS ☐ VD ☐ MW ☐ MA ☐ IM ☐ UL ☐ MB ☐ SE ☐ N/A ☐ LP ☑ HP PRange 50-700 Other	☑ AAQ ☑ NAQ ☑ AKAQ ☐ CST ☐ SAQ ☐ TRP ☐ PD ☐ OR ☐ PDG ☐ EM ☐ BM ☐ EX ☐ HCFC ☐ AOH Other	☑ AM ☑ CR ☑ BE ☑ MD ☑ MF ☑ MB ☑ OP ☐ PT ☐ PCB ☑ PL ☑ PI ☑ PR ☑ SC ☑ GC ☐ MR Other	☐ AD ☑ BP ☑ CD ☑ CO ☑ CT ☑ FX ☑ GR ☑ IN ☑ LL ☑ MR ☐ PT ☑ RR ☐ RS ☐ WX Other	☑ AL ☑ BR ☑ CS ☑ CR ☑ CU ☑ GS ☑ GQ ☑ AU ☑ RB ☑ SS ☑ Steel ☑ AG ☑ NI ☑ Tin ☐ Alloys ☑ Plastic Other	160° F
Advanced Liquid Recycling, Inc. ALR1435A Air-operated Mobile Aqueous Brake Washer		☑ Cleaning ☐ Rinsing ☐ Drying ☐ Stand Alone ☐ Accessory ☑ Batch ☐ Continuous ☑ Standard ☐ Custom	 Included 22”x18”x41” 	☐ CS ☐ VD ☐ MW ☑ MA ☐ IM ☐ UL ☐ MB ☐ SE ☐ N/A ☐ LP ☐ HP PRange Other	☐ AAQ ☑ NAQ ☑ AKAQ ☐ CST ☐ SAQ ☐ TRP ☐ PD ☐ OR ☐ PDG ☐ EM ☐ BM ☐ EX ☐ HCFC ☐ AOH Other	☐ AM ☐ CR ☐ BE ☐ MD ☐ MF ☐ MB ☐ OP ☐ PT ☐ PCB ☐ PL ☐ PI ☐ PR ☐ SC ☑ GC ☑ MR Other	☐ AD ☐ BP ☑ CD ☐ CO ☐ CT ☐ FX ☑ GR ☐ IN ☐ LL ☐ MR ☐ PT ☐ RR ☐ RS ☐ WX Other Brake dust	☐ AL ☐ BR ☐ CS ☐ CR ☐ CU ☐ GS ☐ GQ ☐ AU ☐ RB ☐ SS ☐ Steel ☐ AG ☐ NI ☐ Tin ☐ Alloys Plastic Other	Flow-through brush with adjustable valve, OSHA preferred method for controlling brake dust, 15 gal. Capacity.

Figure 6.9 DIRECTORY ENTRIES OF CLEANING EQUIPMENT VENDORS, 1999

Company Name **Product Name** **Description**	**Standards:** **ASTM** **Mil Spec** **FDA** **EPA** **Other**	**Machine Parameters**	**Cleaning Chemicals**	**Industrial Applications**	**Contaminant Removal**	**Substrate Compatibility**	**Temperature** **Cycle Time** **pH Range** **$ Price Range** **$ Shipping Costs** **$ Installation Costs** **Shipping Method** **Order-to-Delivery**	**Length Height** **Width Weight** **Additional Info.**
Ahlstrom Paper Group Filtration Media		☐ Cleaning….. ☐ Rinsing…… ☐ Stand-Alone ☐ Accessory... ☑ Batch… … ☐ Continuous. ☐ Standard…. ☐ Custom…… ☐ Automation. ☐ Oil Skimmer.. ☑ Ultrafiltration. ☑ Microfiltration ☐ Bag Filter….. ☐ Biological….. ☐ Centrifuge…. ☐ N/A………… ☐ Ion Exchange/Resin Bed ☐ Reverse Osmosis……… ☐ Evaporator/Condenser…. Other Mechanism:	☐ AAQ.. ☐ NAQ.. ☐ AKAQ ☐ CST... ☐ SAQ... ☐ TRP… ☐ PD….. ☐ OR….. ☐ PDG... ☐ EM….. ☐ BLT . ☐ EX….. ☐ HCFC ☐ AOH .. Other..	☐ AM. ☐ CR. ☐ BE. ☐ MD ☐ MF ☐ MB ☐ OP ☐ PT. ☐ PC ☐ PL. ☐ PI.. ☐ PR ☐ SC ☐ GC ☐ MR Other	☐ AD. ☐ BP. ☐ CD ☐ CO ☐ CT. ☐ FX. ☐ GR ☐ IN.. ☐ LL.. ☐ MR ☐ PT… ☐ RR... ☐ RS... ☐ WX.. Other	☐ AL ☐ BR ☐ CS ☐ CR ☐ CU ☐ GS ☐ GQ ☐ AU ☐ RB ☐ SS ☐ Steel ☐ AG... ☐ NI…. ☐ Tin... Other.... ☐ Alloys. ☐ Plastic	$ $ $	Glass fiber, cellulose, diagnostic, specialty and absorbent media, synthetics.
AJ Associates ARR Suparator Oil Separator		☑ Cleaning….. ☐ Rinsing…… ☑ Stand-Alone ☐ Accessory... ☑ Batch… … ☑ Continuous. ☑ Standard…. ☑ Custom…… ☐ Automation. ☐ Oil Skimmer.. ☐ Ultrafiltration. ☐ Microfiltration ☐ Bag Filter….. ☐ Biological….. ☐ Centrifuge…. ☐ N/A………… ☐ Ion Exchange/Resin Bed ☐ Reverse Osmosis……… ☐ Evaporator/Condenser…. Other Mechanism: Velocity of fluid	☑ AAQ.. ☑ NAQ.. ☑ AKAQ ☑ CST... ☐ SAQ... ☐ TRP… ☐ PD….. ☐ OR….. ☑ PDG... ☐ EM….. ☐ BLT . ☐ EX….. ☐ HCFC ☐ AOH .. Other..	☑ AM. ☑ CR. ☑ BE. ☑ MD ☑ MF ☑ MB ☐ OP ☐ PT. ☐ PC ☐ PL. ☑ PI.. ☐ PR ☐ SC ☑ GC ☑ MR Other	☑ AD. ☑ BP. ☑ CD ☐ CO ☑ CT. ☐ FX. ☑ GR ☐ IN.. ☑ LL.. ☑ MR ☐ PT… ☐ RR... ☐ RS... ☐ WX.. Other	☐ AL ☐ BR ☐ CS ☐ CR ☐ CU ☐ GS ☐ GQ ☐ AU ☐ RB ☐ SS ☐ Steel ☐ AG... ☐ NI…. ☐ Tin... Other.... N/A ☐ Alloys. ☐ Plastic	70 – 200 5 N/A $8000–50000 US $300 US $ Truck 6	Removes floating oil from liquid baths using velocity of fluid to separate oil from water. Results in closed-loop cleaning tank. Increases bath life.
AJ Associates PSI Water System Evaporator		☑ Cleaning….. ☑ Rinsing…… ☑ Stand-Alone ☐ Accessory... ☑ Batch… … ☑ Continuous. ☑ Standard…. ☑ Custom…… ☐ Automation. ☐ Oil Skimmer.. ☐ Ultrafiltration. ☐ Microfiltration ☐ Bag Filter….. ☐ Biological….. ☐ Centrifuge…. ☐ N/A………… ☐ Ion Exchange/Resin Bed ☐ Reverse Osmosis……… ☑ Evaporator/Condenser…. Other Mechanism:	☑ AAQ.. ☑ NAQ.. ☑ AKAQ ☑ CST... ☐ SAQ... ☐ TRP… ☐ PD….. ☐ OR….. ☑ PDG... ☐ EM….. ☐ BLT . ☐ EX….. ☐ HCFC ☐ AOH .. Other..	☑ AM. ☑ CR. ☑ BE. ☑ MD ☑ MF ☑ MB ☑ OP ☐ PT. ☐ PC ☐ PL. ☑ PI.. ☐ PR ☐ SC ☑ GC ☑ MR Other	☑ AD. ☑ BP. ☑ CD ☐ CO ☑ CT. ☐ FX. ☑ GR ☐ IN.. ☑ LL.. ☑ MR ☐ PT… ☐ RR... ☐ RS... ☐ WX.. Other	☐ AL ☐ BR ☐ CS ☐ CR ☐ CU ☐ GS ☐ GQ ☐ AU ☐ RB ☐ SS ☐ Steel ☐ AG... ☐ NI…. ☐ Tin... Other.... N/A ☐ Alloys. ☐ Plastic	Boiling 5 – 9 $5000-200000US $1000 US $ Truck 4 – 12	Vary Vary Vary
AJ Associates ST 200 DI Filtration		☐ Cleaning….. ☑ Rinsing…… ☑ Stand-Alone ☐ Accessory... ☑ Batch… … ☑ Continuous. ☑ Standard…. ☑ Custom…… ☑ Automation. ☐ Oil Skimmer.. ☑ Ultrafiltration. ☑ Microfiltration ☐ Bag Filter….. ☐ Biological….. ☐ Centrifuge…. ☐ N/A………… ☑ Ion Exchange/Resin Bed ☑ Reverse Osmosis……… ☐ Evaporator/Condenser…. Other Mechanism:	☑ AAQ.. ☑ NAQ.. ☑ AKAQ ☑ CST... ☐ SAQ... ☐ TRP… ☐ PD….. ☐ OR….. ☑ PDG... ☐ EM….. ☐ BLT . ☐ EX….. ☐ HCFC ☐ AOH .. Other..	☑ AM. ☑ CR. ☑ BE. ☑ MD ☑ MF ☑ MB ☑ OP ☐ PT. ☐ PC ☐ PL. ☑ PI.. ☐ PR ☑ SC ☐ GC ☐ MR Other	☐ AD. ☑ BP. ☑ CD ☐ CO ☑ CT. ☑ FX. ☑ GR ☐ IN.. ☑ LL.. ☑ MR ☐ PT… ☐ RR... ☐ RS... ☐ WX.. Other	☑ AL ☑ BR ☑ CS ☑ CR ☑ CU ☑ GS ☑ GQ ☑ AU ☐ RB ☑ SS ☑ Steel ☑ AG... ☑ NI…. ☑ Tin... Other.... ☑ Alloys. ☐ Plastic	70 – 140 3 Neutral $6000-15000 US $400 US $ Truck 4	36" 54" 31"
Cast Ion Corp. CAST III Wastewater and Chemistry Recovery System	EPA: Yes	☐ Cleaning….. ☐ Rinsing…… ☐ Stand-Alone ☐ Accessory... ☐ Batch… … ☑ Continuous. ☑ Standard…. ☑ Custom…… ☑ Automation. ☐ Oil Skimmer.. ☐ Ultrafiltration. ☐ Microfiltration ☐ Bag Filter….. ☐ Biological….. ☐ Centrifuge…. ☐ N/A………… ☐ Ion Exchange/Resin Bed ☐ Reverse Osmosis……… ☑ Evaporator/Condenser…. Other Mechanism: Vacuum distillation	☐ AAQ.. ☐ NAQ.. ☐ AKAQ ☐ CST... ☐ SAQ... ☐ TRP… ☐ PD….. ☐ OR….. ☐ PDG... ☐ EM….. ☐ BLT . ☐ EX….. ☐ HCFC ☐ AOH .. Other..	☑ AM. ☐ CR. ☑ BE. ☐ MD ☑ MF ☑ MB ☐ OP ☐ PT. ☑ PC ☐ PL. ☑ PI.. ☐ PR ☑ SC ☐ GC ☑ MR Other	☐ AD. ☐ BP. ☐ CD ☐ CO ☐ CT. ☐ FX. ☐ GR ☐ IN.. ☐ LL.. ☐ MR ☐ PT… ☐ RR... ☐ RS... ☐ WX.. Other	☐ AL ☐ BR ☐ CS ☐ CR ☐ CU ☐ GS ☐ GQ ☐ AU ☐ RB ☐ SS ☐ Steel ☐ AG... ☐ NI…. ☐ Tin... Other.... ☐ Alloys. ☐ Plastic	 Varies $Varies $ $	Varies Varies Varies Varies Has been evaluated by MA. Executive Office of Environmental Affairs (EOEA) and MA. Department of Environmental Protection (DEP).

Figure 6.10 DIRECTORY ENTRIES OF RECYCLING EQUIPMENT VENDORS, 1999

Abbreviation codes and explanations used in the interpretation of cleaning products' information in the Directory can be found in Table 6.9.

Chemical Cleaner Classification	**Industrial Uses** ***Most Used =1***	**Contaminants Removed**	**Compatible Substrates**	**Compatible Equipment**	**Chemical Constituents**
Acidic Aqueous AAQ	Aerospace / Military AM	Adhesive AD	Aluminum AL	Cold Solvent CS	Builder B(D)
Neutral Aqueous NAQ	Cleanrooms CR	Buffing/Polishing Compounds BP	Brass BR	Vapor Degreasing VD	Surfactant SF
Alkaline Aqueous AKAQ	Basic Electronics BE	Carbon Deposits CD	Carbon Steel CS	Manual Wipe MW	Emulsifier EF
Caustic CST	Medical MD	Coatings CO	Ceramics CRM	Immersion/Soak IM	Saponifier S(P)
Semi-Aqueous SAQ	Metal Finishing MF	Cutting/Tapping Fluids CT	Copper CU	Mechanical Agitation MA	Rinse Aid / Silicate RAS
Terpene TRP	Metal Fabrication MB	Fluxes FX	Galvinized Steel GS	Ultrasonics UL	Water Conditioner / Sequestering, Chelating Agent WCS
Petroleum Distillate PD	Optics OP	Greases GR	Glass/Quartz GQ	Media Blasting MB	Corrosion Inhibitor / Rust Prohibitor CR
Organic OR	Painting PT	Inks IN	Gold AU	Supercritical Extract SE	Anti-Microbial AM
Powder Detergent PDG	Printed Circuit Boards PCB	Lubricating / Lapping Oils LL	Rubber RB	Low Pressure Spray LP	Supercritical Fluid SC
Enzymatic / Microbial EM	Plastics PL	Mold Releases / Silicones MR	Stainless SS	High Pressure Spray HP	Blasting Media BM
Blasting BLT	Precision Instruments PI	Paints PT	Steel Steel	High-Low Pressure Range: P-Range	
Extracting EX	Printing PR	Resins / Rosins RR	Sterling/Silver AG	Testing Profile ☑ = Product performance evaluated by SCL.. HMIS - Hazardous Material Information System and *NFPA - National Fire Protection Association from MSDSs for Ratings of 0 = low to 4 = high Where H = Health F = Flammability R = Reactivity	
HCFC HCFC	Semiconductors SC	Rust / Scale RS	Nickel NI		
Alcohol AOH	General Cleaning GC	Waxes WX	Tin Tin		

Table 6.7 ABBREVIATION CODES TO CLEANING PRODUCTS LISTED IN VENDOR DIRECTORY, 1999

A comparison of vendor participation for the 1995, 1997 and 1999 editions is presented in Table 6.8.

Vendors of: For Year	Cleaning Chemicals	Cleaning Equipment	Recycling Equipment	TUR Planners / Consultants
1995	54	63	N/A	N/A
1997	80	82	23	N/A
1999	51	57	23	15

Table 6.8 NUMBERS OF VENDORS PARTICIPATING IN DIRECTORY, 1995-1999

Conclusions

Based on legislative drivers discussed in chapter two, this section concludes:

(1) The amounts and kinds of equipment and chemicals available for industrial cleaning have increased, and a survey of end users indicated a need for more thorough information on these topics.

(2) Feedback from vendors of cleaning equipment (i.e., the appearance of more recycling devices) led to the development of a separate category for recycling equipment in the directory by 1997 as a result of this thesis' research. This trend in cleaning machinery also reveals the marketplace's response to the need for companies using alternative cleaning systems to manage water less wastefully (chapter eight).

(3) While the redesign of vendor questionnaires provided the opportunity for manufacturers of cleaning products to supply better information to their customers, the forms were oftentimes inaccurately completed. For example, one manufacturer simply checked off every box for contaminant removal, substrate compatibility, et al, rendering the information on the chemical cleaner useless. This was most probably done in the hopes of marketing his/her product to the most potential consumers, regardless of applicability.

(4) The reduction in the number of vendors participating in the *Directory* by 1999 (Table 6.8) may reveal unwillingness on the part of vendors to publicly divulge information on products' constituents without regulatory enforcement.

and/or

(5) The above reduction *may* reflect a lack of vendor technical expertise, substantiated by a two-fold increase in the amount of time it took the SCL to obtain the completed, redesigned forms (originally, three months and by 1999, up to six months). A number of incorrectly fill-out forms were also received. It may *not* be as a result of a decrease in available cleaning products, but a shift from chemicals to equipment, as evidenced in Table 6.9.

Numbers of: For Year	Chemical Cleaners	Cleaning Machinery	Recycling Equipment
1997	339	107	35
1999	222	156	49

Table 6.9 NUMBER OF CLEANING PRODUCTS IN DIRECTORY, 1997-1999

(6) This information gap may be filled with the recently initiated training of expert process/environmental engineers within the cleaning trades, as signaled by the evolution of a separate toxics use reduction (TUR) planners and consultants heading in the *Directory* for 1999.

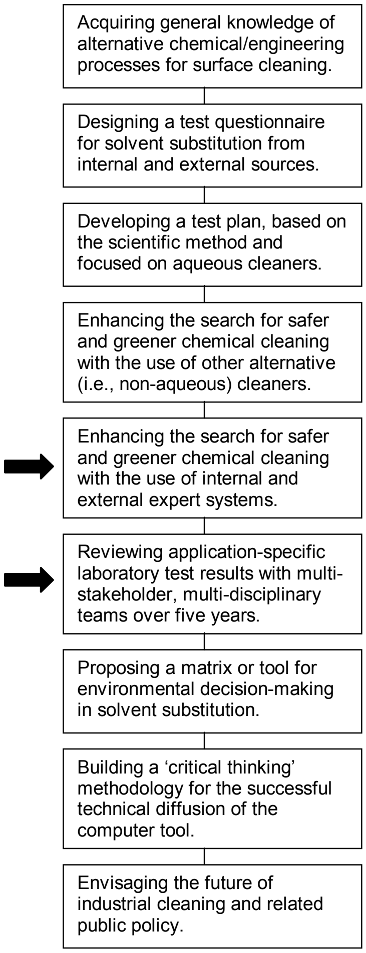
Recommendations

Initial forays into solvent substitution for industrial cleaning met with unsubstantiated claims that aqueous cleaning would be untenable. Having overcome that obstacle, the appropriate surface-cleanliness inspection tool must be as readily available to firms performing cleaning-related tasks during parts manufacture as the correct choice for cleaning chemicals and equipment. A new "Surface Analysis" section is recommended for the 2001 edition of the TURI vendor database.

The lack of vendor technical service may be driven by low purchase prices of many alternative chemical cleaners, coupled with low volume order (products are routinely diluted upon usage). Vendor technical expertise may also be thwarted by the high turnover rates suffered by marketing/sales organizations. This may be countered by offering training workshops to those individuals, as is the case with engineering students at the University of Massachusetts Lowell and within this state's TUR program.

The wealth of information obtainable since 1999 in the Toxics Use Reduction Institute's *Industrial Cleaning Survey: Directory of Vendors* is best suited for computer-driven searches. Plans should be made to develop a disk or CD-ROM version of the publication, so that the public can use this database more effectively. Electronic versions of the vendor questionnaires should also be made available on the web at http://www.turi.org/.

7 Enhancing the Search for Safer, Greener Chemical Cleaners, Part II



After thoroughly examining sources of technical information for solvent substitution, this chapter ends by using some of those sources to detail five years of metal cleaning.

7.1 Identifying and Using Appropriate Databases and Standards

The Technology Transfer Center (TTC) of the Toxics Use Reduction Institute houses New England's largest research library and clearinghouse on pollution prevention.[64] Searches can be conducted by process, chemical or industry.

7.1.1 The TOMES® Plus System

Of the many electronic resources available at the research library, TOMES® is the most valuable in the search for alternative chemical cleaners. TOMES®, an acronym for the Toxicology, Occupational Medicine and Environmental Series is a database product of the Micromedex Company of Denver, Colorado founded in 1974. The firm has a significant presence in the healthcare industry, serving 9,000 facilities worldwide. This database and other Micromedex products supply clinical information to pharmacologists, toxicologists, emergency and acute care givers, occupational specialists, as well as chemical safety and industrial regulatory compliance professionals.[65]

The TOMES® Plus system provides rapid, easy access to information on virtually any chemical for safe management purposes in the workplace and the environment. A compilation of sixteen licensed databases, entries are peer-reviewed by field-related experts and updated quarterly. Some databases claim government authorship while others are proprietary and are found only in TOMES.® The collection's unique Integrated Index™ feature allows simultaneous searches of all sixteen databases. This comprehensive approach is important, considering the thousands of compounds, along with an estimated 2.1 million chemical synonyms, now in use.[65] An overview of select TOMES® databases is presented in Table 7.1, along with commentary on the relevant entries for solvent substitution.

Selected TOMES® Databases	Brief Descriptions
Hazardous Substances Data Bank (HSDB) from the U.S. National Library of Medicine	Details the impact on health and the environment of more than 4,000 chemicals and presents specific data on environmental fate, human toxicity excerpts, animal studies, chemical handling and manufacturing.
Chemical Hazard Response Information System (CHRIS) from the U.S. Coast Guard	Originally developed in 1985, addresses the properties, isolation, reactivity and hazard classification of approx. 1200 chemicals.
Integrated Risk Information System (IRIS) from the U.S. EPA	Contains important values (cancer slopes, reference doses, etc.) for over 500 chemicals. U.S. EPA's first source for toxicity information in assessing health risks.
Registry of Toxic Effects of Chemical Substances (RTECS®) from NIOSH (National Institute for Occupational Safety and Health), Dept. of Health and Human Services.	Presents specifics on mutagenicity, carcinogenicity, reproductive hazards, and acute and chronic toxicities. One of the world's most extensive listings.
New Jersey (NJ) Fact Sheets from the NJ Department of Health	Developed by NJ's 'Right-to-Know' Program, it offers exposure risk information for workers and training programs, which is non-technical and easy to understand. Also, frequently asked questions and answers are provided.
REPROTOX® Reproductive Hazard Reference	Built by Dr. Anthony Scialli of Georgetown University Medical Center and Reproductive Toxicology Center, Columbia Hospital for Women Medical Center in Washington, DC. Includes data on all aspects on fertility, male exposure and lactation.

Table 7.1 INTERNAL DATABASES OF THE TOMES® PLUS SYSTEM[65,66]

Hazardous Substances Data Bank

In general, the most extensive chemical reports can be generated from the Hazardous Substances Data Bank (HSDB). Consequently, the SCL routinely uses this TOMES® database in pursuit of more sustainable cleaning processes. Searches can be conducted by a chemical's generic or trade names as well as by chemical formula or chemical abstract services (CAS) number. All chemicals manufactured in the United States must have this numeric registration. An HSDB report may contain as many as ten categories, as listed in Table 7.2.

Section Number and Title	Information
0.0 Administrative	HSDB Number. Peer review history and date of last revision.
1.0 Substance Identification	CAS Registry Number. Related HSDB records. Synonyms.
2.0 Manufacturing / Use Information	Methods and sites of manufacture. Consumption patterns, U.S. production, import/export figures. Lists products containing this component.
3.0 Chemical and Physical Properties	Color, form, odor, taste, solubilities, chemical and physical properties (boiling point, density, etc.).
4.0 Safety and Handling	Emergency guidelines including fire, explosion, protective clothing, first aid, hazardous reactions and decomposition data. Warning, preventive, and safe handling measures (storage, disposal, etc.).
5.0 Toxicity / Biomedical Effects	Antidote treatment. Human toxicity excerpts and animal testing with dose-specific damage to organs and tissues. Ecotoxicity values with sources.
6.0 Pharmacology	Bioneccessity (for example, an essential nutrient for sustaining life or proper organ functioning), if any. Therapeutic and veterinarian uses.
7.0 Environmental Fate / Exposure Potential	Soil, air and aquatic, marine and ground water. Environmental transformations, biodegradation. Probable routes of human exposure (for example, inhalation) and NIOSH estimated number of workers exposed.
8.0 Exposure Standards and Regulations	OSHA Permissible Exposure Levels (PELs). NIOSH recommendations. FDA requirements.
9.0 Monitoring and Analysis Methods	Sampling procedures. Analytical laboratory methods. Workplace monitoring.
10.0 Additional References	Any special reports.

Table 7.2 FRAMEWORK OF TOMES® HAZARDOUS SUBSTANCE DATA BANK REPORT

A TOMES® HSDB reports on sodium hydroxide (NaOH), a chemical used for its alkaline pH in cleaner formulations, is included in Appendix A of this thesis. Other electronic resources at the TTC are given in Table 7.3.

CD-ROM or Software Programs	Brief Descriptions
County Business Patterns, 1993-94: 1992 Economic Census	Provides a detailed portrait of the U.S. economy every five years according to geographical areas. The 1992 data released in 1996 covers retail and wholesale trade, utilities, transportation, communication, financial markets, manufacturing and the service, mineral and construction industries. Uses ZIP codes.
Patty's Industrial Hygiene and Toxicology	Contains information on toxicological properties of chemical agents, research trends, regulations and permissible exposure-level data. Patty's is a well-used and well-regarded resource.
U.S. Toxics Release Inventory (TRI) Data	Includes manufacturers reports of toxic chemical releases to air, water and land as well as transfers to publicly-owned treatment works (POTWs). Uses Standard Industrialization Codes (SICs).
Waste Minimization Prioritization Tool (WMPT) Beta Version 1.0	Assists stakeholders in identifying source reduction and recycling priorities. Developed by U.S. EPA.

Table 7.3 ADDITIONAL ELECTRONIC RESOURCES OF THE TTC[66]

7.1.2 Inmagic® at TURI's Technology Transfer Center

A useful tool of the TTC's clearinghouse is Inmagic®, a software program for special libraries designed by the company of the same name located in Woburn, Massachusetts. Inmagic® is considered the industry leader in automation and information management with over 15 years experience. The company's systems are installed in more than 50,000 specialty libraries worldwide.

Basically, Inmagic® programming allows the Institute to catalogue library acquisitions as well as the most recent articles and periodicals pre-identified by TURI technical staff as noteworthy in the field of pollution prevention. Searches can then be conducted by key word or words. Similar to the World Wide Web, queries are tailored according to the number of 'hits' generated by the use of the key words. For example, a search resulting in 493 matches needs to be re-submitted with refined parameters (i.e., the original key words or phrases resulted in too broad a field) to arrive at more manageable and meaningful data.

When the researcher is comfortable with the search's qualitative and quantitative results, individual abstracts can be called up to the screen one at a time and the catalogue numbers recorded for the full papers' retrieval in the library as necessary. University of Massachusetts Lowell graduate students enter these abstracts into the program.

An Inmagic® search before and after a surface cleaning application can ensure that no related, significant factor has gone unnoticed. Typical key-word topics deal with materials of construction for substrates, contaminant types, (vapor) degreasing, metal cleaning, metal industries, aqueous and semi-aqueous cleaners, (chlorinated) solvents, cleaning equipment (ultrasonics et al), cleaning methods (media blasting, etc.) as well as surface cleanliness.

7.1.3 ASTM, Military and Industrial Standards

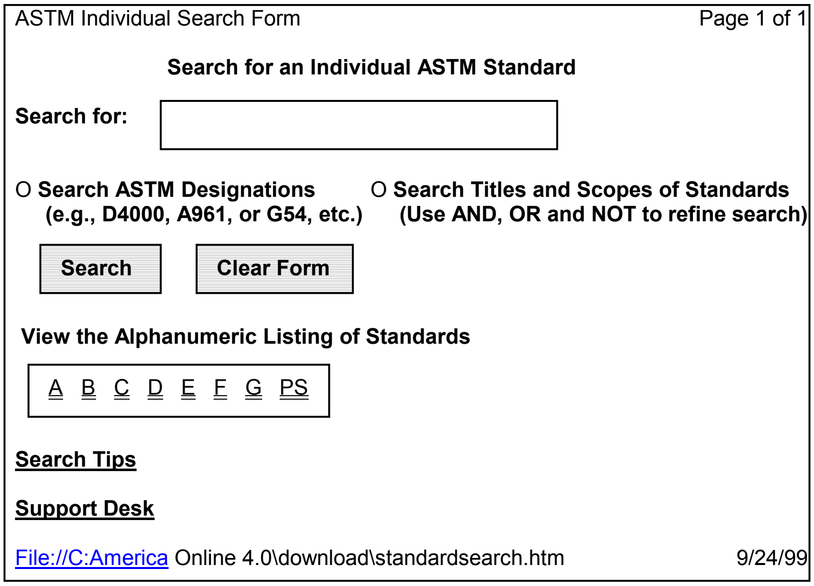
American Society for Testing and Materials

The American Society for Testing and Materials (ASTM) was founded in 1898 and is one of the largest standards development systems in the world. ASTM is a non-profit organization dedicated to providing a forum for producers, end-users, consumers and interested parties (government, academia, etc.) to cooperatively write standards for materials, products, systems and services. More than 10,000 standards are published annually from the work of volunteers serving on technical subcommittees and expert task groups on ASTM's 132 main committees.

Following a written request outlining the need for a new standard that can be verified by the Society, various drafts of the proposed standard are prepared and ballot votes taken by subcommittee members over a period of approximately two years until acceptance is reached. To ensure adherence to proper procedures, ASTM's Committee on Standards reviews the standard for final approval.

Standards are written with varying degrees of consensus, including company, industry, professional and government professionals. Full consensus standards are defined as those "developed through the cooperation of all parties who have an interest in participating in the development and/or use of the standards." There are six principal types of full consensus ASTM standards. They are (1) Standard Test Method, (2) Standard Specification, (3) Standard Practice, (4) Standard Terminology, (5) Standard Guide and (6) Standard Classification. Definitions of these terms and an explanation of the categorization of ASTM standards can be found in an assortment of publications, CD-ROM products and the Society's web site at http://www.astm.org.

The web site offers an important electronic tool that can be used to enhance the search for appropriate testing information on cleaning applications. Figure 7.1 is the web-based form used to conduct an Internet search of ASTM standards.



ASTM Individual Search Form Page 1 of 1

Search for an Individual ASTM Standard

Search for:

○ **Search ASTM Designations (e.g., D4000, A961, or G54, etc.)**

○ **Search Titles and Scopes of Standards (Use AND, OR and NOT to refine search)**

View the Alphanumeric Listing of Standards

A B C D E F G PS

Search Tips

Support Desk

File://C:America Online 4.0\download\standardsearch.htm 9/24/99

Figure 7.1
INTERNET FORM USED TO CONDUCT SEARCH FOR ASTM STANDARDS

Searches by ASTM designation are conducted by entering the alphanumeric designation of the standard required, e.g., **A961**. If unsure of the complete designation, an asterisk (*) can be entered as a wild card. For example, **A96*** will yield A960, A961, etc. and **A9*1** will yield A901, A911, etc. Alternatively, the Alphanumeric Listing of Standards can be used to browse the designations and titles of ASTM standards in a particular series.

Searches by titles and scopes of standards are conducted by entering a word or multiple words to describe the content of the standard(s) requested. For example, "copper," "flammability" or "tension." If this produces too many results to easily browse, the use of *operators* and *modifiers* applies logic to the query and pinpoints the exact information. Popular operators are AND, OR, ACCRUE, and NEAR. A modifier can be used with an operator to further define questions for the search engine. Frequently used modifiers are MANY and NOT. By default, the words "and," "or," and "not" are interpreted as verity query language. All other query language elements, such as the NEAR operator, are interpreted as words unless surrounded by angle brackets.

The AND operator selects documents that contain all of the search elements specified. To find standards that contain both the topic named "copper" and at least one stemmed variation of the word "tension," the query, copper AND tension is used. The OR operator selects documents that show evidence of at least one of the search elements. To find these standards, the query, copper OR tension is used instead. It is not necessary to indicate a date of the standard's publication since in every instance the most recent version is retrieved.

Table 7.4 lists the number of standards found for a total of 26 searches conducted by cleaning-related topics in the ASTM Designations and Titles/Scopes of Standards modes.

Categories Searched for ASTM Standards	Standards Found via ASTM Designations	Standards Found via Titles and Scopes
Cleaning	46	266
Surface Cleaning	0	7
Cleaning AND Degreasing	0	7
Industrial Cleaning	64	2
Rinsing	2	20
Rinsing Surfaces	0	0
Drying	37	125
Drying Surfaces	0	0
Cleanliness	4	32
Surface Cleanliness	0	4
Contamination	35	234
Surface Contamination	0	6
Metal Cleaning	0	3

Table 7.4 RESULTS OF WEB-BASED SEARCH FOR CLEANING-RELATED ASTM STANDARDS

Duplicate entries are possible among the categories. The most extensive albeit general listing, i.e., 266 entries under the first category can be found in Appendix E of this thesis (the headings are *hyperlinked* (that is, electronically connected) to their on-line abstracts. See chapter eight for a complete definition). By way of illustrating how this database can be used, ASTM Standards Search found 3 matching standards under the final category *metal cleaning*:

D800-91 Standard Test Methods of Chemical Analysis of Industrial Metal Cleaning Compositions
D5616-94 Standard Specification for Reclaimed Trichloroethylene
D5396-94 Standard Specification for Reclaimed Perchloroethylene

These references are also hyperlinked to summaries of the individual ASTM standards online. For example, in the case of the first standard listed above, the following information is obtained **by clicking on the item, provided the user's browser is running on the desktop for these and all other activated web sites opened on a PC platform from this MS Word document:**

D800-91 Standard Test Methods of Chemical Analysis of Industrial Metal Cleaning Compositions Copyright 1999 AMERICAN SOCIETY FOR TESTING AND MATERIALS, West Conshohocken, PA. All rights reserved.

1. Scope

1.1 These test methods describe the procedures for the chemical analysis of industrial metal cleaning compositions in solid, paste, or liquid form. These cleaning compositions may contain caustic alkalis, silicates, phosphates, chromates, carbonates, bicarbonates, borates, sulfates, sulfites, nitrates, chlorides, soaps, rosin, sulfonated wetting agents, anti-foaming agents, organic bases, organic solvents, organic coupling agents, and sometimes inorganic acid salts or organic acids. Occasionally, such cleaning compositions may contain sulfonated oils; in such cases, reference should be made to Method D500. The examination under a low power microscope or magnifying glass, supplemented by a few qualitative tests, will often indicate the number of components and their identity.
1.2 The analytical methods appear in the following order:
Section Preparation of Sample 4 Total Alkalinity as Na2O 5 to 7 Total Fatty Acids (and Rosin) 8 and 9 Na2O Na[inf]2[r]O 5 to 7 Total Fatty Acids (and Rosin) 8 and 9 Na[inf]2[r]O Combined with Fatty Acids (and Rosin) 10 and 11 Anhydrous Soap 12 Rosin (McNicoll Test Method): Qualitative 13 and 14 Quantitative 15 to 18 Total Silica Calculated as SiO[inf]2[r] 19 to 22 Phosphates: Qualitative 23 and 24 Quantitative 25 to 32 Combined Sodium and Potassium Oxides 33 to 36 Chlorides 37 to 39 Sulfates 40 to 42 Water Distillation Test Method 43 to 46 Carbon Dioxide by Evolution-Absorption Test Method 47 to 51 Loss at 105[deg]C 52 and 53 Total Matter Insoluble in Alcohol 54 to 56 Free Alkali 57 to 59 Synthetic Detergent or Wetting Agent 60 and 61 Volatile Hydrocarbons 62 to 66 Loss on Ignition 67 and 68 Report 69 and 70.
1.3 This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.> Material Safety Data Sheets are available for reagents and materials. Review them for hazards prior to usage.
Adopted by: DOD Approved ANSI Adopted
Developed by ASTM Subcommittee: D12.12
Subject Index
Acidity, alkalinity, pH-detergent materials; Alcohol-insoluble matter content; Anhydrous soap

content; Carbon dioxide content; Chemical analysis-detergent materials; Chloride content-cleaning agents/detergents; Cleaning-metal cleaners; Combined sodium/potassium oxides; Detergent materials/systems-industrial cleaning compounds; Distillation; Evolution-absorption method; Fatty acids and rosin acids content; Heating tests-loss on heating; Hydrocarbon content-volatile; Ignition-loss on ignition; Industrial materials/applications-metals/alloys; McNicoll method; Phosphate content; Potassium oxide content; Rosin acids and fatty acids content; Rosin acids content; Silica content; Sodium oxide (NaO[inf]2[reset]) content; Sulfate content-cleaning materials; Synthetic detergent content; Volatile hydrocarbons content; Water content; Wetting agents; chemical analysis of industrial metal cleaning compositions, methods.

Ordering and cost information for the full standard is also provided.

As of this writing, ASTM is in the process of creating, *Standard Guide for Selecting Cleaning Agents and Processes* in Committee D26 on Halogenated Solvents and Subcommittee .03 for Cold Cleaning.

Military Standards

Already referenced in chapter one, The U.S. Department of Defense (DoD) has been very active in the writing of surface cleaning specifications for the safety of personnel and the proper operation of equipment.

ASTM standards linked to DoD standards can be found by searching, DoD AND Cleaning to obtain the following list of 41 matching standards under the Titles/Scopes mode:

F861-94(1998) Standard Specification for Commercial Dishwashing Racks
F502-93(1998)e1 Standard Test Method for Effects of Cleaning and Chemical Maintenance Materials on Painted Aircraft Surfaces
E1417-99 Standard Practice for Liquid Penetrant Examination
E1099-96 Standard Specification for Soda Ash, Anhydrous (Sodium Carbonate, Anhydrous)
E866-96 Standard Specification for Corrosion-Inhibiting Adhesive Primer for Aluminum Alloys to Be Adhesively Bonded in Honeycomb Shelter Panels
E864-98 Standard Practice for Surface Preparation of Aluminum Alloys to be Adhesively Bonded in Honeycomb Shelter Panels
E729-96 Standard Guide for Conducting Acute Toxicity Tests on Test Materials with Fishes, Macroinvertebrates, and Amphibians
E709-95 Standard Guide for Magnetic Particle Examination
E3-95 Standard Practice for Preparation of Metallographic Specimens
D5119-99 Standard Test Method for Evaluation of Automotive Engine Oils in the CRC L-38 Spark-Ignition Engine
D4814-99 Standard Specification for Automotive Spark-Ignition Engine Fuel
D4749-87(1994)e1 Standard Test Method for Performing the Sieve Analysis of Coal and Designating Coal Size
D4417-93 Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel
D2724-87 Standard Test Methods for Bonded, Fused, and Laminated Apparel Fabrics
D2251-96 Standard Test Method for Metal Corrosion by Halogenated Organic Solvents and Their Admixtures

D2200-95 Pictoral Surface Preparation Standards for Painting Steel Surfaces
D2156-94(1999) Standard Test Method for Smoke Density in Flue Gases from Burning Distillate Fuels
D2022-89(1995)e1 Standard Test Methods of Sampling and Chemical Analysis of Chlorine-Containing Bleaches
D2013-86 Standard Method of Preparing Coal Samples for Analysis
D1779-98 Standard Specification for Adhesive for Acoustical Materials
D1732-67(1998) Standard Practices for Preparation of Magnesium Alloy Surfaces for Painting
D1730-67(1998) Standard Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting
D929-85(1997) Standard Specification for Borax
D800-91 Standard Test Methods of Chemical Analysis of Industrial Metal Cleaning Compositions
D609-95 Standard Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products
D595-85(1997) Standard Specification for Tetrasodium Pyrophosphate (Anhydrous)
D498-74(1990)e1 Standard Specification for Powdered Soap (Nonalkaline Soap Powder)
D496-74(1990)e1 Standard Specification for Chip Soap
D495-99 Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation
D460-91(1997) Standard Test Methods for Sampling and Chemical Analysis of Soaps and Soap Products
D456-85(1997) Standard Specification for Caustic Soda (Anhydrous)
D257-93(1998) Standard Test Methods for DC Resistance or Conductance of Insulating Materials
D235-95 Standard Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
C428-97 Standard Specification for Asbestos-Cement Nonpressure Sewer Pipe
B600-91(1997)e1 Standard Guide for Descaling and Cleaning Titanium and Titanium Alloy Surfaces
B322-85 Standard Practice for Cleaning Metals Prior to Electroplating
B253-87 Standard Guide for Preparation of Aluminum Alloys for Electroplating
B183-79(1997) Standard Practice for Preparation of Low-Carbon Steel for Electroplating
A849-97 Standard Specification for Post-Applied Coatings, Pavings, and Linings for Corrugated Steel Sewer and Drainage Pipe
A829/A829M-95 Standard Specification for Alloy Structural Steel Plates
A380-96 Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems

Note the appearance of aircraft cleaning and aerospace topics of this is a partial listing. Known collectively as military specifications or *mil specs*, the advancement of the science on no- or low-solvent cleaning has meant the recent re-write of many of these standards in Mil Spec Reform.

The Department of Defense Single Stock Point (DODSSP) was created “to centralize the control, distribution and access to the extensive collection of Military Specifications, Standards, and related standardization documents either prepared by or adopted by the DoD. The responsibilities of the DODSSP include electronic document storage, indexing, cataloging, maintenance, publish-on-demand, distribution, and sale of Military Specifications, Standards, and related standardization documents and publications comprising the DODSSP Collection. The DODSSP also maintains the Acquisition Streamlining and Standardization Information System (ASSIST) management/research database."

DODSSP's mission is under the auspices of the Defense Automation and Production Service (DAPS) located in Philadelphia, Pennsylvania. The DODSSP web site at http://www.dodssp.daps.mil provides access to related web sites: the ASSIST Online digital library, the ASSIST Quick Search (no password required) and the ASSIST Shopping Wizard online.

Industrial Standards

The Chemical Specialties Manufacturers Association (CSMA) is a trade association founded in 1914 and located in Washington, DC. CSMA represents the consumer products industry, including 400 suppliers of aerosols, automotive chemicals, cleaning supplies and detergents, disinfectants and sanitizers, waxes, polishes, and floor finishes, and home and garden pesticides.

CSMA's Detergents and Cleaning Compounds Compendium is a "comprehensive reference work in a loose-leaf binder format <that> includes bibliography of pertinent textbooks and periodical articles that discuss laboratory-testing techniques. The guide also contains CSMA, ASTM, ANSI <American National Standards Institute> and AATCC <American Association of Textile Chemists and Colorists> test methods, and current consumer practices in the use of cleaning products."

The contents of the 1995 third edition of this important technical publication is listed in Table 7.5.

Detergents Division Test Methods Compendium	
Section 1.	CSMA Performance Test Methods for Cleaning Products
Section 2.	Bibliography of Test Methods for Laboratory Evaluation of Performance Attributes of Cleaning Products
Section 3.	Independent Contract Laboratories in the United States
Section 4.	Literature Review of Detergents and Cleaning Products Performance Testing
Section 5.	CSMA Bibliography of Detergent Technology
Section 6.	Appendix

Table 7.5 CSMA TABLE OF CONTENTS FOR TEST METHODS COMPENDIUM

This organization's primary cleaning focus is on janitorial, maintenance, and institutional (schools, hospitals, hotels, et al) products. Their web site is http://www.csma.org.

7.1.4 Other Organizations and Standards

The Waste Management and Research Center (WMRC), affiliated with the University of Illinois' Champaign campus operates an Alternative Cleaners Laboratory similar to the SCL. More information about this organization and its research facility can be found at the web site http://www.wmrc.uiuc.edu/industryhelp/altcleanlab.htm. Two other groups deserve mention in this chapter concerning cleaning and cleaning standards: the University of Tennessee (Knoxville) Center for Clean Products and Clean Technologies and Green Seal, Inc. of Washington, DC. Incorporated in 1989, Green Seal is an "independent, nonprofit organization dedicated to protecting the environment by promoting the manufacture and sale of environmentally responsible consumer products. It sets environmental standards and awards a "Green Seal of Approval" to products that cause less harm to the environment than other similar products. By setting standards for environmentally responsible products, Green Seal seeks to reduce air and water pollution; cut the waste of energy and natural resources; slow ozone depletion and the risk of global warming; prevent toxic contamination; and protect fish and wildlife and their habitats."

Before a product is awarded the Green Seal, it must pass the organization's tests and environmental standards. Green Seal develops these environmental standards on a category-by-category basis. Similar to the ASTM's approach, industry, environmentalists, consumer groups and the public are invited to suggest product categories for review. Categories are generally chosen according to the significance of the associated environmental impacts, and the range of products available within the category. Once a category is selected, a study of the environmental impacts of products in that category is conducted. The study identifies the characteristics of the product and the points in the manufacturing process, use of the product and disposal that have significant environmental effects. The study is released in the form of a proposed standard. Proposed standards are circulated for public review and comment. Manufacturers, trade associations, environmental and consumer groups, government officials and the public are invited to comment. After reviewing the comments, Green Seal publishes a final standard.

The steps to certify a product with the Green Seal Mark can be found at the web site http://www.greenseal.org/howto.htm. (If a standard does not exist for the product category, it may be necessary to first develop one.)

Every Green Seal environmental standard includes the following sections:

(1) Certification

These Environmental Standards and Criteria contain the basic requirements for certain products to be certified by Green Seal, and for their manufacturers to receive authorization to use the Green Seal Certification Mark on products and their packaging, and in product advertising. The requirements are based on an assessment of the environmental impacts of product manufacture, use, and disposal and reflect information and advice obtained from industry, trade associations, users, government officials, environmental and other public interest organizations, and others with relevant expertise. These requirements are subject to revision as further experience and investigation may show is necessary or desirable. Green Seal solicits information and advice on issues associated with these Standards and Criteria.

(2) Compliance with the Standards and Criteria

Compliance with one of the following Standards and Criteria is one of the conditions of certification of a product by Green Seal.

(3) Compliance with Government Rules

In order to be authorized to use the Green Seal Certification Mark, the manufacturer of the certified product must disclose all governmental allegations or determinations of violation of federal, state, or local environmental laws or regulations with respect to facilities in which the product is manufactured. Certification will be denied any product manufactured in violation of environmental laws or regulations if, in Green Seal's judgment, such violations indicate that the environmental impacts of the product significantly exceed those contemplated in the setting of the standards and criteria.

(4) Limitations on Purpose of Standard

Green Seal's Standards and Criteria provide basic measures to promote environmental quality. Provisions for product safety have not been included in these Standards and Criteria because government agencies and other national standard-setting organizations establish and enforce safety requirements.

(5) Substantially Equivalent Products

Products that are substantially similar to those covered by these standards and criteria in terms of function and environmental impact may be evaluated and certified by Green against the intent of the requirements of these standards and criteria.

(6) Unanticipated Environmental Impacts

A product which complies with a Green Seal Standard or Criteria will not necessarily be certified by Green Seal if, when examined and tested, it is found to have other features which significantly increase its impact on the environment. In such a situation, Green Seal will ordinarily amend its standards to account for the unanticipated environmental impacts.

(7) Certification Agreement and Green Seal Rules

In order to be authorized to apply the Green Seal to a product or its packaging, or to use the Green Seal in product advertising, the manufacturer of the product must undergo an initial product evaluation to determine that the product complies with Green Seal's requirements, sign a Green Seal Certification Agreement that, among other things, defines how and where the Green Seal may be used, pay fees to cover the costs of testing and monitoring, agree to an ongoing program of factory inspections and product testing, and comply with the requirements found in the most recent version of "Rules Governing the Use of the Green Seal Certification Mark."

(8) Disclaimer of Liability

Green Seal, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. Green Seal shall not incur any obligations or liability for damages, including consequential damages, arising out of or in connection with the interpretation of, reliance upon, or any other use of these Standards and Criteria.

(9) Care in Testing

Many tests required by Green Seal's Standards involve safety considerations. Adequate safeguards for personnel and property should be employed in conducting such tests.

(10) Referenced Standards

A later edition may have superseded standards referenced in this document, and it is intended that the most recent edition of all referenced standards be used in determining compliance of a product with these Standards and Criteria.

(11) Labeling Requirements

These Standards and Criteria neither modify nor supersede government labeling requirements. Labeling language which varies in form from the requirements of this section may be used with the written approval of Green Seal.

Under contract to Green Seal, the Center for Clean Products and Clean Technologies produced a document in 1992 entitled, Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners. Both groups are currently working with the U.S. Army's Aberdeen base to generate other environmental standards for cleaning/degreasing agents and industrial/institutional cleaners.

7.1.5 Results, Conclusions and Recommendations

The extent of standards' usage at TURI's research laboratory and the author's service on the ASTM technical subcommittee D26.03 as well as on two Green Seal Stakeholder Committees for standards development, form the basis for the comments in this section.

Results

ASTM and DoD standards are not routinely used in the search for greener and safer chemical processes at the SCL. In addition to the dependence on specialized equipment and glassware, applicable test procedures are often more complex (for example, soil compounding) and time consuming than is warranted for many of the cleaning problems facing Massachusetts' companies *unless they are acting as subcontractors to the federal government*. Furthermore, these analytical techniques are not always environmentally friendly (section 5.7).

However, review of and familiarity with existing mil specs and standards prior to conducting any research on an analogous cleaning process can be helpful. This expertise may reduce the time needed to complete the experimental portion of a project, as well as add credence to the kind of cleaning system eventually recommended by the SCL. As a consequence, the Surface Cleaning Laboratory is listed in the ASTM International Directory of Testing Laboratories with the following descriptors at the web site http://www.astm.org/labs/PAGES/146000.htm:

Surface Cleaning Laboratory Individual Listings
http://www.cleanersolutions.org/ Email: leblanchom@aol.com
Toxics Use Reduction Institute at Univ. of Massachusetts
One University Ave Lowell, MA 01854-2866
Phone: (978) 934-3249 Fax: (978) 934-3050

SPECIALTY: The lab's mandate is to identify and promote safer/ greener alternatives to hazards such as organic and chlorinated solvents. Cleaning processes are investigated on an application-specific basis using state-of-the-art databases. Testing is performed for companies whose products/parts must be cleaned during manufacture and vendors developing chemical cleaners and cleaning equipment.

TESTING:
- Chemical Testing
- Mechanical Testing
- Nondestructive Evaluation
  - Optics/Photometry
  - Surface Analysis/Microscopy
  - Spectroscopy

LAB SERVICES:
- Construction Materials Engineering
- Environmental Impact
- Environmental Simulation
- Product Performance

SPECIFIC TESTS:

A380-96 Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
B322-85 Standard Practice for Cleaning Metals Prior to Electroplating
C756-87 Standard Test Method for Cleanability of Surface Finishes
D460-91(1997) Standard Test Methods for Sampling and Chemical Analysis of Soaps and Soap Products
D1280-89 Standard Test Method of Total Immersion Corrosion Test for Soak Tank Metal Cleaners
F502-93(1998)e1 Standard Test Method for Effects of Cleaning and Chemical Maintenance Materials on Painted Aircraft Surfaces
G31-72(1995)e1 Standard Practice for Laboratory Immersion Corrosion Testing of Metals
G122-96 Standard Test Method for Evaluating the Effectiveness of Cleaning Agents
G131-96 Standard Practice for Cleaning of Materials and Components by Ultrasonic Techniques

EQUIPMENT; TESTING CAPABILITIES; APPLICATIONS:

The lab has an inventory of chemical cleaners and cleaning equipment such as: ultrasonics, spray washing, immersion and air sparging. Cycle times, cleaner concentrations and temperatures, rinsing and drying are examined. Analytical methods include goniometry, gravimetry, FTIR, fluorescence and microscopy.

MATERIALS & PRODUCTS:

Air: indoor and outdoor atmospheres; stack emissions; noise levels
Water: ground water, wastewater, high purity, industrial effluent, saline recycled, rain, surface, process Hazardous waste, solid (nuclear and chemical)

LAB ACCREDITATIONS:

STAFF:

30 Staff including:
  2 PHD/MDPHD/MD
  2 Engineers
  2 Technicians

Conclusions

(1) The advancement of science based on consensus can be a slow process, known for its lack of technological leadership since *all* parties must agree to its principal components. An example would be the possible inclusion of white glove or wipe tests in ASTM's D26.03 Guide. These tests have a 50-year history within the military community while other, more advanced and acceptable methodologies exist. Nevertheless, consensus science is an essential part of policy making, especially as more environmental issues are viewed from a global perspective.

(2) Uncompensated, voluntary participation on advisory boards to standards promulgation has also led to a recent shift in the kind and/or number of stakeholders present at the table. That is, committees are often saturated with chemical and equipment vendors, those enterprises having the most to gain (or lose) economically upon the completion of the written standard. This is not to say that the science behind a proposed new standard is questionable; rather, the initial avenues of investigation are themselves cut short.

(3) As industrial surface cleaning becomes greener, the chemical cleaners employed by commerce will become more similar to those formulations used in households. Overlaps in standards, guides, specifications and classifications may become more commonplace.

(4) Organizations like Green Seal appear better suited to addressing product performance, and not just environmental criteria. This is a critical matter since green products, in many fields, initially suffered from a reputation of being poor performers.

Recommendations

The importance of standardization in the future of the cleaning trades cannot be overstated with regard to measuring environmental progress and the implementation of management systems such as the ISO 14000 series and its European counterpart, EMAS. Specifically, the potential impacts of surface cleaning processes conducted under a wide range of settings depends upon (1) establishing industry standards or a ranking system for the energy and water efficiency of cleaning-related equipment, (2) an improved understanding of what defines a green chemical cleaner and (3) better labeling of cleaning products. These systems are already in place for a number of other consumer markets such as the automobile and home appliances.

Attempts to speed up environmental certification processes should not be made at this time. It is precisely because of the plethora of products arriving on the marketplace with relatively unknown consequences that has led to the threat of toxic chemical exposure. However, the high cost of product certification needs to be addressed.

The differences between *certification* (Green Seal) and *verification/validation* (The Toxics Use Reduction Institute's Surface Cleaning Laboratory) programs warrant further explanation. In some instances, certification of cleaning products may make it too easy to avoid evaluating the latest, improved products. This may result in the inadvertent 'selling' of commercial wares by well-intended non-governmental organizations (NGOs).

7.2 Employing Databases of Laboratory Test Results

In order to arrive at meaningful data in a more timely fashion, the SCL developed a database of trial outcomes, based on five years of predominantly metals (86%) cleaning. The program most often used is known as the Effective Test Conditions or ETC Database.

7.2.1 Searchable Fields

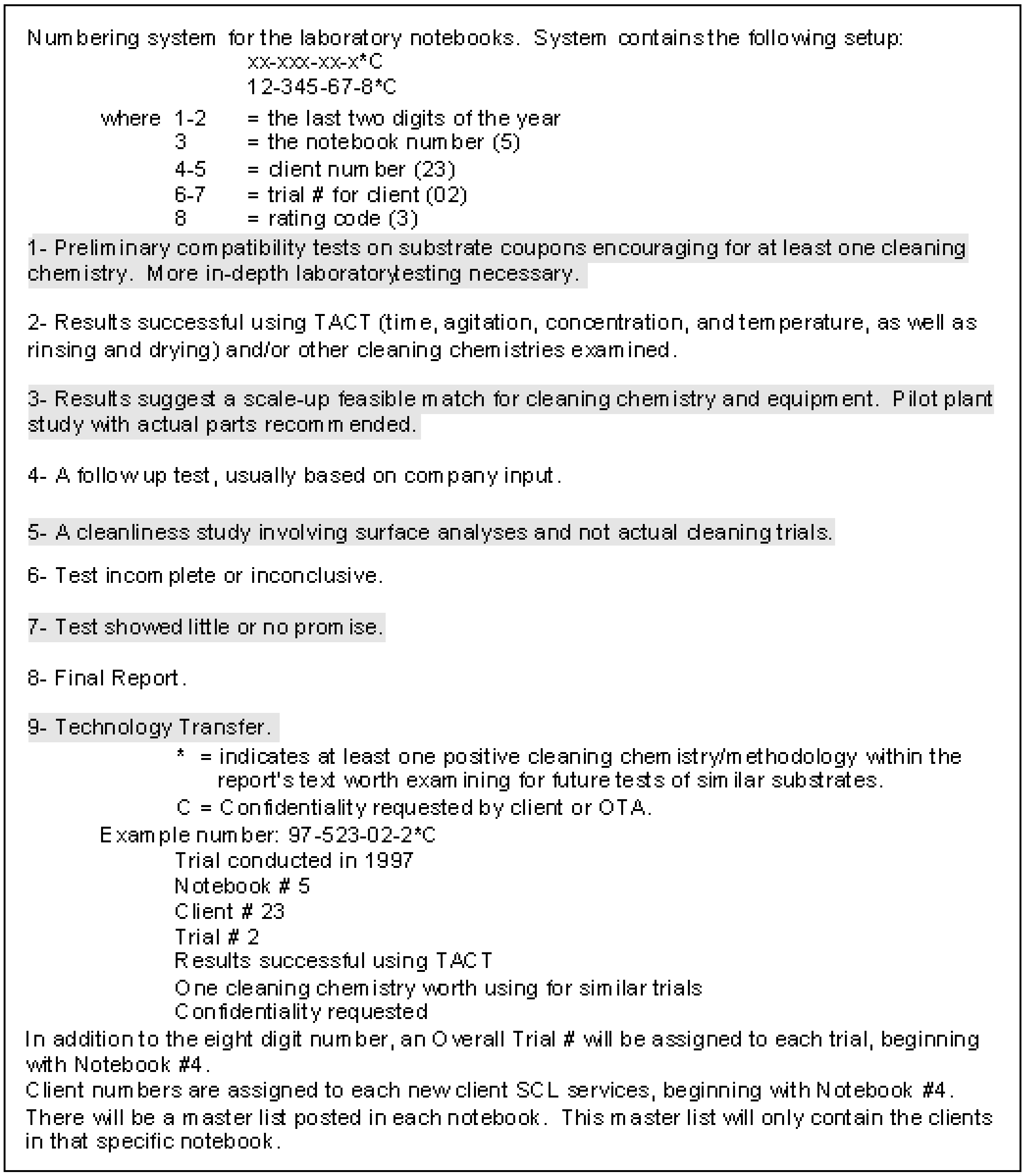
ETC is searchable by four fields selected by the author: surface substrate, surface contaminant, chemical cleaner and cleaning equipment. To demonstrate the use of this program, the data in Table 7.6 was obtained as a result of the inquiry, *"What recommendations can be made to a Manufacturer of opto-mechanical devices to clean lenses dealing with stain sensitivity?"*[45]

SCL Number	*Substrate*	Soil	Mechanism	Cleaner Mfg
95-409-01-2	*Glass*	Wax	Ultrasonics	Oakite
95-409-02-2	*Glass*	Wax	Immersion	Alconox
95-409-03-2	*Glass*	Wax	Ultrasonics	Alconox
96-435-01-8	*Glass*	Rosin	Immersion	Occidental
97-550-01-3	*Glass*	Grease	Spray	Alconox

Table 7.6
PARTIAL LIST OF SUCCESSFUL GLASS-CLEANING TESTS CONDUCTED BY SCL

For purposes of illustration, Table 7.6 contains hyperlinks to the SCL tests within Appendix F of this thesis. This information is routinely provided to businesses *after* their completion and submission of the Laboratory Test Request Form (Figure 4.3) but *before* SCL experimental trials. This ensures that all stakeholders note any trends and/or anomalies among applications.

The present ETC program allows SCL staff to access pertinent test data such as temperature, cleaner identification/concentration and cycle times by referring to the laboratory's notebook in search of a specific SCL experiment/code number or SCL# (Table 7.6). An explanation of the code developed by the author and modified by SCL technician J. Marshall is given in Figure 7.2.



Numbering system for the laboratory notebooks. System contains the following setup:
xx-xxx-xx-x*C
12-345-67-8*C

where 1-2 = the last two digits of the year
3 = the notebook number (5)
4-5 = client number (23)
6-7 = trial # for client (02)
8 = rating code (3)

1- Preliminary compatibility tests on substrate coupons encouraging for at least one cleaning chemistry. More in-depth laboratory testing necessary.

2- Results successful using TACT (time, agitation, concentration, and temperature, as well as rinsing and drying) and/or other cleaning chemistries examined.

3- Results suggest a scale-up feasible match for cleaning chemistry and equipment. Pilot plant study with actual parts recommended.

4- A follow up test, usually based on company input.

5- A cleanliness study involving surface analyses and not actual cleaning trials.

6- Test incomplete or inconclusive.

7- Test showed little or no promise.

8- Final Report.

9- Technology Transfer.

* = indicates at least one positive cleaning chemistry/methodology within the report's text worth examining for future tests of similar substrates.
C = Confidentiality requested by client or OTA.

Example number: 97-523-02-2*C
Trial conducted in 1997
Notebook # 5
Client # 23
Trial # 2
Results successful using TACT
One cleaning chemistry worth using for similar trials
Confidentiality requested

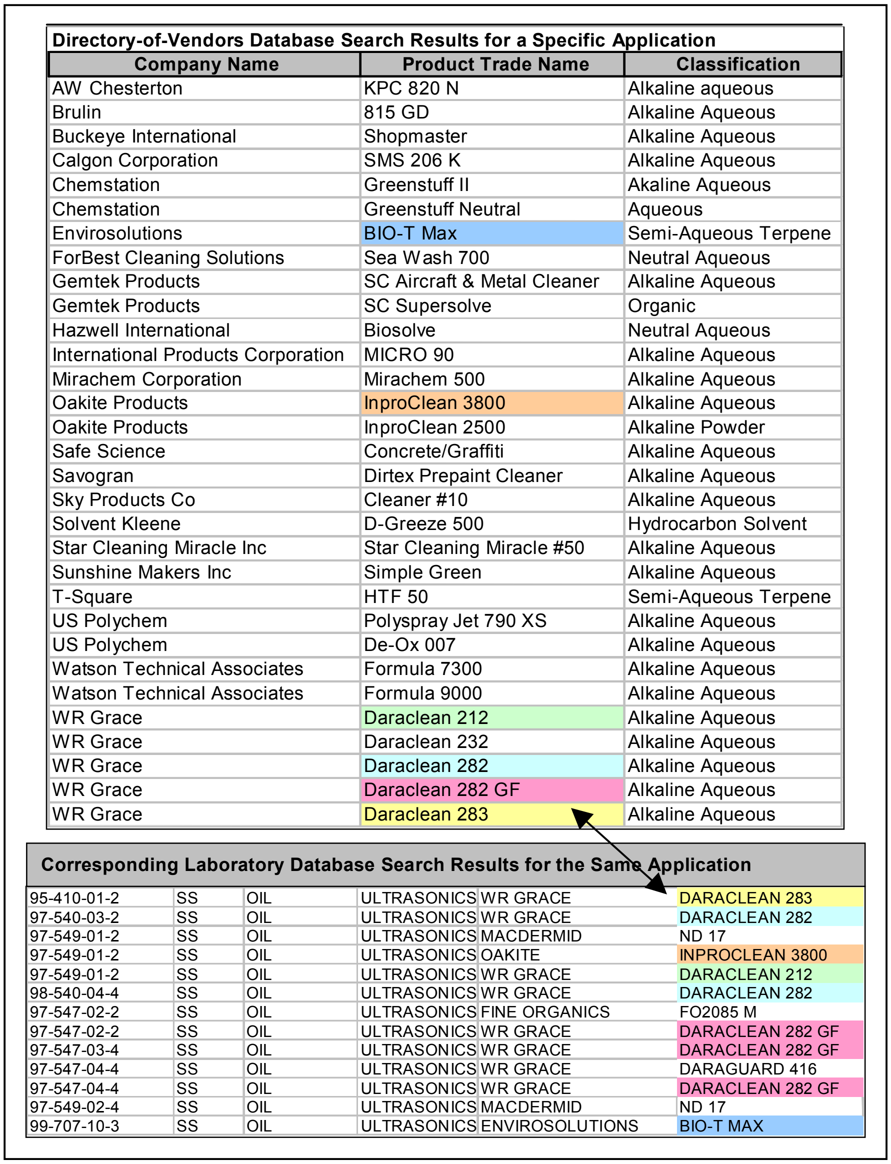
In addition to the eight digit number, an Overall Trial # will be assigned to each trial, beginning with Notebook #4.
Client numbers are assigned to each new client SCL services, beginning with Notebook #4.
There will be a master list posted in each notebook. This master list will only contain the clients in that specific notebook.

Figure 7.2 EXPLANATION OF CODING SYSTEM DEVISED FOR TESTS

7.2.2 Results, Conclusions and Recommendations

Results

Prior to an investigation, the SCL conducts two computer-driven searches of its own records: the Industrial Cleaning Survey: Directory of Vendors and the Effective Test Conditions (ETC) Database. Each of these databases supplies suggestions for any given application based on (1) vendor recommendations and (2) related SCL case studies, respectively. Figure 7.3 details the searches' results for an actual SCL client/Massachusetts company.



Directory-of-Vendors Database Search Results for a Specific Application

Company Name	Product Trade Name	Classification
AW Chesterton	KPC 820 N	Alkaline aqueous
Brulin	815 GD	Alkaline Aqueous
Buckeye International	Shopmaster	Alkaline Aqueous
Calgon Corporation	SMS 206 K	Alkaline Aqueous
Chemstation	Greenstuff II	Akaline Aqueous
Chemstation	Greenstuff Neutral	Aqueous
Envirosolutions	BIO-T Max	Semi-Aqueous Terpene
ForBest Cleaning Solutions	Sea Wash 700	Neutral Aqueous
Gemtek Products	SC Aircraft & Metal Cleaner	Alkaline Aqueous
Gemtek Products	SC Supersolve	Organic
Hazwell International	Biosolve	Neutral Aqueous
International Products Corporation	MICRO 90	Alkaline Aqueous
Mirachem Corporation	Mirachem 500	Alkaline Aqueous
Oakite Products	InproClean 3800	Alkaline Aqueous
Oakite Products	InproClean 2500	Alkaline Powder
Safe Science	Concrete/Graffiti	Alkaline Aqueous
Savogran	Dirtex Prepaint Cleaner	Alkaline Aqueous
Sky Products Co	Cleaner #10	Alkaline Aqueous
Solvent Kleene	D-Greeze 500	Hydrocarbon Solvent
Star Cleaning Miracle Inc	Star Cleaning Miracle #50	Alkaline Aqueous
Sunshine Makers Inc	Simple Green	Alkaline Aqueous
T-Square	HTF 50	Semi-Aqueous Terpene
US Polychem	Polyspray Jet 790 XS	Alkaline Aqueous
US Polychem	De-Ox 007	Alkaline Aqueous
Watson Technical Associates	Formula 7300	Alkaline Aqueous
Watson Technical Associates	Formula 9000	Alkaline Aqueous
WR Grace	Daraclean 212	Alkaline Aqueous
WR Grace	Daraclean 232	Alkaline Aqueous
WR Grace	Daraclean 282	Alkaline Aqueous
WR Grace	Daraclean 282 GF	Alkaline Aqueous
WR Grace	Daraclean 283	Alkaline Aqueous

Corresponding Laboratory Database Search Results for the Same Application

95-410-01-2	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 283
97-540-03-2	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 282
97-549-01-2	SS	OIL	ULTRASONICS	MACDERMID	ND 17
97-549-01-2	SS	OIL	ULTRASONICS	OAKITE	INPROCLEAN 3800
97-549-01-2	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 212
98-540-04-4	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 282
97-547-02-2	SS	OIL	ULTRASONICS	FINE ORGANICS	FO2085 M
97-547-02-2	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 282 GF
97-547-03-4	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 282 GF
97-547-04-4	SS	OIL	ULTRASONICS	WR GRACE	DARAGUARD 416
97-547-04-4	SS	OIL	ULTRASONICS	WR GRACE	DARACLEAN 282 GF
97-549-02-4	SS	OIL	ULTRASONICS	MACDERMID	ND 17
99-707-10-3	SS	OIL	ULTRASONICS	ENVIROSOLUTIONS	BIO-T MAX

Figure 7.3 SEARCH RESULTS FROM VENDOR DIRECTORY AND ETC DATABASE

Results indicate that five cleaners, Bio-T Max, InproClean 3800, and Daraclean 212, 282 GF and 283 formulations were recommended by the vendors for this application as well as tested positively in similar trials conducted at the SCL. These four alkaline aqueous and one semi-aqueous terpene cleaners would then be selected for initial laboratory testing.

Conclusions

(1) The SCL's databases of test results and TURI's Vendor Directory database have been established to compliment one another, that is, their formats match, following the redesign of the vendor questionnaires for the thesis. This has sped up the search for alternative cleaners in environmentally-friendlier cleaning processes by virtually eliminating the need for subjective coupon testing depicted as part of the SCL's Phase I of an aqueous-based test method (Figure 5.10).

(2) Meanwhile, the Vendor Directory database prepares staff at the plant for any time-sensitive, major equipment purchases that may be required due to process changes. This also serves to alert personnel of any installation and training issues that must be addressed.

(3) As a result, the SCL and the company may discuss the potential appointment of a University of Massachusetts Student Intern to the in-house portion of the project (Phase V of the aqueous-based test method) as well as possible funding sources (for example, TURI Matching Grants. Additional technology transfer assistance is provided in the form of cleaning and degreasing workshops held on campus and off-campus training sessions developed specifically for this thesis (chapter eight).

(4) The time spent by the SCL on any given application has remained fairly constant between 2 and 3, even though the number of individual projects has increased *and* become more difficult (Figure 7.4).[i] This may be attributed to the use of the state-of-the-art databases described in this chapter

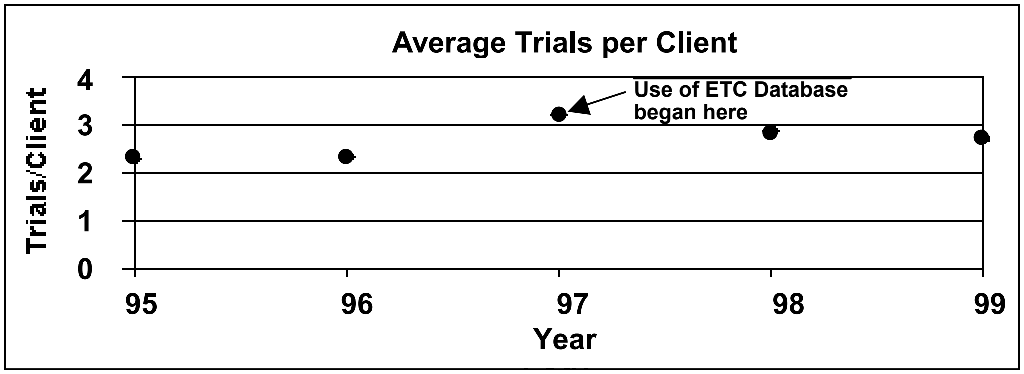


Figure 7.4 NUMBER OF TESTS CONDUCTED FOR INDIVIDUAL APPLICATIONS AT SCL

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[i] The difficulty of an application was roughly judged by the terminology (i.e., the number of terms) the client company required to describe it. This is usually in reference to the complexity of part configuration.

Recommendations

Better company follow-up after testing at the SCL is recommended. Whereas an average time lapse of eighteen months is commonplace in well-established (i. e., older than fifty years) before implementation,[68] newer endeavors such as alternative cleaning methods may require longer periods. The questions in Figure 7.5 may prove useful.

WHAT WAS YOUR COMPANY'S APPRAISAL OF LAB-CLEANED PARTS/COUPONS COMPARED TO YOUR CURRENT CLEANING SYSTEM (OR SCL CLEANLINESS EVALUATION, IF CLEANING TRIALS WERE NOT PERFORMED)?
____
____

WHAT SCALE-UP CHEMISTRY AND PROCESS HAVE YOU SELECTED?
Cleaner ____________________ Temp. ________°F Conc. ________%
If known: 9 Aqueous 9 Semi-aqueous Other____________________
Cleaning Equipment (Ultrasonics/KHz, Pressure Spray, etc.) ____________________
Factors Influencing Your Decision:
____

HOW DO THESE PARAMETERS COMPARE TO LAB TEST RESULTS?
____

WHAT IS THE ESTIMATED TIMETABLE FOR SYSTEM INSTALLATION/OPERATION?
____

IF NO CLEANING CHANGES ARE PLANNED, WHAT WERE SOME OF THE OBSTACLES?
____
____

DO YOU REQUIRE ADDITIONAL SCL ASSISTANCE? YES NO
Describe Problem (Rinsing, Drying, Quality Control, etc.): ____________________
____

WOULD YOU RECOMMEND OR USE THE LAB AGAIN? YES NO
Comments/Suggestions: ____________________

Figure 7.5 FOLLOW-UP QUESTIONS SUGGESTED FOR SURFACE CLEANING RESEARCHERS

However, the format of the questionnaire (the order of questions, personal contact during interviews, etc.) is seen by most marketing experts to be as important as the questions themselves to arrive at truly valid data. Chapter four mentions the results of a brief study, conducted by a student from Clark University, Worcester, Massachusetts in determining the adoption rates of new cleaning technologies after laboratory testing. At least one client company suggested that additional technical assistance was necessary for system piloting.

This is due to the three chronological steps that can be ascertained for all manufacturing protocols, including cleaning, with regard to final implementation: laboratory, pilot and production trials. The SCL miniaturizes or *microscales* most cleaning parameters accurately but must depend on vendors for some production-like runs (Table 6.3). A pilot plant installation at the SCL would serve to identify potential problems before scale-up in a less biased atmosphere, leading to improved technical diffusion.

7.3 Examination of Cleaning by Substrate Surface

7.3.1 Cleaning Steel

Steel is defined as “an iron-based alloy, malleable in some temperature ranges as initially cast, containing manganese, usually carbon, and often other alloying elements.”[7] In carbon steel and low-alloy steel, the maximum carbon is approximately 2%; in the high-alloy version, this concentration is about 2.5%. Carbon steel has no minimum quantity for any alloying elements other than manganese, silicon and copper. It contains only incremental amounts of other substances other than those mentioned and sulfur and phosphorus. The differentiating line between low- and high-alloy steels is generally 5% metallic alloys.

Steels may be separated from cast irons, the large family of cast ferrous metals (containing at least 2% carbon, plus silicon and sulfur with or without other alloying elements) and low-carbon pure iron. In very low-carbon steels, the manganese content is the primary difference. Steel usually contains at least 0.25% manganese and ingot iron much less. Cold rolled sheets are milled from a hot rolled, pickled coil that has been given substantial cold reduction at room temperature. This results in a product requiring further processing but with improved characteristics and uniformity.

Of the many different kinds of steel, the majority of tests conducted by the SCL with this substrate were categorized as stainless steel (in a few cases, companies were unaware of the steel classification of parts from their suppliers). These steels contain 12-30% chromium as the alloying element and usually exhibit passivity in aqueous settings. Some trends for the effective cleaning of steel substrates in the laboratory are revealed in Table 7.7.

Steel Part and *Contaminant*	**Cleaner Types and Concentrations (volumetric %)**	**Cleaning Methods, Temperature and Cycle Time**	**Rinsing Methods, Temperature and Cycle Times**	**Drying Methods, Temperature and Cycle Times**	**Surface Analyses**
*316 Stainless Steel Heat Exchangers *Fingerprints and light oils*	5% Aqueous Cleaner at Neutral pH	Ultrasonics (25 KHz) at 140° F for 10 minutes	Tap Water at 140° F or Deionized Water at Ambient Temperature for 2 minutes each	Convection Oven at 100° F or Infrared Heat Lamp for 30 minutes each	Visual
Stainless Steel Pump Seals *Coolant and metal fines*	4 -10% Several Aqueous Cleaners at Alkaline pH	Ultrasonics (40 KHz) or Spray Wash at 110° - 150° F for 5 - 15 minutes	Tap Water at 130° – 150° F or Deionized Water at Ambient Temperature for 2 - 5 minutes each	Convection Oven at 140° - 145° F for 30 - 60 minutes or Air Knife at Ambient Temperature for 2 minutes	Photomicrography
Carbon Steel Jet Engine Parts *Rust preservative and quenching oil*	100% Terpene / Semi-Aqueous Cleaner and A Hydrocarbon	Immersion / Soak at Ambient Temperature for 2 minutes	None	Air Dry at Ambient Temperature Overnight	Customer Performance Test
**1010 and 1020 Cold Rolled Steel *Lubricant and metal chips*	3 - 5% Several Aqueous Cleaners at Alkaline pH	Ultrasonics (40 KHz) or Tank Agitation at 100° - 130° F for 2 - 5 minutes	Tap Water With/out Rust Prohibitor at 120° F for 0.5 minutes	Infrared Heat Lamp for 1 minute	FT-IR
Unspecified Steel Rachet Handles *Dirt, metal fines, grease, buffing compound*	5% Aqueous Cleaner at Alkaline pH	Immersion / Agitation at 150° F for 5 minutes	Tap Water at 120° F for 0.5 minutes	Air Dry at Ambient Temperature Overnight	Customer Performance Test

*Alloy designation (refers to steel’s state of composition, annealing, hardness, etc.)
**Customer-reported grade designation

Table 7.7 CLEANING, RINSING, DRYING AND SURFACE ANALYSES OF STEEL AT SCL

In two of the above case studies, several potential replacement cleaners performed proficiently under almost identical operating conditions. This suggests that cleaning practitioners should source equipment and chemicals *separately*, since a chemical cleaner proffered by a cleaning equipment vendor may reflect an economic partnership, rather than the optimum selection for a particular application.

7.3.2 Cleaning Aluminum

The silvery-white, ductile metallic element aluminum is used to form many hard, light alloys. Nevertheless, fewer tests were performed by the SCL on this metal than on steel (Figure 4.6). Cleaning aluminum substrates can be challenging because of its proclivity to etch. *Etching* occurs when some of the metal is dissolved along with the contaminant, as a consequence of cleaning. Properly conducted gravimetric analysis can prove most useful during cleaning trials on aluminum surfaces since cleaned weights may be less than original (i.e., pre-cleaned) weights. Table 7.8 illustrates this effect.

Trial I.	***Percent Soil Removal Rates, Lubricant Mix**			
Aqueous Cleaner	**A**	**B**	**C**	**D**
Coupon #1	87.15	96.04	99.26	*98.60*
Coupon #2	91.99	99.77	93.17	*99.58*
Coupon #3	78.57	100.00	94.97	*99.25*
Average	**85.90**	**98.60**	**95.80**	***99.14***
Std Deviation	6.80	2.22	3.13	*0.50*
Trial II.	***Percent Soil Removal Rates, Vanishing Oil**			
Aqueous Cleaner	**A**	**B**	**C**	**D**
Coupon #1	100.32	100.77	101.26	*99.79*
Coupon #2	100.54	100.05	101.24	*99.68*
Coupon #3	100.76	99.72	99.70	*99.16*
Average	**100.54**	**100.18**	**100.73**	***99.54***
Std Deviation	0.22	0.54	0.89	*0.33*
Trial III.	***Percent Soil Removal Rates, Drawing Compound**			
Aqueous Cleaner	**A**	**B**	**C**	**D**
Coupon #1	100.76	99.58	99.36	*99.62*
Coupon #2	100.57	100.00	99.18	*99.72*
Coupon #3	100.50	99.17	99.77	*99.89*
Average	**100.61**	**99.58**	**99.44**	***99.74***
Std Deviation	0.13	0.41	0.31	*0.14*

*Complete Percent Soil Removal Rate = 100.00%

Table 7.8 GRAVIMETRY OF CLEANED ALUMINUM REVEALS SURFACE DAMAGE BY ETCHING

The assumption is made that no cleaner is capable of removing more than 100.00% of a soil. In the above application, all three soils are present on the surface of aluminum parts. A cleaner must be found to remove the contaminants *without* damaging the substrate. In the first trial, *Cleaners B, C* and *D* were relatively successful on the viscous and difficult-to-remove lubricant mix. In trials II and III on the easier-to-remove vanishing oil and drawing compound, however, *Cleaners A, B* and *C* pose moderate (light-gray shaded area) to substantial (dark-gray shaded areas) etching risks, based on their average soil removal rates. This is especially true if not all cleaning-cycle durations and temperatures can be accurately monitored at all times. *Cleaner D* is the best selection since it removed the vast majority of the three contaminants without etching in any of the test replicates.

7.3.3 Cleaning Other Metal Surfaces

Other metallic substrates, including brass, bronze, copper, gold, molybdenum, nickel and nickel alloys, silver, tin and titanium are cleaned by the SCL in the search for safer, greener chemical solvents. Some of those results are generalized in Table 7.9.

Metal Part	Surface Contaminants	Present Chemical Cleaner	Recommended Chemical Cleaner
Copper Tubes	Machining Oil	TCE	Alkaline Aqueous
Nickel Engine Parts	Oil, Grease, Wax	Acetone	Semi-Aqueous
Inconel Turbine Blades	Penetrating Oil	None (New System)	Alkaline Aqueous

Table 7.9 EXAMPLES OF OTHER METAL-CLEANING APPLICATIONS

7.3.4 Results, Conclusions and Recommendations

Results

Examination of hundreds of cleaning trials on different substrate surfaces for this thesis revealed interesting and useful trends, such as those noted for processing equipment and cycle times, cleaner types and concentrations, and cleaning temperatures in Tables 7.7. These findings substantiate (1) the universality of aqueous cleaning, regardless of industrial setting and part conformation, (2) the use of ultrasonics to cover a wide range of applications, (3) the importance of involving all aspects of the process, including rinsing and drying cycles, to establish effective cleaning parameters and (4) the significance and application-specific nature of surface analyses, for the determination of surface damage as well as surface cleanliness.

A full account of laboratory test results can be found in Appendix G of this thesis. Examination of these results suggest that (1) concentrations of alkaline-based aqueous cleaners, typically supplied as 50% hydroxide concentrates, are well under 10% for most cleaning projects and are therefore deemed safer to use than most if not all organic and/or chlorinated solvents and (2) elevated temperature (140^o-160^o F) plays a primary role in the success of those aqueous-cleaning operations.

Conclusions

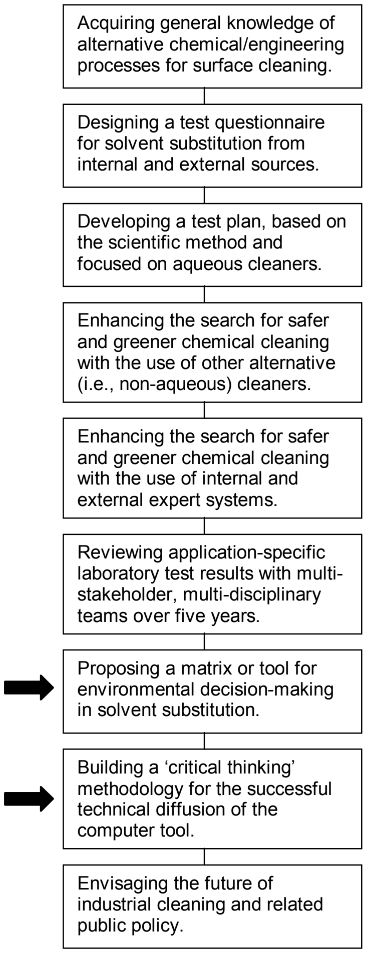
In closing, the use of all databases and standards, whether external or internal to TURI/SCL, is *<u>not</u> viewed by the author as a substitute for testing, but as an enhancement*. Application-specific validation is still necessary.

Recommendations

The same thorough examination of cleaning by contaminant type, rather than substrate surface, is possible with the Effective Test Conditions Database. For example, a database search could be conducted and a different research project designed for the removal of oil or any other industrial contaminant of interest. A system for ranking categories of soils with regard to ease of removal could then be devised. Resolution of the contaminant's physical properties, such as surface tensions and viscosities (cP) at cleaning temperatures, should prove worthwhile.

In addition, hyperlinks presented in Appendix E to access abstracts of ASTM standards could be used in a similar fashion to access abstracts of SCL tests in Appendix G. Table 7.6 is representative of such an approach, which would require funding for public access, either in a database or on-line format.

8 The Proposed Tool for Environmental Decision-Making



The first part of this chapter deals with summarizing the results obtained to this point in the thesis and laying the foundation for the formation of the proposed tool. The interactive matrix is then presented as part of a larger, critical thinking methodology and its application is evaluated. Following a review of the answers to the work's central scientific questions, the shortcomings of aqueous cleaning technology are detailed.

8.1 Summation of Notable Findings

This thesis was initiated with the expectation that a tool could be developed to assist "governments, companies, researchers and cleaning practitioners in the identification and selection of safer and more sustainable cleaning chemicals and processes" (chapter one). The Toxics Use Reduction Institute's (TURI) environmental indicators of reducing or eliminating the ingredients of chemical cleaners that contain volatile organic compounds, add to ozone depletion or global warming, or contain other toxic or reactive (for example, carcinogenic or flammable) materials were essential to this endeavor. On the way to developing this tool, a number of lessons were learned and documented in chapters four through seven. They include:

(1) The new cleaning test form developed for end users met with Massachusetts industries' approval, especially within the metalworking trade. The abbreviated, simplified format was a key to this very positive response.

(2) Gravimetric analysis is a quick, easy-to-duplicate, inexpensive and accurate means to measure surface cleanliness to determine the efficacy of different cleaning chemicals and processes. The resolution of *baselines* (the point at which no further cleaning is warranted) and *benchmarks* (the point at which an aqueous cleaner performs as well as its solvent counterpart) is very important for furthering the science of surface cleaning. Mixtures of contaminants (for example, oil and dirt) behave differently on surfaces than the individual contaminants, both for cleaning and for surface inspection.

(3) Setting up a test design for chemical cleaners demanded a multi- or trans-disciplinary approach, involving the interpretation of Material Safety Data Sheets (MSDSs), technical data sheets and other information to determine the chief phases of experimentation. This is because both cleaning expertise *and* product/part expertise were necessary. The stages of the test design manipulated the process parameters of time, agitation, concentration and temperature (*TACT*) in a scientific way and included: (a) preliminary 'lift' studies of potential replacement cleaners on laboratory-contaminated coupons (instead of actual parts), followed by visual, i.e., subjective, analysis, (b) cleaning of laboratory-contaminated coupons at the chemical vendors' recommended settings for temperature and concentration with the cleaners successful in phase one, followed by gravimetric, i.e., objective analysis, (c) testing the equipment proposed by the

company as most feasible for scaling up with the cleaners and conditions successful in phase two, followed by application-specific, objective surface analysis, (d) cleaning of actual parts under the laboratory conditions successful in phase four and finally (e) piloting these results with the most successful cleaner(s) and equipment settings for a number of actual parts under plant conditions for production.

Cleaning coupons with ultrasonic energy (the form of agitation most easy to measure, control and duplicate in the laboratory) throughout most of this protocol eliminated the wasteful use of expensive and/or rare parts and saved time during testing. This demonstrated MIT's N. Ashford's principle, "fail early, fail often, fail cheap" in arriving at reasonable solvent alternatives for industry.

(4) The cleaning alternatives of blasting with sodium bicarbonate and extracting with carbon dioxide were found to be less versatile than aqueous cleaning. This was due to the limitations of part size and configuration for blasting and the relatively high equipment costs associated with supercritical carbon dioxide extraction. Both methods represent progress in worker health and safety and diminish industrial cleaning's demand on natural resources such as water and energy and the generation of toxic waste, however.

(5) A marked enhancement in the efficiency of accessing/sharing technical information and test data was achieved after major improvements were made to the cleaning questionnaires for vendors in three categories and a new consultant section was added to the vendor database.

Surveys revealed the education and training needs of different industrial sectors and the additional implementation assistance required by firms after laboratory testing.

(6) The databases of TURI's Technology Transfer Center, specifically, Inmagic® and Micromedex's TOMES® were found to be much more helpful in conducting green chemistry searches than were standards provided by various professional associations.

The rapid growth of the World Wide Web will form the basis for the improved diffusion of all technologies, lending to both transparency and expanded accountability to the sciences.

(7) Four primary fields were used to search the TURI's Surface Cleaning Laboratory's (SCL) Effective Test Conditions (ETC) database via a readily-available Microsoft© program: surface substrate, contaminant, chemical cleaner and type of agitation. As more fields (temperatures, cleaner concentrations, etc.) and more tests on alternative cleaners are added, the importance of/dependence on search engines will increase.

(8) The analyses of cleaning various metal products, in particular, steel and aluminum, revealed that while information obtained from databases is useful in speeding up the search for safer and greener cleaners, *there is still no substitute for application-specific testing*.

Major Recommendations

Recommendations based on these findings include:

(1) Other test forms should be developed to meet the needs of non-industrial groups, for example, communities and municipalities searching for safer institutional/janitorial cleaners.

(2) Better analytical methods should be devised for the evaluation of surface cleanliness, since each application ideally requires two different measuring techniques to verify results.

(3) Improvements are needed in the way projects are piloted after laboratory testing, if success on the production floor can be expected.

(4) More research and development should be performed on non-aqueous alternatives, even though aqueous (i.e., water-based) cleaners remain the most viable substitutes for organic solvent-based cleaners for the vast array of industries studied.

(5) The policies of governments should support (i.e., fund) multi-faceted, computer-based enterprises in researching solvent alternatives for the advancement of the public health.

(6) Differences in *certification* programs such as the non-profit organization Green Seal and *validation* programs such as the SCL should be made clearer to the public.

(7) While continuing to formulate better aqueous cleaners by investigating chemical ingredients, scientists should place more emphasis on the physical properties of contaminants and parts' materials of construction. This could lead to innovation in composites for the development of new surface structures that may not require cleaning.

These findings and recommendations, along with information from various tables and figures throughout the thesis highlighting five years of SCL experiments, are summarized in Table 8.1.

Topics	Results and Observations	Test-Related Settings	Leading Statistics (%)
Test Forms Evaluated/ Developed	2 Evaluated 1 Developed	Cleaning Chemicals Replaced	37 – TCE, TCA (Perc)
		Cleaning Chemicals Tested	>90 – Aqueous
Test Protocols Evaluated/	2 Evaluated 1 Developed and Amended	Substrate Surfaces Cleaned	86 – Metals, esp. steels
		Contaminants Removed	48 – Oils
Number of Tests Conducted per Year	1995 - 50 1996 - 44 1997 - 54 1998 - 100 1999 -125 TOTAL - 373	Cleaning Methods Used	41 – Tank Agitation 28 – Ultrasonics
Standards Used:	ASTM, CSMA, Green Seal, Mil Specs	Rinsing Method Used	54 – Tap Water
Databases Used:	Inmagic, Micromedex, SCL's ETC	Drying Method Used	38 – Air Knife
Vendor Forms Developed/Amended	3 Developed and Amended for Chemicals/ Equipment; 4th Developed for Consultants	Analytical Techniques Used	32 – Gravimetric 24 – Visual

Table 8.1 LABORATORY TOPICS AND CLEANING STATISTICS EVALUATED, 1995-1999[69]

The five-year analysis of the technical services provided by the SCL as outlined above reveal:

(1) Although the regulations governing solvents and the science of solvent substitution are not new, the number of tests performed by this research facility for its client firms remained relatively steady (1995-1997) and then continued to rise (1998 and 1999). This may be partially due to (a) a robust economy in which the companies increased their solvent consumption as a result of an unforecast growth in orders received, (b) business' mistaken belief that the previous U.S. Congress would be successful in relaxing environmental regulations and/or (c) confusion as to how these regulations applied to their specific industrial usages.

(2) Vendor forms, completed by suppliers to enter their products into a cleaning directory database, were an obvious adjunct to this study. Many forms were submitted partially or incorrectly completed, exposing an apparent lack of technical expertise on the suppliers' staffs.

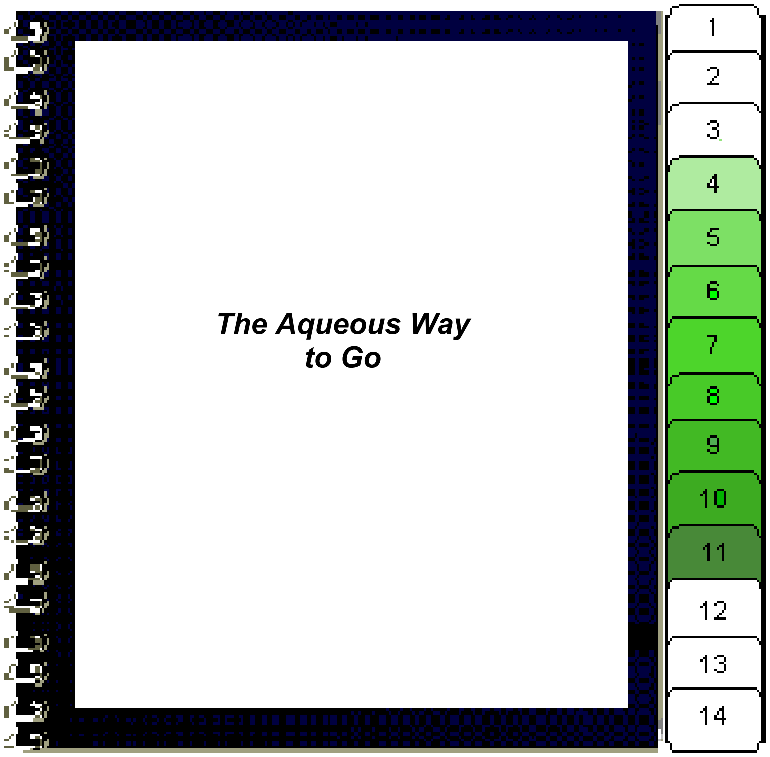
8.2 Need for a Management Information System

Understanding all of this data underscores the need for a system to make this information user-friendly. Otherwise, correctly applying the myriad of interrelated principles governing chemical usage would be next to impossible for most practitioners who face daily manufacturing concerns, in addition to surface cleaning. As defined by the American Heritage® Dictionary of the English Language (fourth edition, Houghton Mifflin, 2000), such a management information system (MIS) consists of a "a computer system designed to help managers plan and direct business and organizational operations." These programs are generally associated with matters like personnel. No such MIS for solvent substitution as yet exists.

8.2.1 Formation of an Interactive Matrix as an Information Management Tool

Using the data from Table 8.1 as a cornerstone, an interactive and potentially web-based search tool was developed. The tool allows an investigator on a PC to ‘click on’ various parameters presented as ‘hyperlinked’ tabs in an electronic notebook to access information, such as the SCL’s performance testing and total cost accounting, stored separately within the program. Locations to enter individualized test data and document the development of new technologies and/or environmental indicators are also included. A report can then be assembled and saved for each cleaning chemical of a project, and a more thorough investigation conducted.

The newly developed ‘cleaning materials’ assessment tool named *The Aqueous Way to Go*, utilizes fourteen topics, depicted in Figure 8.1, as hyperlinked tab-headings in an electronic notebook for the comparative analysis of chemical cleaners. The ensuing tab descriptions include examples, with the exception of notebook tab thirteen, which provides regulatory information. Under ideal conditions, a single cleaning project would demonstrate the usefulness of all notebook topics in the organization of data and records in the proposed matrix. This is simply not the case, since every project is uniquely complex. Instead, individual examples are used to clearly and concisely illustrate each tab, pointing out the potential applications of each of the chosen categories.



1. Introduction
2. Index: Solvents and Detergents
3. Chemical / Physical Properties: Merck Index
4. Health and Safety, Part I
    MSDSs and HMIS/NFPA Ratings
    Handling Requirements
5. Environmental Effects, Part I: the Indicators
6. Case Studies and Standards: SAGE, ASTM
7. Process Parameters: SCL Databases
    Tests and Vendors
8. *Results of Application-Specific Testing
9. Health and Safety, Part II
    TOMES® HSDB, Section 5.0
    Consequences of <Over>exposure
10. Environmental Effects, Part II
    TOMES® HSDB, Section 7.0
    Environmental Fate
11. Sustainability Factors
    TOMES® HSDB, Section 2.0
    Methods and Locations of Production
12. Total Cost Accounting/Worksheet
13. Regulations
14. *Advances in Cleaning Technologies

*For individualized entries.

Figure 8.1 INTERACTIVE MATRIX AS AN ELECTRONIC NOTEBOOK FOR SOLVENT SUBSTITUTION

The shaded areas in Figure 8.1, the light-to-dark green notebook tabs numbered four through eleven, reflect (1) the results of most of the work done for this thesis and (2) the best opportunities for governments, companies, researchers and cleaning practitioners to make substantial contributions to the greening of solvent selection and usage.

Notebook Tab 1
Introduction

The purpose of this matrix, or decision-assisting template, is to provide a format, in this case, an electronic notebook, for the collection and systematic storage of pertinent data in the search for greener and safer cleaners. The notebook tabs have been placed in chronological order to coincide with the critical-thinking methodology developed within this thesis for the determination of alternatives in cleaning processes. As previously mentioned, all of the notebook's tabs are hyperlinked to the next tab as well as to appropriate World Wide Web sites and to additional resource files.

Notebook Tab 2
Index of Solvents and Detergents

Notebook tab two contains the names of the chemical cleaners under review for a given application. Initially, the list contains the cleaner(s) currently in use. It may also include recommendations from the present chemical supplier and suggestions from plant personnel. As a particular application progresses, more cleaners can be added, especially after conducting searches of the SCL's databases (notebook tab seven). This is also a good place to store (1) information about chemical types (aqueous, semi-aqueous, etc.) and (2) vendor contact information for quick reference.

> *Example*
> A metalworking job shop is seeking a safer, greener chemical that will function under ultrasonic conditions for cleaning oil from stainless steel surfaces. The current supplier has not been helpful in providing technical advice, consequently, the company is unaware of potential replacements and so there are no suggestions to offer for entry into the index from these two sources. Using the actual case from Figure 7.3 in chapter seven, however, the index should contain the present solvent, plus the following chemical candidates suggested by searches conducted on the SCL's databases:

Solvents	**Chemical Type** `	**Manufacturer Information**
Trichloroethylene	Chlorinated Organic	XXX
Detergents		
1. BIO-T Max	Semi-Aqueous Terpene	EnviroSolutions 203-452-7225
2. Daraclean 212	Alkaline Aqueous	WR Grace 708-458-0340
3. Daraclean 282 GF	Alkaline Aqueous	WR Grace 708-458-0340
4. Daraclean 283	Alkaline Aqueous	WR Grace 708-458-0340
5. Inproclean 3800	Alkaline Aqueous	Oakite 908-508-2107

> In this particular case, each of the five cleaners was recommended by the SCL's testing database *and* the SCL's vendor database for similar applications. Each cleaner's name would be hyperlinked to its electronically-stored MSDS in notebook tab four.

Notebook Tab 3

Chemical Description of the Substances / Physical Properties, derived from the Merck Index, or from other similar chemical reference books

Notebook tab three contains thumbnail descriptions of the major physical and behavioral properties of cleaners' important *ingredients*. The ingredients are listed in the cleaners' MSDSs. The properties of components may differ substantially from the properties of formulated solvents and detergents outlined in chapters two and three. Notebook tab three exists only to enhance technology transfer among stakeholders with varying degrees of chemical expertise.

Click here for: Information on the Merck Index (scroll down page)
Click here for: Chemical Fact Sheets from U.S. EPA Office of Pollution Prevention and Toxins
Click here for: “ “ “ “ Canadian Centre for Occupational Health and Safety
Click here for: “ “ “ ”U.S. Agency for Toxic Substances and Disease Registry
(search also, ToxFAQs)

Example

Merck Twelfth Edition, 1996

9767. 1,1,2-Trichloroethane. Vinyl Trichloride. $C_2H_3Cl_3$; mol wt 133.40. C 18.01%, H 2.27%, Cl 79.73%. $CH_2ClCHCl_2$. Prepd. by chlorination of ethane or ethylene: Joseph, U.S. pat. 2,752,401 and Pye, U.S. pat. 2,783,286 (1957) to Olin Mathieson). Toxicity data: H.F. Smyth et al., *Am. Ind. Hyg. Assoc. J.* 30, 470 (1969).
Nonflammable liquid**;** pleasant odor; d_4^{20} 1.4416. mp –35° bp 113-114°. n_D^{20} 1.4711. Insol. in water. Misc with alcohol, ether, and many other organic liquids. LD50 orally in rats: 0.58 ml/kg (Smyth).
Caution: Potential symptoms of overexposure are irritation of nose and eyes; central nervous system depression; liver and kidney damage. Potential occupational carcinogen. *See NIOSH Pocket guide to Chemical Hazards* (DHHS/NIOSH 90-117, 1990) p 216.
USE: Solvent for fats, waxes, natural resins, alkaloids.[70]

Notebook Tab 4

Health and Safety, Part I: Storage of Material Safety Data Sheets (MSDSs)

Notebook tab four contains electronically-stored MSDSs of all the chemicals listed in the index (notebook tab two) via hyperlinks. While the Hazardous Materials Information System (HMIS) and the National Fire Protection Association (NFPA) ratings are optionally listed on these forms, they can be used to filter-out substitutes that do not represent sufficient process improvements over the current cleaner OR simply shift risks from one focus (for example, ozone depletion) to another (such as flammability). For this reason, handling requirements are noted here as well. An explanation of NFPA safety categories is given in Figure 8.2.

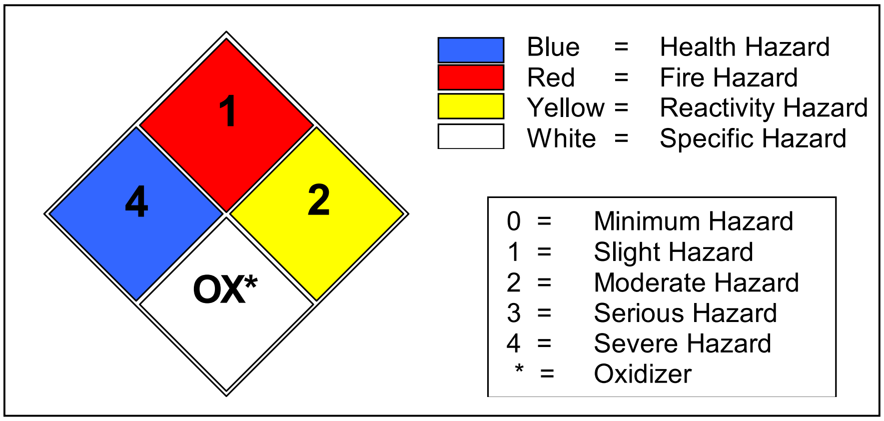


Figure 8.2
EXPLANATION OF COLOR CODING AND NUMERIC RATING OF FOUR HAZARD CATEGORIES IN NFPA-TYPE CHEMICAL LABELING

Click here for: More information on NFPA Chemical Hazard Labeling System
Click here for: Material Safety Data Sheets (Hint: Cornell and Vermont sites are best)
Click here for: More MSDSs

Example
Seven cleaners plus the current solvent have been hyperlinked to their MSDSs and technical data sheets (if any). A comparison of their NFPA ratings reveals the following:

NFPA Hazard Categories:	**Health**	**Fire**	**Reactivity**	**Specific**
Current Solvent	**3**	1	1	N/A
Company-Recommended Replacement	0	**3**	2	N/A
1. SCL-Candidate Cleaner A*	0	1	1	N/A
2. SCL-Candidate Cleaner B	0	1	1	N/A
3. SCL-Candidate Cleaner C*	1	0	1	N/A
4. SCL-Candidate Cleaner D	1	0	0	N/A
5. SCL-Candidate Cleaner E	1	1	1	N/A
6. SCL-Candidate Cleaner F	1	**2**	1	N/A

Table 8.2 COMPARISON OF NFPA NUMERIC RATINGS OF A SOLVENT AND POTENTIAL REPLACEMENT CLEANERS

The company-recommended replacement is included during application-specific tests in notebook tab eight for comparative purposes only. It would not be recommended as a substitute since its NFPA score does not represent an improvement over the current solvent. In fact, **all chemicals with a rating of three (3) or higher (that is, representing a serious-to-severe hazard) in any of the NFPA/HMIS categories are considered inherently unsuitable as safer and greener, alternative cleaners**.

With such a large field of initial replacement candidates, the decision could be made to eliminate the final candidate, cleaner F, from the application-specific testing in notebook tab eight. This is because (1) cleaners A through F performed equally well under similar conditions in a search of the SCL's databases (notebook tab seven) and (2) cleaner F is the only SCL candidate that has a rating of more than '1' in any of the NFPA hazard categories. The determination to eliminate cleaner F would be made more difficult if one of the vendors does not post the voluntary NFPA numeric values. It would *not* follow that a product without the HMIS or NFPA rating should be automatically deemed less safe. An asterisk (*) denotes that at least one ingredient in one category on the MSDS is listed as "test data unavailable" and/or a vendor refuses to disclose information concerning ingredients listed as "proprietary." If performance criteria can be met by all cleaners (tabs seven and/or eight), this presents yet another opportunity to eliminate potential replacements by applying the precautionary principle, discussed in chapter nine of this thesis.

The company-recommended replacement requires handling as any potentially flammable product. The MSDSs of Cleaners A- F mandates the use of gloves.

Notebook Tab 5

Environmental Effects, Part I: The Environmental Indicators

Notebook tab five contains a record of the Toxics Use Reduction Institute's environmental indicators: (1) volatile organic compound (VOC) content, (2) ozone depletion potential (ODP), (3) global warming potential (GWP), (4) toxicity and (5) reactivity data for each of the indexed cleaners. Vendors sometimes supply this information, if it is not already included on MSDSs, in technical data sheets that can be electronically stored and hyperlinked in this notebook tab.

Example

The examination of MSDSs for two aqueous cleaners revealed no important differences, but the technical data sheet (unfortunately, there is no electronic version and the document did not scan properly) of one of the cleaners revealed a VOC. The VOC was not required listing on the MSDS due to its low level (i.e., < 1%). This information is therefore entered into notebook tab five:

Manufacturer: Brulin Product: Compliance Blend
VOC content (of concentrate) less than 0.5 lbs/gallon
The VOC is listed as a contaminant (not an ingredient), which may still be a concern, especially for continuously-operating systems generating large volumes of cleaning solution/wastewater.

Notebook Tab 6

Case Studies and Standards

Notebook tab six contains the results of computer-program or web-based searches of the Solvent Alternative Guide (SAGE) for a listing of case studies related to the application and relevant standards from the American Society of Testing and Material (ASTM). This tab may also include testing protocols from the Chemical Specialty Manufacturers' Association (CSMA) and guidelines/certification information from the non-profit organization Green Seal, Inc.

Click here for: ASTM Standards, UNZIP file to word search (use Edit/Find function in Toolbar)
Click here for: CSMA Home Page (compendium ordering information under Publications)
Click here for: Green Seal Home Page (standards, guidelines and certification program)
Click here for: SAGE, Solvent Alternatives Guide's Process Advisor and Case Studies
Click here for: Massachusetts Office of Technical Assistance (OTA) Case Studies

ASTM standards are hyperlinked to their abstracts on the Web (see section 7.1.3 for the U.S Department of Defense and Appendix E of this thesis). A small fee is charged to order a complete standard.

Example

The Green Seal proposed standard for general-purpose, bathroom and glass cleaners includes the following references for *performance* criteria:

ASTM D4488-95	For Evaluating Resilient Flooring and Washable Wall Cleaners
ASTM D5343	For Evaluating Ceramic Tile Cleaners
CSMA DCC-09	For Evaluating Glass Cleaners

Notebook Tab 7

Process Parameters: the Surface Cleaning Laboratory (SCL) Databases

Notebook tab seven is potentially the most unique feature of the *proposed* tool (*hyperlinks to the entire set of SCL test data are not yet available since the contents of the laboratory's notebooks would first need to be converted to a compatible electronic/search format*). Actual laboratory test data are currently field-searchable by (1) surface substrates, (2) surface contaminants, (3) chemical cleaners and (4) cleaning equipment. In addition, this tab contains technical recommendations from more than 200 chemical vendors that are self-registered with the Massachusetts Toxics Use Reduction Institute, if any. Cleaners appearing on both lists as a result of these two database searches represent the most likely candidates to succeed during trials in the next phase. Repeated database searches may be required, depending on how each project progresses, as more process parameters (for example, equipment selection) are identified and fine-tuned. While tab seven is referenced early in the matrix, its placement in the notebook is predicated on assisting the development of the testing parameters in tab eight.

> *Example*
>
> In a project involving glass cleaning, Table 7.6 of chapter seven revealed the following SCL tests to contain pertinent testing information for similar applications:
>
> **SCL Laboratory Report Numbers**
>
> **95-409-01-2** **95-409-02-2** **95-409-03-2** **96-435-01-8** **97-550-01-3**
>
> These numbers have been hyperlinked to the actual laboratory tests performed at the SCL for a record of appropriate temperatures, cycle times and cleaner concentrations used. Refer to Figure 7.2 of chapter seven for an explanation of the coding system used in generating laboratory report numbers. Reports ending with the digit '2 = results successful using *TACT*', '3 = results suggest a scale-up feasible match' or '8 = final report' offer the most accurate technical advice on how best to proceed with the testing in notebook tab eight.

Notebook Tab 8*

Results of Application-Specific Testing

Notebook tab eight contains data on tests conducted with an initial pool of no more than six chemical cleaners, due to the scientific restrictions explained in chapter five of this thesis, and identified in notebook tabs one and seven. Accurate recordings of (1) process temperatures, (2) forms of agitation, (3) cleaner concentrations and (4) cycle times (collectively known as *TACT*) are essential in cleaning test coupons and actual parts. Refer to chapter five of this thesis for a complete test plan. Following bench-scale trials, tests are completed with successful performers in conjunction with equipment vendors and/or in-house piloting, to mimic batch sizes and production quotas. These results are also recorded in this notebook tab. *Note: tab seven is not a replacement for tab eight, because eliminating application-specific testing risks downstream manufacturing failures.*

*Failure of these chemical cleaners to perform satisfactorily will require additional testing of chemical cleaners already compiled throughout the notebook (for example, in tab six) and/or the prioritization of criteria in tab five.

Example
Click here for: Tests conducted on-site, that is, *not* at the SCL

Notebook Tab 9

Health and Safety, Part II: Opportunity for improvement in existing technology leading to cleaner production

Several top performers from notebook tab eight may not reveal many differences in cleaning efficiencies, but a more thorough review of their chemical components may form the basis for better selection. A report on the consequences of over-exposure, generated from the Toxicology, Occupational Medicine and Environmental Series' (TOMES®) Hazardous Substances Data Bank's (HSDB) section 5.0, is stored in notebook tab nine for each of their constituents listed in tabs three and/or four. This information can not be utilized wisely until the cleaners were first characterized by their performance (notebook tab eight), since eliminating them from testing too early may result in no/too few alternative cleaners from which to choose.

Click here for: Information on Micromedex' TOMES® System (commercially available)
Click here for: Example Complete TOMES® HSDB Report
Click here for: HAPs Health Effects Fact Sheets

Example
Aluminum scrubbers (part of an exhaust system) are successfully cleaned by two aqueous cleaners. Only one manufacturer provides NFPA ratings on its product's MSDS, so that these numbers cannot be used to compare the relative safety of the two cleaners. One cleaner contains glycol ether. Examination of the TOMES® HSDB report of this chemical reveals that the safer and greener choice is the formula without the glycol ether.

Notebook Tab 10

Environmental Effects, Part II: Opportunity for improvement in existing technology leading to cleaner production

As in notebook tab nine, several top performers from tab eight may not reveal many differences in cleaning efficiencies, but a more thorough review of their chemical components may form the basis for better selection. An environmental-fate report, illustrative of life cycle assessment, generated from TOMES® HSDB section 7.0, is stored in notebook tab ten for each of their constituents listed in tab three and/or four. This information could not be utilized wisely until the cleaners were first characterized by their performance (notebook tab eight), since eliminating them from testing too early may result in no/too few alternative cleaners from which to choose.

Click here for: Information on Micromedex' TOMES® System (commercially available)
Click here for: Example Complete TOMES® HSDB Report

Example
Two Rochester Midland EnviroCare products, both aqueous cleaners, perform well under the same conditions for cleaning the same substrate surface in the SCL and on-site. One product contains a terpene, dipentene or limonene. The other does not. TOMES® HSDB Section 7.0 reveals limonene's photochemical nature, perhaps influencing global

warming, as well as its difficulty in biodegrading (level 3 of a 5-tiered rating system). The terpene-free cleaner should be recommended.

Notebook Tab 11

Sustainability Factors: Opportunity for improvement in existing technology leading to more sustainable production practices

Notebook tab eleven stores information from the third and final TOMES® report from HSDB section 2.0. This section reveals manufacturing protocols and manufacturing sites for cleaning chemicals and/or their constituents. Review of these data, along with the exposure potential from Section 7.0 (above) may reveal (1) drain on natural resources due to manufacture, as opposed to use, (2) worker exposure concerns due to manufacture, as opposed to use and (3) environmental justice issues based on plant location.

Click here for: Information on Micromedex' TOMES® System (commercially available)
Click here for: Example Complete TOMES® HSDB Report (Appendix A of this thesis)

Example

An aqueous cleaner containing sodium hydroxide (NaOH) and an aqueous cleaner containing potassium hydroxide (KOH) perform almost equally well for the same manual cleaning application. Because the NaOH is more caustic, especially in manufacture, the decision was made to use the KOH formula, even though a slightly longer cleaning cycle would be needed.

Notebook Tab 12

Total Cost Accounting

Notebook tab twelve contains a financial worksheet to document the total costs associated with switching cleaning chemicals. Labor and chemical treatment costs are delineated. Transportation of cleaners *to* a facility is not addressed. This study often reveals that the purchase price of chemicals is the least influential factor of a process conversion's true cost.

Click here for: Massachusetts Environmentally Preferable Purchasing (EPP) program

Cost Analysis Worksheet	**Option A**	**Option B**	**Option C, etc.**
Initial Costs			
Equipment Purchase			
Disposal of Old System			
Research and Design			
Initial Permits			
Building / Process Changes			
Total Initial Costs			
Annual Costs			
Chemical Purchases			
Maintenance Labor			
Materials			
Production Costs % Increase / % Decrease			
Hours / Year			
Waste Management / Chemical Treatment			
Testing			
Disposal			
Safety Training / Equipment			
Insurance			
(Environmental) Filing Fees			
Labor to Complete Paperwork			
Annual Permitting Fees			
Utilities Water			
Electricity			
Gas / Steam			
Depreciation (straight line)			
Total Annual Costs			
Labor Rate			
Cost of Capital			
Lifetime of Option			
Total Annual Costs			
Total Annual Savings			
Present Value (PV)			
Total Initial Cost (II)			
Net Present Value			
Profit Index			

Source: Pollution Prevention Consultants for the Toxics Use Reduction Institute, 1993

Table 8.3 WORKSHEET FOR FINANCIAL ANALYSIS OF CLEANING OPTIONS[73]

Example

Click here for: Payback on Aqueous Cleaning, Parts I and II
(from chapter eight of this thesis)

Notebook Tab 13

The Regulations

Notebook tab thirteen provides direct access to key U.S. regulations and related materials containing essential compliance information from the web site, Environmental Law Net (ELN). Many of the resources listed here are not even available in law-firm libraries or on expensive online services. From this site, it is possible to access permit and compliance data about a facility, chemical exposure and risk assessments including pesticides and antimicrobials, pollution prevention guidance, tribal and environmental justice issues as well as state sites such as the Massachusetts Toxics Use Reduction Act's list of regulated chemicals. In addition to the above two hyperlinks (underlined), the major regulatory categories involving solvent usage are hyperlinked below:

AIR POLLUTION CONTROL
CAA Federal Register Notices
HAPs Fact Sheets
NESHAPs and MACT
NESCAUM, BACT and RACT

HAZARDOUS WASTE
RCRA Federal Register Notices

OSHA
OSHA Federal Register
OSHA Standards

CERCLA/SUPERFUND PROGRAM (SARA)
CERCLA Federal Register Notices CERCLA Overview SARA Overview

CHEMICAL INVENTORY & RELEASE REPORTING
EPCRA/CEPPO Federal Register Notices EPCRA Overview
TRI Federal Register Notices

Also,

Click here for: Meanings of acronyms (contained in Glossary of this thesis)

Click here for: Any U.S. federal, state, local or Canadian environmental agency or organization

Notebook Tab 14

Advances in Cleaning Technologies: Opportunity for continuous improvement in cleaning methods and materials

Notebook tab fourteen serves as a site to add information from various sources such as scanned publications, technology assistance programs, patents, inventions and web sites to form a digest on the latest advances in industrial cleaning. Topics may include ionic liquids as new chemical cleaners or research on endocrine disrupters in the development of new indicators.

Example

Click here for: The Future of Industrial Cleaning and Related Public Policy-Making (chapter nine of this thesis)

8.2.2 Using the Tool, *The Aqueous Way to Go*

Three Real-World Applications of the Tool and the Status of Their Projects

Hotel Chain: Project Completed

The Aqueous Way to Go was used to provide technical, environmental and regulatory information to Green Seal (chapter seven) who was consulting with the owner of two hotels. The owner was building a third facility in the Boston area and wished to introduce improved cleaning practices to the entire chain at this time. Safer replacements were sought for three applications performed by the housekeeping staffs at each of the two existing location: tub and tile, glass and general-purpose cleaning. The present cleaners, all from the same chemical supplier, are aqueous-based. The owner chose three aqueous cleaners from another vendor, one for each of the three categories, for testing. Table 8.4 outlines the contents of the notebook tabs in running the program for the two general-purpose products in cleaning ceramic and marble tile.

In this case, a variation of the program was offered to members of the hotel chain by using TOMES® HSDB section four (additional safety information) instead of HSDB section two (manufacturing information). This was because (1) HSDB section four could serve in lieu of NFPA ratings and (2) differences in sites/methods of manufacture for components could not be easily ascertained. The web sites of "Safe Cleaning Products for Janitorial Service Work" at http://www.pprc.org/pprc/rpd/statefnd/ucla/safeclea.html and "Janitorial Products Pollution Prevention Project" at http://www.westp2net.org were consulted in addition to the hyperlinks provided in section 8.1.1. Since the majority of the janitorial staff were Hispanic, some speaking English only with difficulty, a free, multi-lingual web-based translator at http://www.freetranslation.com was utilized by the author of this thesis, with limited success.

From notebook tabs 2-14* →

Aqueous Cleaners/ Vendor	**Components and Percentages**	**MSDS Information (Section II)**	**TURI Indicators**	**TOMES or Web Information**	**TURI SCL Findings**	**Hotel Staff Testing**	**Regulation/ Comments (if any)**
Oasis 266/ Ecolab: Current Cleaner	1. Nonylphenol ethoxylate, 10% 2. Alkyl dimethyl benzyl ammonium chloride, 1%	No NFPA Ratings; No proprietary ingredients	OSHA PEL (i.e., toxicity): not established for either component	First component is suspect endocrine disrupter	Chemical tests reveal that this cleaner is being used at concentrations too high at one location	Color/odor important; staff satisfied but some complain of skin irritation from Oasis product line	First component is SARA 313 listed
Rochester Midland/ Tough Job Cleaner: Substitute Candidate	1. D-Glucopyranoside, 1-5% 2. Dipentene, 5-10% 3. Linoleamide DEA, 5-10% 4. Cocamphopropionate, 1-5% 5. Diethanolamine, 1-5%	No NFPA Ratings; No proprietary ingredients; all five components vendor-listed as nonhazardous	No VOC, No ODP, ~ GWP, not toxic, not flammable	Dipentene is limonene/ terpene which may add to global warming	Product works at least as well as current cleaner under similar conditions for concentrations, etc.	Performance results vary by location; may be due to some staff using current cleaner out-of-spec	None / Vendor is listed on Mass. Environmental Preferable Purchasing program

*The cost analysis in notebook tab 12 was not required since this is a hand-cleaning operation, needing no additional equipment or supplies, only gloves. The difference in the purchase price of the two cleaners is negligible, provided that the dilution factors are comparable.

Table 8.4 INSTITUTIONAL DEMONSTRATION OF *THE AQUEOUS WAY TO GO*

The information in the table was used to recommend to management that (1) the hotel staff, satisfied with the cleaning performance of the substitute candidate, should begin using Rochester Midland's Touch Job Cleaner in place of Ecolab's Oasis 266, (2) the hotel that was using the current cleaner at concentrations that may be unsafe to employees as well as guests, should install an automated dispensing unit for the dilution of Ecolab's Oasis 266 and (3) this second hotel should consider re-testing Rochester Midland's Tough Job Cleaner, after Oasis 266's cleaning performance at Ecolab's suggested concentration has been ascertained. The differences noted between the two locations were found to be due to the varying amounts, kinds and the age of marble and ceramic surfaces at the hotels.

The files from running the program, *The Aqueous Way to Go,* were supplied on a 3.5” floppy disk to all of the project’s stakeholders (that is, hotel management, Green Seal and the vendor Rochester Midland). To date, one of the hotels and the new hotel are using the recommended cleaners. A published article about this work in hotel sustainability is included in Appendix H of this thesis.

Public University: Project Underway

In much the same way, *The Aqueous Way to Go* program was utilized to evaluate six aqueous cleaners now being used in some of the buildings at the University of Massachusetts Lowell’s north campus. Table 8.5 outlines three of the six cleaners investigated.

Product Name And Manufacturer	Product Use Identification (MSDS Section 1)	HMIS NFPA Hazard Ratings	Ingredient Regulatory Information (MSDS Section 2) Hyperlinked to TOMES® Databases
Citrus Stride™ S. C. Johnson & Son Racine, WI 53403 800-725-6737 MSDS No. 113905 Dated 9/16/94	Industrial/ Institutional: Floor Care	1 Health 1 0 Flammability 0 0 Reactivity 0 N/A Special Hazard (if any) N/A	1. 1-3% Alkoxylated Fatty Alcohol 2. 95-98% Water
Complete® S. C. Johnson & Son Racine, WI 53403 800-725-6737 MSDS No. 114650035 Dated 4/4/97	Industrial/ Institutional: Floor Care	1 Health 1 0 Flammability 0 0 Reactivity 0 N/A Special Hazard (if any) N/A	1. *SARA[1] 1-3% Ethylene Glycol 2. *SARA 1-3% Diethylene Glycol Monoethyl Ether 3. *MA[2] 1-3% Ammonium Hydroxide 4. 3-6% Waxes (non-hazardous) 5. 10-20% Acrylic Polymers (non-hazardous) 6. 70-85% Water
Crew NA SC S. C. Johnson Commercial Markets Sturtevant, WI 53177 800-725-6737 MSDS No. 12698001 Dated 8/15/97	Industrial/ Institutional: Cleaning Product	3 Health 3 0 Flammability 0 0 Reactivity 0 N/A Special Hazard (if any) N/A	1. 0.5-1.5% Sodium Metasilicate 2. 1-3% n-Alkyl Dimethyl Benzyl Ammonium Chloride 3. 1-3% Di-N-Alkyl Dimethyl Ammonium Chloride 4. 1-5% Alkylphenoxy Polyethoxyethanol 5. 1-5% Tetrasodium salt of EDTA 6. 80-90% Water

[1] U.S. Superfund Amendments and Reauthorization Act

[2] Massachusetts

Table 8.5 SAMPLING OF UNIVERSITY OF MASSACHUSETTS LOWELL CLEANING PRODUCTS

Information from the table reveals that while the cleaners are water-based, an opportunity exists to significantly reduce the risk of chemical exposure to workers, since four of the six chemicals (all supplied by the same vendor) have high-hazard ratings for health. In addition, one of the above cleaners, though ranked safer, contains regulated substances (*). This ‘alternative-cleaners’ project may become an integral part of the University’s plans to obtain ISO 14000 certification for the building that houses the chemistry department.

The files from running the program *The Aqueous Way to Go* were likewise supplied to the janitorial staff on a 3.5" floppy disk. Comparative performance tests (at the SCL) and on-site piloting (at the University) of possible substitutes have not yet been performed.

School System: Project Planned

Plans are underway to use the same approach for evaluating current and potential replacements of chemical cleaners used in an elementary school system in Chicopee, Massachusetts during the 2001 spring break. This last application is being supported by a grant from the U.S. EPA and administered by a local teacher's union to help identify possible asthmagens in cleaning chemicals used in classrooms.

Strengths and Weaknesses of the Tool

One of the strengths of *The Aqueous Way to Go,* determined from the hotel and university case studies is the ability of the program to be useful, even for applications where both the candidate *and* the current cleaners were water-based. This scenario will become more prevalent as more solvent substitutions are made. Another strong point of the program is its capability to use different notebook tabs and web sites to fill in technical gaps, as mentioned in the hotel study.

Reliance on the SCL's database of test results (notebook tab seven) for institutional/janitorial cleaning could be viewed as a weakness, however, since the SCL has not conducted many tests in this field. Moreover, any decision-making tool that depends heavily on the use of newer computers, databases and web sites is flawed with regard to the gap between those who control and have access to information and technology and those who do not. Despite the unprecedented growth in the use of the internet and computer ownership, there are still widespread differences in adoption rates across geographic, income, and educational lines. This societal disparity has come to be known as the 'digital divide.' Solving this technical problem is beyond the scope of this work, although corporations such as Microsoft© have lent financial support to community-based projects addressing this issue.

Major Findings and Suggestions from Using *The Aqueous Way to Go*

The examples used to illustrate the notebook tabs and the real-world applications of the interactive matrix/tool revealed:

(1) Utilization of standards, databases and information obtained from the World Wide Web provided opportunities for cleaner production that would not have been possible otherwise. Notebook tabs nine through eleven reveal the importance of life cycle[j] considerations to all solvent substitution endeavors. Environmental justice issues pertaining to its manufacturing locations may also be uncovered. As defined by the U.S. EPA, environmental justice is "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies."

(2) NFPA and/or HMIS ratings, discussed in notebook tabs four and nine, should be mandatory on all MSDSs[k] and a system devised to ensure consistent ratings of component chemicals among cleaning chemical vendors.

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[j] The drain on an ecosystem by a chemical cleaner's manufacture, and not just usage can be unveiled by tracking its ingredients as part of a life cycle assessment. For example, an ingredient used in its natural state (i.e., raw material) may be greener to use in a cleaner's formulation than an ingredient that itself required synthesis (i.e., synthetic material).

[k] Refer to section 5.1.1 for more on the shortcomings of MSDSs.

8.3 Relationship of the Tool to the Methodology Developed

Figure 8.4 presents the *Critical Thinking for Cleaning Alternatives* methodology or flow of the *entire* decision-making process, developed to this point in the thesis. It utilizes and organizes important chapter headings as themes. Figure 8.4 also illustrates the relationship of the interactive matrix/tool, *The Aqueous Way to Go* and the role of the test protocol in facilitating decision-making for solvent substitution.

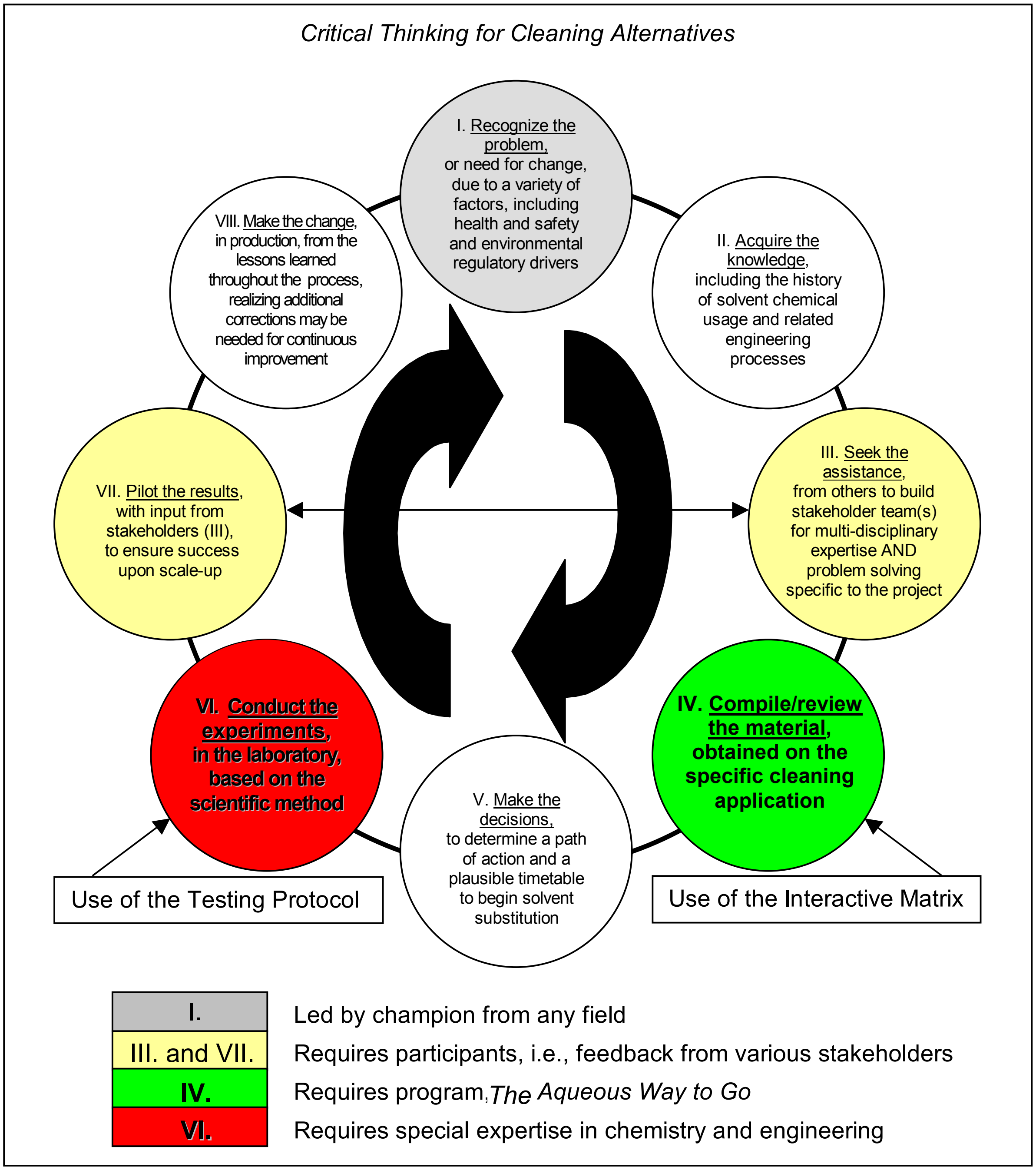

Figure 8.3 OVERVIEW OF METHODOLOGY DEVELOPED FOR DECISION-MAKING PROCESSES IN SOLVENT SUBSTITUTION

Methods and Methodologies Research[l]

No discussion concerning the development of an interactive matrix and its corresponding methodology would be complete without mention of existing methods (including test protocols) and methodologies researched, as they have influenced the author's final proposed tool.

Of the myriad of test methods practiced by various industrial and government sectors, no test method could be directly adopted by the author in conducting performance tests for potentially safer and greener chemical cleaners. Nevertheless, ASTM's *Standard Practice for Cleaning of Materials and Components by Ultrasonic Techniques* (G131-96*), Standard Test Method for Evaluating the Effectiveness of Cleaning Agents* (G122-96) and *Standard Practice for Preparation of Contaminated Test Coupons for the Evaluation of Cleaning Agents* (G121-98) were consulted more than others.

While the implementation of a test method does not occur until step VII in the practice and the dissemination of the methodology, its creation occurred early in this investigation, *so that the comparative performance of the purported greener and safer cleaners would be unquestioned.*

Aside from anecdotal advice obtained at cleaning conferences (Appendix D), the author could not find a solvent substitution methodology that could be universally applied to all applications. Thus, it became necessary to develop one. Nevertheless, methodologies from other research organizations and individual researchers impacted the author's approach.

Two sources are especially noteworthy. One involved the treatment of sound scientific principles (i.e., the scientific method) under circumstances governed by some conditions that are beyond the researcher's control, such as economics. The other provided counsel in information management, resulting from a complex set of research questions. Most cleaning practices are, indeed, limited by funds and are multifaceted, lending confusion to the project and discouraging practitioners from recognizing and adopting positive change.

The first resource was the management style promulgated and published by the U.S. National Aeronautics and Space Administration (NASA) as *The Mars Pathfinder Approach to "Faster-Better-Cheaper:" Hard Proof from the NASA/JPL Pathfinder Team on How Limitations Can Guide You to Breakthroughs*. The resultant empowerment of relatively young and inexperienced entrepreneurs led to a series of spectacularly successful robotic excursions on Mars that far exceeded the scientific community's expectations. Consequently, the author decided upon designing an environmental decision-making tool with an interactive component.

The second was the author's participation in a seminar/training session given by Dr. Edward Tufte of Princeton University. Dr. Tufte specializes in the presentation of complex data-points to reveal important information and trends for researchers. Three texts were used, including an exposition of the laboratory notebooks of the Italian astronomer, Galileo. They were *Visual Explanations*, *Envisioning Information* and *The Visual Display of Quantitative Information*.

These references helped the author of this thesis shape the electronic notebook format of *The Aqueous Way to Go* tool and the training style of the *Critical Thinking for Cleaning Alternatives* methodology. They are responsible, at least in part, for the program's success.

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[l] See section 1.1 for further clarification of the meanings of these terms.

8.3.1 Field Testing the Methodology, *Critical Thinking for Cleaning Alternatives*

The methodology was field-tested by the author four times with over fifty professionals. Three half-day (approx. three hours) and one full-day (approx. six hours) sessions were conducted in a traditional classroom setting. The audiences were comprised of engineers and chemists, plant managers and environmental health and safety officers from a variety of industries, consultants, and state/federal government agents. Figure 8.5 contains the outlines for both session lengths.

HALF-DAY TRAINING
INTRODUCTION
Part 1. General Introduction
A. Statement of the Problem
B. Central Scientific Questions
C. Importance of Definitions
Part 2. Solvent Background
A. Historical Discovery of Substances
B. Characterization of Chemical Types
C. Environmental and Health Effects
D. Legislative Initiatives

CLEANING ALTERNATIVES RESEARCH
Part 3. Returning to Water-Based Cleaning
A. The Role of Environmental Indicators
B. Aqueous and Semi-Aqueous Cleaners: How They Work
Part 4. Developing a Testing Protocol for Surface Cleaning
A. Designing a Questionnaire for Companies with Cleaning Problems
B. Determining the Phases of an Aqueous Cleaning Trial
C. Using Analytical Techniques to Measure Cleaning Efficiencies

CLEANING ALTERNATIVES RESEARCH (CONT.)
Part 5. Other Replacement Chemical Cleaners and Mechanical Cleaning Methods
A. Blasting with Sodium Bicarbonate
B. Extracting with Carbon Dioxide
Part 6. Identifying Sources of Technical Information and Assistance
A. Databases and Vendors
B. Performance Standards and the World Wide Web
C. Publications et al
Part 7. Some Results
A. By Substrate Surfaces
B. Process Conversion Costs
C. Shortcomings of Present Technology

FULL-DAY TRAINING
INTRODUCTION
Part 1. General Introduction
A. Statement of the Problem
B. Central Scientific Questions
C. Importance of Definitions
D. Structure of this Workshop
Part 2. Solvent Background
A. Historical Discovery of Substances
B. Characterization of Chemical Types
C. Environmental and Health Effects
D. Legislative Initiatives

CLEANING ALTERNATIVES RESEARCH
Part 3. Returning to Water-Based Cleaning
A. The Role of Environmental Indicators
B. Aqueous and Semi-Aqueous Cleaners: How They Work
Part 4. Developing a Testing Protocol for Surface Cleaning
A. Designing a Questionnaire for Companies with Cleaning Problems
B. Determining the Phases of an Aqueous Cleaning Trial
C. Using Analytical Techniques to Measure Cleaning Efficiencies
Part 5. Other Replacement Chemical Cleaners and Mechanical Cleaning Methods
A. Blasting with Sodium Bicarbonate
B. Extracting with Carbon Dioxide

CLEANING ALTERNATIVES RESEARCH (CONT.)
Part 6. Identifying Sources of Technical Information and Assistance
A. Databases
B. Performance Standards
C. Publications et al
Part 7. Other Considerations
A. Natural Resource Management
B. Environmental Management Systems
C. Life Cycle Assessment and Sustainability Factors
D. Defining Costs

FOR DISCUSSION
Part 8. The Future of Industrial Cleaning and Related Public Policy
A. The Precautionary Principle
B. Environmental Epidemiology

OBSERVATIONS AND RESULTS
Part 9. Summation of Notable Findings
A. Shortcomings of Present Technology: A Review
B. Utilizing this Workshop as a Tool for Environmental Decision-Making

Figure 8.4 CRITICAL THINKING FOR CLEANING ALTERNATIVES, COURSES' CONTENT

The full-day session was conducted during the Toxics Use Reduction (TUR) planners course for continuing education, as an industry-specific training option on March 29, 1999 at a hotel conference room in Marlborough, Massachusetts. Attendees were requested to complete the conference and course evaluations, depicted in Figures 8.6 and 8.7, respectively.

Please provide feedback on this conference and suggestions for future continuing education workshops by completing this form. The first section address the overall conference and the second section is for suggestions for future conferences and requests for specific workshops.

Use the following scale for ratings: 1 = unsatisfactory, 2 = moderately satisfactory, 3 = satisfactory, 4 = good and 5 = excellent.

I. OVERALL CONFERENCE EVALUATION

Overall conference rating	**1**	**2**	**3**	**4**	**5**
Facilities:	**1**	**2**	**3**	**4**	**5**
Agenda:	**1**	**2**	**3**	**4**	**5**
Conference Location:	**1**	**2**	**3**	**4**	**5**
Conference Materials:	**1**	**2**	**3**	**4**	**5**

Figure 8.5 FORM USED TO EVALUATE TUR OVERALL CONFERENCE

Please answer the following questions and rate the following elements of today's event according to the scaled provided. Under "*comments*" please offer specific examples and suggestions regarding strengths and weaknesses. Thank you for taking the time to provide your feedback.

1. Delivery of instruction:		NOT USEFUL		OK		VERY USEFUL
Comments:		POOR		OK		EXCELLENT
	Usefulness:	1	2	3	4	5
	Quality:	1	2	3	4	5
2. Instructional materials:		NOT USEFUL		OK		VERY USEFUL
Comments:		POOR		OK		EXCELLENT
	Usefulness:	1	2	3	4	5
	Quality:	1	2	3	4	5
		TOO LITTLE	·	JUST RIGHT	·	TOO MUCH
3. Length of time allowed was: Comments:		1	2	3	4	5
4. Level of depth/detail covered was: Comments:		1	2	3	4	5

5. List other industries you would like to see covered in an industry-specific training:

6. Other comments and suggestions:

Figure 8.6 FORM USED TO EVALUATE TUR INDUSTRY-SPECIFIC TRAINING

Strengths and Weaknesses of the Methodology
In practice, this methodology requires an up-front investment of time for the organization of materials that pays off handsomely in the knowledge, and finally expertise and wisdom, gained. It does not numerically rank alternatives, nor does it present unequivocal answers to industrial cleaning problems. It provides a format to evaluate potentially related data that can be adjusted to suit many needs, in preparation for the decision-making process. *Stakeholders retain the decision-making authority, while still using the latest technical information available.*

Critical Thinking for Cleaning Alternatives' greatest weakness is the difficulty in maintaining the interest of different expert stakeholders in the project throughout the entire decision-making process. Implementing the methodology at the SCL easily spanned several weeks, so that successful solvent substitution depended upon frequent and productive discussions among individuals that may not have shared common goals, or interacted for any other purpose. This was especially true in step VII for piloting, if these groups had not communicated often and well since step III of Figure 8.4.

8.3.2 Results, Conclusions and Recommendations

Results
A total of fifteen evaluation forms were completed by fifty-two attendees of the surface-cleaning module: twelve for the conference and three for the course. Results are presented in Table 8.5.

Evaluation Topics for Overall Conference	**Average Scores[m] Conference Attendees**	**Average Scores[m] "Critical Thinking" Attendees**	**Evaluation Topics / Average for Course Scores,[m] Answers**
Conference Rating	3.98	3.20	Delivery of Instruction Usefulness: 3.60 Quality: 3.60
Facilities	3.96	3.80	Instructional Material Usefulness: 3.30 Quality: 3.60
Agenda	3.91	3.40	Length of Time Allowed: 3.30
Conference Location	3.64	2.60	Level of Depth/Detail: 3.30
Conference Material	3.98	3.80	Other Industries/Topics Needing Coverage: *EMS

*Environmental Management System

Table 8.5 RESULTS OF TUR OVERALL CONFERENCE AND COURSE EVALUATIONS

Comments from attendees of the surface-cleaning module included the following answers to specific questions:

What did you find most useful?

"Samples of cleaning material." <handouts>

"The critical thinking aspect of the course can be applied to any situation."

"Evaluation methods." <for surface analysis>

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[m] Based on the scale, 5 = excellent, 3 = satisfactory and 1 = unsatisfactory from Figure 8.6.

What did you find least useful?

“Just the lack of relation<ship> to my specific industry.”
“Overload of information – so much detail – but interesting.”
“Cost accounting, though useful tool in selling project, extremely dry material.”

What improvements can be made?

“Expansion of types of alternative cleaning techniques other than aqueous cleaning.”
“Give more technical details about how cleaners work, on what ‘soils’.”
“Promote more discussion.”

Conclusions

For a first attempt at presenting this methodology to working environmental professionals, the attendees rated the course’s content similar to other conference sessions. This was true, even though the participants were unaware that the material had been developed as a graduate project.

The location of the conference was more unacceptable to the attendees of *Critical Thinking for Cleaning Alternatives* than to those attending other sessions. The thesis’ author believes that this was because the course was originally intended for twelve to fifteen participants, as opposed to this much larger group, which made for an uncomfortable learning atmosphere.

Traditional references and citations (i.e., handouts and overhead slides), and not web-based search tools, were received with more enthusiasm by the class as a whole. This is in keeping with the results of the survey quoted in chapter six and possibly reflects the lack of computer literacy of participants from the different industrial sectors.

Recommendations

Web-based tools almost assuredly represent the future for the technologies surviving into the new millennium. Computer skills of all workers should be upgraded to meet this increasing need. Future sessions should also include vendors and interested local and international NGOs, not traditional invitees to the TUR training offered by the Institute.

Training on environmental management systems (EMS) was suggested in at least two of the course evaluations as additions to the course curriculum. ISO 14001 information could easily be included in notebook tabs six or thirteen, for standards or regulations in the tool, the *Aqueous Way to Go* as part of the methodology, *Critical Thinking for Cleaning Alternatives*.

The comment, *“the critical thinking aspect of the course can be applied to any situation”* in one of the written evaluations, is encouraging because it is central to this thesis’ tenet on how learning could/should continue. In other comments, participants alluded to wanting concrete answers to specific cleaning problems, representing the exact opposite approach, and signifying a desire for a drop-in solution with a particular case in mind (in deference to them, J. Marshall’s ETC database is included in Appendix G in abstract form). The author has noticed this discrepancy between equally competent professionals on several occasions, over a period of seven years. In conversations with these individuals, those preferring the theory of critical thinking were often left-handed, perhaps reflecting the influence of right-brain/left-brain functioning on decision-making processes.

Postscript

Changes were made to the methodology *Critical Thinking for Cleaning Alternatives* to obtain better feedback from attendees on *The Aqueous Way to Go*. This included (1) modifying the course's content and (2) developing another evaluation form. On October 27, 2000 the module was again taught to approximately twelve working professionals. Both the new course structure and the evaluation questionnaire, along with the survey's results, are located in Appendix I.

8.4 Review of the Answers to the Central Scientific Questions

What, then, can finally be said of the impact on solvent substitution projects as a consequence of the tool, *The Aqueous Way to Go* and its associated methodology, *Critical Thinking for Cleaning Alternatives*? First, the hypothesis that a tool and/or methodology could be developed has been proven as true. The tool and methodology should function well for all types of solvent substitutions for which aqueous cleaning is at least theoretically possible. The remaining questions have been answered, in part, throughout the thesis, as the work towards building the tool and its training module proceeded. The answers, in the order in which the questions were first postulated in chapter one, can be summarized as follows:

(1) The time required to conduct a search for safer, greener chemical cleaners *was* decreased, as evidenced by using re-designed vendor and testing databases in conjunction with one another (section 7.2.2). Figure 7.4 confirms this trend, even for applications that are increasingly difficult.

(2) The safety, if not the proficiency, of the final cleaner selection *was* increased, as determined by the screening process using environmental indicators (chapter six) with the guidelines set forth in the tool, especially Notebook Tab 4. Proficiency was more difficult to measure, since identical applications would need to be evaluated with and without the use of the tool. Nevertheless, the success rate (> 90%) in finding effective aqueous replacements in the laboratory most probably means that the larger universe of candidate cleaner catalogued by the lab leaves less of the selection process to chance.

(3) Useful trends in cleaning operations *were* revealed, including those similarities between parts and institutional cleaning that were not evident prior to the investigation (section 8.1.2) and the universality of properly-applied aqueous cleaning technology, as opposed to the other alternatives studied (section 6.1).

(4) Heretofore unknown differences in cleaning systems *were* revealed, in particular, for those potential replacement cleaners not containing HMIS/NFPA hazard ratings, making a direct comparison without the use of the tool difficult if not impossible (Table 8.4).

(5) While the tool *does* expand to incorporate the discovery and testing of new cleaning chemicals and processes (Notebook Tab 14), the true potential for continuous improvement exists within the methodology (step VII).

8.5 Shortcomings of Aqueous Cleaning Technology

If the tool and the methodology have met the challenge of assisting decision makers to select and utilize safer and greener effective aqueous cleaners for most industrial applications, the remaining technical problems are often (1) re-contamination of parts from over-extended cleaning baths, (2) rinse cycle re-deposition of contaminants and (3) insufficient part drying to meet product quality standards and/or production quotas. All of these issues involve motivation, good 'housekeeping' skills, better management and especially energy and water consumption; water quality affects water consumption in both cleaning and rinsing tanks and efficient part drying requires the consumption of energy.

8.5.1 Energy Requirements and Water Usage

Energy Requirements

By the mid-to-late 1990s, process conversion costs became more complex and difficult to ascertain, as energy costs became deregulated in a number of regions throughout the United States, including Massachusetts. Many case studies had previously omitted energy requirements in their analyses, perhaps assuming that these costs were negligible or relatively fixed.

In 1998, B. Kanegsberg conducted a series of interviews, based on an investigation designed by the author, that may have revealed another reason why the energy factor was overlooked.[75] Her discussions with end users, regulators, vendors and the energy industry suggest that insufficient information has been collected and made publicly available on the subject. One recommendation would be to have the U.S. EPA provide energy ratings on cleaning equipment, as the government has already done for computers, automobiles and other consumer products. Another is the observance of peak/off peak utility rates by plant managers in bringing large pieces of temperature-regulating equipment on line.

A literature search uncovered some thorough cost analyses for solvent substitution, in particular, one by S. Karr and M. McMonagle completed in 1993 for a metal finishing company.[76] Their results, outlined in Figures 8.8 and 8.9, demonstrate the kinds of information and computational skills needed to perform an accurate financial evaluation of cleaning options. Note the similarity to the format found in Table 8.3 for initial and annual costs.

Payback on Solvent Vapor Degreasing Replaced with Aqueous Cleaner (No Aqueous Cleaner Recovery)
Application: Removal of machinery oil and soils from small metal parts and stampings
Production Load: 1,440 m^2 (15,500 ft^2) per week (wk)
Bath Life: 64 hours (4 days)

Equipment Configuration	**Installed Cost**
1,020 L (270 gal) tank with heater	$7,500
Rinse tank	6,750
Conveyor	800
Total	**$15,050**
Operating Costs (per year)	
Cleaner	$18,813
125 L (33 gal) concentrate/1, 155 m^2 (12,441 ft2) x 1440 m2 (15,500 ft^2)/wk x 52 wk/yr x $8.80/gal	
Water	1,498
2 gal/min x 60 min/hr x 16 hr/day x 260 day/yr x $0.003/gal	
Cleaner Disposal	6,608
1,135 L (300 gal) of 10% cleaner/1,155 m^2 (12,441 ft2) x 1,440 m^2 (15,500 ft^2)/wk x 52 wk/yr x $0.34 gal	
Maintenance	301
2% of equipment cost	
Labor to Dump and Replenish Cleaner	2,600
2.5 hr/wk x 52 wk x $20/hr	
Steam Heat	450
0.83 m^2 (9 ft2) of tank x 2,000 BTU/hr ft^2 x 52wk/yr x 80 hr/wk x $6/1,000,000 BTU	
Total Operating Costs (per year)	**$30,270**
Operating Costs with Solvent	
1,1,2-TC at $0.39/lb	$39,383
Disposal of Spent Solvent at $175/drum	1,575
Labor to Decant Degreaser	2,600
2.5 hr/wk x 52 wk x $20/hr	
Total Costs*	**$43,558**

Savings in Operating Costs: $43,558 - $30,270 = $13, 288
Payback: Equipment/Operating Savings/Year ($15,050/$13,288) = 1.13 years

* Cooling H$_2$O and steam heating were not included in solvent operating costs (neg.)

Figure 8.7 PAYBACK ON AQUEOUS CLEANING (NO RECOVERY) vs. SOLVENT VAPOR DEGREASING[76]

Figure 8.8 PAYBACK ON AQUEOUS CLEANING (WITH RECOVERY) vs. SOLVENT VAPOR DEGREASING[76]

Payback on Solvent Vapor Degreasing Replaced with Aqueous Cleaner and Recovery
Application: Removal of machinery oil and soils from small metal parts and stampings
Production Load: 1,440 m^2 (15,500 ft^2) per week (wk)
Bath Life: Indefinite bath life with recovery

Equipment Configuration	**Installed Cost**
1,020 L (270 gal) tank with heater	$7,500
Rinse tank	6,750
Cleaner Recovery System	21,000
Conveyor	800
Total	**$36,050**

Operating Costs (per year)	
Electricity	$1,395
7.5 hp x 0.745 kw/hr x 260 day/yr x $0.06/kwh x 16 hr/day	
Cleaner (at 46%)	8,424
46 x 125 L (33 gal) concentrate/1, 155 m^2 (12,441 ft2) x 1440 m2 (15,500 ft^2)/wk x 52 wk/yr x $8.80/gal	
Water	1,498
2 gal/min x 60 min/hr x 16 hr/day x 260 day/yr x $0.003/gal	
Labor for Operating the Cleaner Recovery Unit	1,300
0.25 hr/day x 260 day/yr x $20/hr	
Labor to Dump and Replenish Cleaner	2,600
2.5 hr/day x 260 day/yr x $20/hr	
Chemical Cleaning	364
1 lot cleaner chemicals x $7/lot x 52yr	
Soils Disposal	88
19 L (5 gal)/wk x 52 wk/yr x $0.34/gal	
Maintenance	721
2% of equipment cost	
Steam Heat	449
0.83 m^2 (9 ft^2) of tank x 2,000 BTU/hr ft^2 x 52wk/yr x 80 hr/wk x $6/1,000,000 BTU	
Total Operating Costs (per year)	**$16,839**

Operating Costs with Solvent	
1,1,2-TC at $0.39/lb	$39,383
Disposal of Spent Solvent at $175/drum	1,575
Labor to Decant Degreaser	2,600
2.5 hr/wk x 52 wk x $20/hr	
Total Costs*	**$43,558**

Savings in Operating Costs: $43,558 - $16,839 = $26,719
Payback: Equipment/Operating Savings/Year ($36,050/$26,719) = 1.35 years

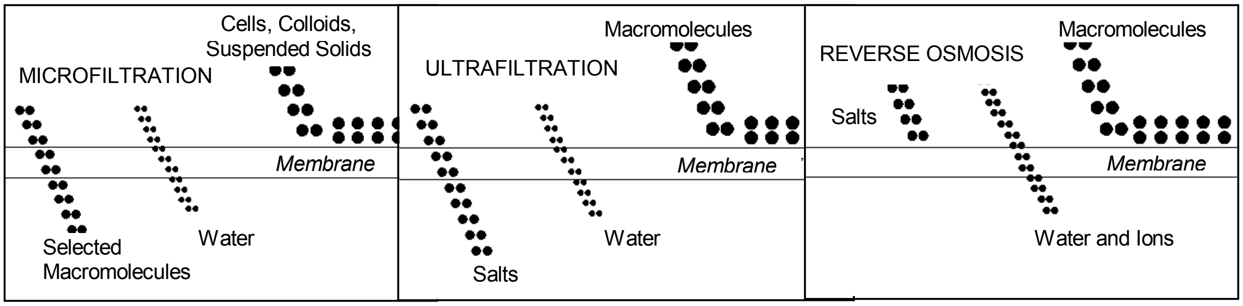
* Cooling H_2O and steam heating were not included in solvent operating costs (neg.)

This case demonstrates the increase in initial capital expenditure for aqueous cleaning with reclamation ($15,050 vs. $36,050 US). Even though payback periods remained relatively the same (1.13 vs. 1.35 years), this may still pose too great a financial burden for many companies. The examples also illustrate the close linkage between electrical requirements and water consumption in aqueous cleaning, the subject of the next section.

Water Usage

To achieve the savings in Figure 8.9, a treatment unit had been installed in the cleaning station. Modern cleaning facilities also perform separation or filtration processes on rinse baths, referred to as ‘closing the loop’, since all water is effectively re-circulated for indefinite reuse, to hopefully attain zero discharge.

These systems may involve microfiltration, ultrafiltration or reverse osmosis (RO) depicted in Figure 8.10, as well as nanofiltration, an intermediate process between ultrafiltration and RO. Filter membranes are made of different composite materials, and packaged in plate-and-frame, spiral wound, tubular or hollow fiber configurations, based on the application. These technologies became possible with the advent of crossflow or tangential flow filtration, allowing for the continuous processing of bulk liquid streams parallel to the filter’s surface.



Source: Peter S. Cartwright, P.E.

Figure 8.9 ILLUSTRATIONS OF PRINCIPAL FILTRATION METHODS USED FOR THE SEPARATION OF SUSPENDED SOLIDS, MACROMOLECULES AND IONS[77]

Traditional electrodialysis and ion exchange are also performed in critical situations. Decantation and mechanical separation (separator, coalescing unit) are used for heavier oil loads. Figure 8.11 presents an overview of methods, covering a wide range of contaminant levels/sizes.

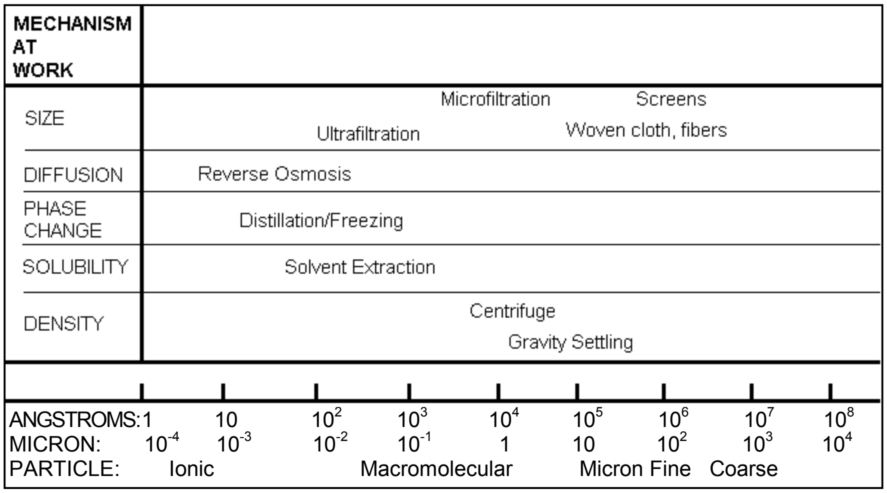


Figure 8.10 SEPARATION PROCESSES AND APPLICATION RANGES[78]

In all of these systems, proper maintenance of the cleaning and rinsing baths is important, such as periodic turbidity measurements, pH control, titrations and the reduction of contaminants at their sources, prior to cleaning. While cleaning bath replenishment is possible, at some point-to-be-determined the full bath should be disposed of according to all regulations and a new bath prepared, in order to achieve maximum cost benefits.[79]

The most difficult separation processes often involve emulsified contaminants, due to the increased use of water-based surface chemicals. Counter-intuitively, using a less effective detergent ($<k_b$, solubility factor) may enhance downstream separation efforts. Other shortcomings of present cleaning technologies include (1) the inability to effectively filter semi-aqueous cleaners, frequently used at undiluted concentrations and therefore representing a more costly alternative than their aqueous counterparts and (2) the lack of staff expertise for the selection and utilization of correct filter membranes, pore sizes and flow rates, allowing chemical components such as surfactants to remain in solution, while still filtering out the contaminants.

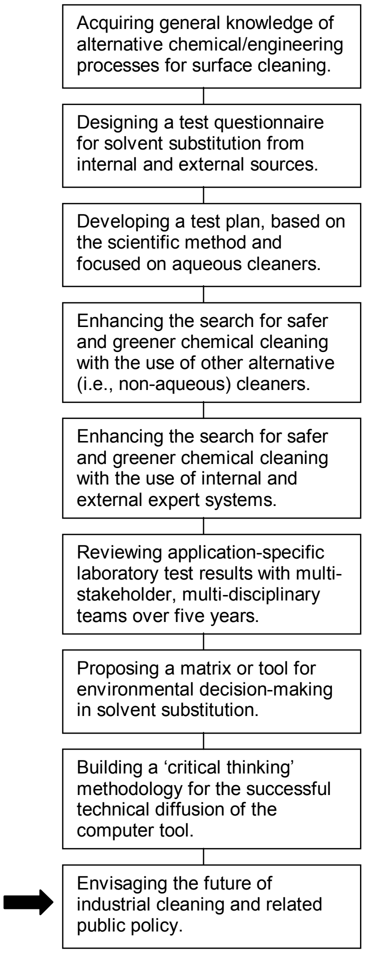
“Many of the interactions within and between these <biological> systems depend on fairly simple chemicals – all potential targets for imitation by man-made chemicals. *The pharmaceutical industry deliberately produces chemicals that affect these systems – the chemical industry does it accidentally <italics added>.* Every chemical is potentially a pharmaceutical.”
A. M. Warhurst, Introduction to the Endocrine System

9 The Future of Industrial Cleaning and Related Public Policy-Making

In this concluding chapter, the author builds upon the findings presented in the earlier chapters and discusses some of the new directions that the science of cleaning may take in the next five to ten years.

9.1 Research and Development of Chemical Cleaners

If the physical properties of liquids were any indication, successful solvent substitution with aqueous cleaners would never be possible. The components and the behavior of the water molecule are nothing like those of a typical organic solvent used for cleaning, as evidenced by water’s polarity and dipole moment (chapter three). To illustrate, some important chemical properties of the chlorinated solvent trichloroethylene (TCE) and water are compared in Table 9.1.



Properties	TCE	Water
Chemical Formula	C_2HCl_3	H_2O
Molecular Weight	131.39	18.02
Boiling Point	87^{o} C	100^{o} C
Density	1.46 kg/l	0.99 kg/l

Table 9.1
PHYSICAL PROPERTIES OF A CHLORINATED SOLVENT AND WATER

Chemists often try to come as close as possible to the physical characteristics of the original solvent in formulating new cleaners for the same application. This is entirely understandable. Devising test protocols in which the solvent behaves in a certain known fashion and expecting a water-based cleaner to function in the same manner, however, is not very realistic or even a fair analysis of its potential performance. For this reason, chapter three described the significance of choosing the right piece of mechanical equipment in process conversions involving aqueous cleaning.

Nevertheless, the author is familiar with at least two situations in which an over-dependence on chemical properties led investigators to a much narrower field of replacement candidates than the program, *The Aqueous Way to Go* would have recommended. In both cases, an organic solvent was replaced with another organic solvent. As a result, only incremental improvements, if any, were made to the health and safety of workers and to the protection of the environment upon implementing the alternative cleaners. The replacement cleaners shared a variety of traits with the original solvents and the inherent dangers in using *any* organic and/or chlorinated compound remained the same.

9.1.1 Molecular Modeling

The advent of 'designer molecules'[n] has led to the development of products without the drudgery of comparing and matching chemicals' physical properties at every step on the bench. Designer molecules allow scientists to visualize molecular structures and how they behave under certain conditions and in the presence of other molecules before they are actually synthesized. Chemical modeling software reveals important molecular functions, just as engineering modeling programs reveal stress and metal fatigue patterns in, for example, aircraft parts.

RasMol and CHIME are two popular computer programs for the visualization of molecules. RasMol was written by Roger Sayle of Glaxo-Wellcome and CHIME, a web browser plug-in based on RasMol, is a product of MDL Information Systems. Instructions for downloading RasMol can be found at http://www.umass.edu/microbio/rasmol and instructions for downloading CHIME are located at http://www.mdli.com/.[80] Originally intended for biological systems such as proteins and nucleic acids, both programs could be used for less complicated systems such as cleaning chemicals in the development of safer and greener alternatives.

An important aspect of the programs is the researcher's ability to manipulate structures. Chemical models can be displayed as traditional stick figures, ball-and-stick figures or space-filled structures. They can be controlled by three-dimensional rotation, size alteration and color coding. Different parts of a model (for example, the asymptotic or active site of an enzyme) can be selected and treated separately. Coupled with the information obtained from the Surfactant Virtual Library at http://www.surfactants.net/, this ability could be very useful in creating new surface-active agents or composite surface materials. Scientists could conceivably formulate chemicals designed to disassociate into benign forms of their components after performing certain tasks, like cleaning.

Figure 9.1 presents a three-dimensional model, capable of rotation, of the simplest chlorinated solvent. For comparison, Figures 9.2 and 9.3 are traditional one-dimensional, line representations of more complex surfactant formulations and an aqueous metal-cleaner in action, respectively.

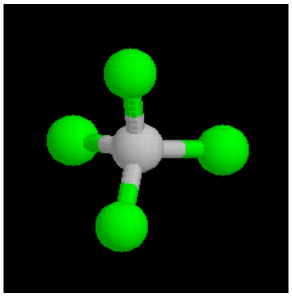


Figure 9.1
BALL-AND-STICK RENDITION
OF CARBON TETRACHLORIDE (CCL_4)

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[n] The term '*designer molecule*' is used by various chemical disciplines in much the same way as the term '*designer gene*' is applied in the field of genetic engineering.

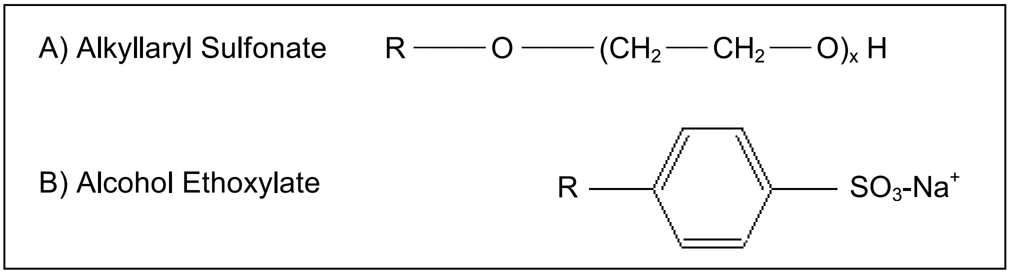

Figure 9.2 LINE STRUCTURES OF ANIONIC (A) AND NONIONIC (B) SURFACTANTS

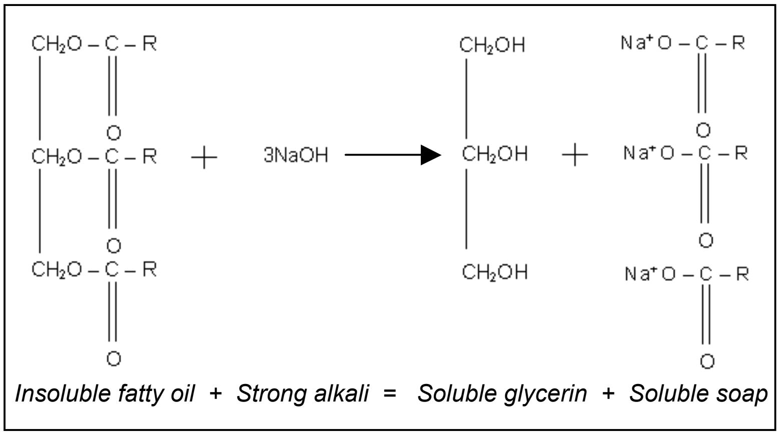

Figure 9.3 LINE-DRAWING OF SAPONIFICATION OF A FATTY OIL WITH A STRONG ALKALI

Much work has already been done in molecular modeling and ‘virtual compounds’ can be ordered from web-based suppliers listed at http://www.umass.edu/microbio/rasmol/whereget.htm or ‘synthesized’ via molecular mechanics calculations with a computational chemistry package such as Chem3D. Once a model is displayed in RasMol, it can be saved in other documents as well as printed. CHIME’s program allows for the dissemination of ‘live’ molecular models on the World Wide Web.

Combined with other sources of data, RasMol and CHIME are powerful integrative tools for global communication among scientists and should be helpful for improving the understanding of chemical information among all stakeholders. Computer modeling of chemical structures also advances the cause of nanotechnology, the study and control of matter at the atomic or molecular level. The manipulation of tiny amounts of substances to the precise site and at the exact moment they are needed should decrease the amounts of chemicals required to achieve a certain response, thereby decreasing the generation of wastes and the likelihood of over-exposure of humans or the environment to toxic substances.

9.1.2 Data Mining of Cleaning Performance Criteria

One of the first attempts to generalize chemical behavior for solvency was the Hansen method. In the Hansen method, a battery of chemical reactions is conducted and monitored in test tubes.

The results are ranked visually and recorded numerically. Based on the Hansen methodology, DuPont scientists developed a proprietary computer program for the selection of semi-aqueous cleaners in the 1980s. Its application was limited to the company's Axarel® line of products. The interactive, web-based tool, *The Aqueous Way to Go* (chapter eight) combines both the computer-assist functionality of the DuPont program and the performance criteria of the Hansen method.

While application-specific testing is still required, the results of pertinent SCL tests are stored in *The Aqueous Way to Go* program. Additional performance information from the SCL or other databases may serve to (1) further decrease the time required to identify greener chemical cleaners and (2) further increase the proficiency of the final selection. Appendix G of this thesis presents a small fraction of this kind of performance data. Like the molecular modeling used to accelerate chemical formulating, a mechanism is needed, preferably computer-based for speed and accuracy, to sort through a plethora of data that may, or may not, be relevant and to determine what chemical interactions, if any, reveal important trends for cleaning. Table 9.2 contains some of the newer tools available to conduct this kind of research.

Research Method or Principle	Description and Uses
Algorithmic Programming	Algorithmic, or procedural, languages are designed for solving a particular type of problem. They are called high-level languages because they are largely independent of hardware. Unlike machine or symbolic languages, they vary little between computers. The first such language was FORTRAN (FORmula TRANslation), developed for scientific calculation followed by the first commercial language, COBOL (Common Business Oriented Language). ALGOL (ALGOrithmic Language), is used primarily in mathematics and science. The latest generation of languages is an outgrowth of artificial intelligence.
Chaos Theory	Also known as nonlinear dynamics, chaos theory is an interdisciplinary science that attempts to reveal structure in seemingly unpredictable dynamic systems. In a linear system, a small change produces a small and easily quantifiable systematic change, but a nonlinear system exhibits a sensitive dependence on initial conditions: small or virtually immeasurable differences in initial conditions can lead to wildly differing results. (This is sometimes called the butterfly effect, in reference to a 1979 address by meteorologist E.M. Lorenz entitled, Predictability: Does the Flap of a Butterfly's Wings in Brazil Set Off a Tornado in Texas?). Uses include the study of diverse phenomena, such as dripping faucets and population growth.
Fuzzy Logic	Whereas, classical logic holds that everything can be expressed in binary terms: 0 or 1, black or white, yes or no; fuzzy logic allows for values between 0 and 1, shades of gray, and maybe; it also allows partial membership in a set. When used with an expert system, logical inferences can be drawn from imprecise relationships. Uses include automatic optimization of household appliances by sensors, automobile subsystems and smart weapons.
Visualization Software	Similar to geographic information systems (GIS) or mapping, visualization software displays sets of interconnected data, often in animation-like format. Uses include aerospace obstacle detection and landscape evaluation.
Data Mining	Data mining (or knowledge discovery in databases, KDD), is a new research area developing methods and systems for extracting interesting and useful information from large sets of data. Uses include commercial/financial databases, telecommunication alarm sequences and epidemiological research.

Table 9.2 EXAMPLES OF MATH-BASED/COMPUTER-ENHANCED RESEARCH TOOLS

Recently, algorithmic programming has been applied to advance the cause of solvent substitution. In March of 2000, three simulation programs with different algorithms were reviewed for designing greener solvents by H. Cabezas, P.Harten and M. Green.[81] The three simulations were:

(1) the U.S. EPA's Program for Assisting the Replacement of Industrial Solvents (Paris II), (2) the Technical University of Denmark's software, Computer Added Molecular Design (CAMD) and (3) Molecular Knowledge Systems' chemical design software, Synapse. The Paris II algorithm <www.tds.cc> uses chemicals from the Design Institute for Physical Property Research (DIPPR) database and "looks for potential replacement solvents whose properties are as close to the required parameters as possible." The CAMD solvent-design algorithm <www.capec.kt.dtu.dk> operates in a five-stage process using appropriate valence (i.e., molecular charge) rules. The Synapse algorithm <www.molknow.com> "generates candidate chemical structures, which are then screened as potential solvent replacements in a four-step methodology."

Unlike these programs that focus on theoretical scenarios with data that are primarily intended for the scientific community, *The Aqueous Way to Go* concentrates on actual performance data of existing cleaners for end users and for applications development. In this instance, data mining offers the best approach for manipulating information to arrive at the knowledge and insight from observed tendencies (for example, the performance of certain surfactants) in would-be relational databases. This could ensure that fewer mistakes are made in decision-making processes involving solvent selection, especially when incorporated in the training session, *Critical Thinking for Cleaning Alternatives* presented in chapter eight.

Nevertheless, it would be possible to use any, or a combination of, the remaining computer tools described in Figure 9.2 for research and development into greener cleaners. The web site Solvent Alternatives for Green Chemistry at http://web.mit.edu/huibers/www/greenchem.html lists a number of computer programs developed for property prediction, solvent replacement studies, and reaction design as well as solvent substitution resources on the World Wide Web, in particular, the U.S. EPA's Envioene's <http://es.epa.gov> links to data systems.

9.1.3 Ionic Liquids as Solvents

Recent advances in ionic liquids show promise in improving the environmental soundness of surface cleaning. Ionic liquids are salts that exist in liquid form at ambient temperature. Like all salts, they possess a positive and a negative charge. Ionic liquids do not occur naturally and must be manufactured. While not much information has been published about them yet, researchers C. Song and E. Roh reported the use of a room temperature ionic liquid for the immobilzation, recovery and recycling of a chiral catalyst in May of 2000.[82] The ionic liquid used was 1-butyl-3-methylimidazolium hexafluorophosphate depicted in Figure 9.4.

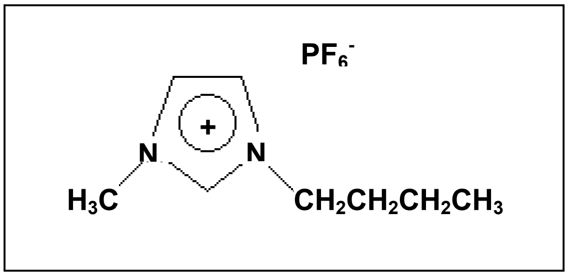

Figure 9.4
IONIC LIQUID,
1-BUTYL-3-METHYLIMIDAZOLIUM HEXAFLUOROPHOSPHATE

Unlike water-soluble compounds that can be extracted with water, or the removal of chemicals with high vapor pressures by distillation, ionic liquids require very high temperatures to effect separation of compounds. This post separation of chemical products from ionic liquids may be difficult to achieve since the heat needed may cause the products to degrade. Furthermore, the energy needed to drive these reactions may be too expensive. If these problems can be solved, ionic liquids may become safer, greener solvents since they do not possess any measurable vapor pressure and so, unlike chlorinated/organic solvents, do not evaporate to be inhaled by workers or to be emitted into the atmosphere and cause air pollution. (The dermatological consequences of exposure to ionic liquids as well as their impact on water pollution are currently unknown.)

To address this separation issue, J. Brennecke of Notre Dame and E. Beckman of the University of Pittsburgh performed experiments with both an ionic liquid and supercritical carbon dioxide (discussed in chapter six) at room temperature.[83] Their experiment, first reported in 1999, is diagramed in Figure 9.5.

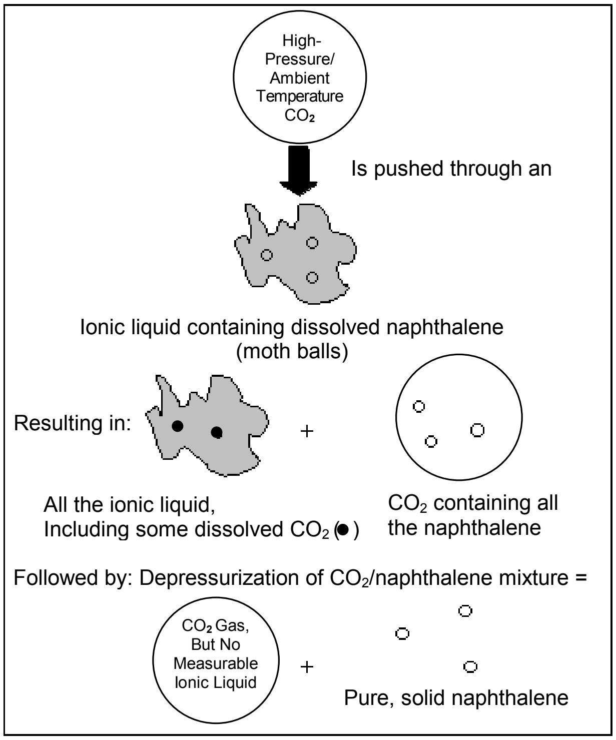

Figure 9.5 THE COMBINATION OF AN IONIC LIQUID AND SUPERCRITICAL CO_2 TO SEPARATE AN ORGANIC COMPOUND FROM SOLUTION

Both the carbon dioxide and the ionic liquid are recoverable for reuse. The same system used for the separation of naphthalene could theoretically be used for the removal of organic surface contaminants. While liquid-liquid (as opposed to liquid-CO_2) extractions would still be possible, they would invariably return the system to the use of organic solvents, depending on the coefficient of partition, or to water, which would be almost entirely ineffectual for the separation of most hydrocarbons. The use of various polymers, surfactants or solubilizers may enhance the extraction/cleaning process.

To date, no toxicological or environmental fate studies have been published on ionic liquids.

This is urgently needed before much additional application work is done, including a comparative assessment to the alternative cleaners recommended by *The Aqueous Way to Go*. Refer also to section 6.1 for performance tests of other non-aqueous cleaning methods.

9.2 Policy Making and Risk Assessment

The first part of this chapter dealt with the future of industrial cleaning in terms of chemical and scientific innovation. The second part is devoted to the underpinnings of public policies that either foster or impede these advances. No other topic is as germane to the issue of chemical discovery, manufacture and use as risk assessment. And no other aspect of risk assessment has been as overlooked as hormesis.

9.2.1 The Case for Hormesis

Hormesis may be defined as the phenomenon observed in science that "the effects <of chemical exposure> produced at high doses are the inverse or apparent inverse of those produced at low doses" in a population.[84] The study of hormesis dates back to the German physician Paracelsus (1493-1541) and father of toxicology who coined the phrase "the dose determines the poison."[85]

It is estimated that approximately 350 studies contain evidence of hormesis. These studies involve a number of different species (fungi, protozoa, bacteria, plants and animals), cover a wide range of chemical types (alcohol and its metabolites, hydrocarbons, metals and pesticides) and exhibit varying effects (alterations in growth rates, reproduction, longevity and cancer). The hormetic effect of hydrocarbons on plant growth, where growth *stimulation* occurred at *low* doses and inhibitory effects at high doses is illustrated in Figure 9.6.

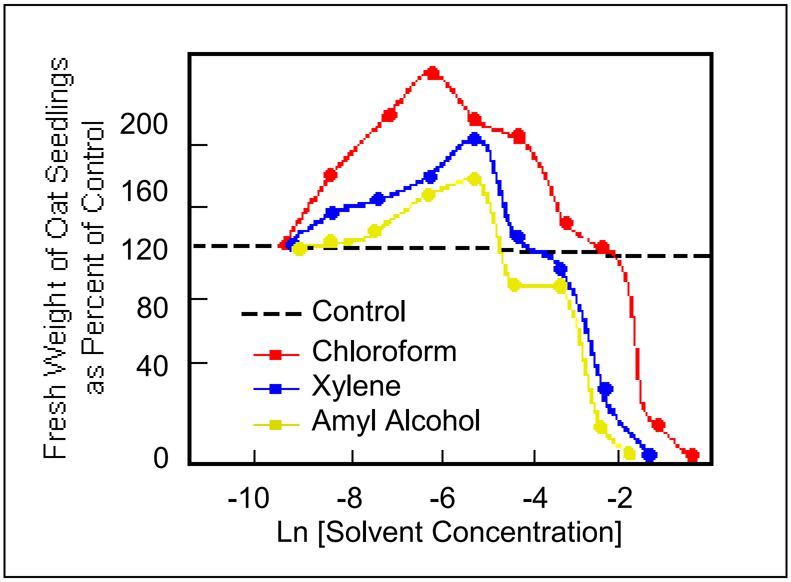

Figure 9.6 HORMETIC EFFECT OF ORGANIC SOLVENTS ON OAT SEEDLING GROWTH[86]

Currently, chemical risk assessments are primarily conducted by studying high-level exposures and extrapolating to predict safe levels (section 2.4.2). Inclusion of hormesis in risk assessments would reveal hormetic zones where the chemical/biological responses may be significant. An example is given in Figure 9.7.

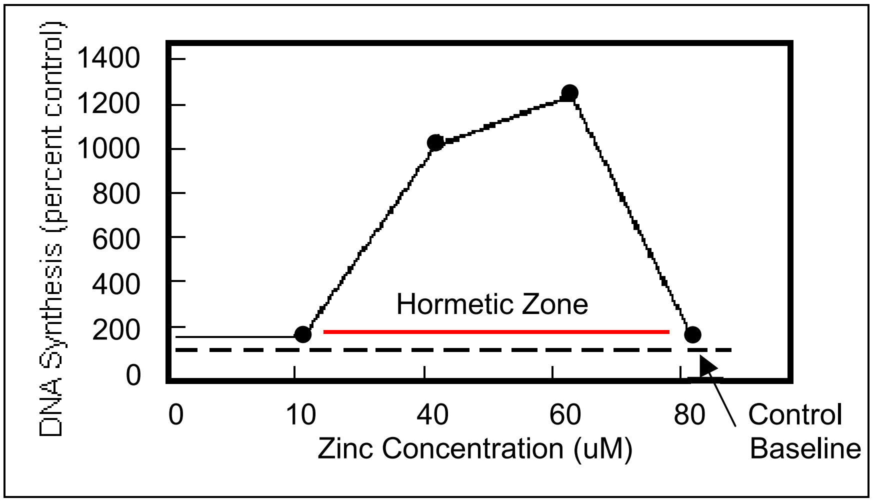

Figure 9.7 IDENTIFICATION OF HORMETIC ZONE OF ZINC EFFECTING CELL REPRODUCTION[87]

Nowhere is this phenomenon more important than in the study of cancer. Approximately twenty toxicological studies have been conducted whereby hormesis occurred, followed by the onset of cancer. All three stages of the disease, initiation, promotion and proliferation, have been linked to hormetic behavior.[88]

Whether or not a chemical is said to exhibit dose-dependent beneficial or deleterious reactions depends upon *the conditions defined at the time of the exposure*. For example, many chemicals used in the treatment of Acquired Immune Deficiency Syndrome (AIDS) are considered toxic under almost every other circumstance. Problems arise when conditions are *not* defined prior to a chemical's release into the general environment, turning the biosphere into a laboratory. This is descriptive of the use of most of mankind's synthesized chemicals, including the detergents and solvents used for cleaning.

The point of this discussion on hormetic behavior is that exposure may be more harmful at lower, as opposed to higher, concentrations for the same chemical, toxicity notwithstanding. This refutes the principle learned by most chemists degreed before 1990 that "dilution is the solution to the problem" and demonstrates the importance of identifying potential chemical hazards *before* they enter the biosphere, as well as the difficulty of downstream separation efforts if they are not. Also, work health and safety and environmental issues need to be addressed.

9.2.2 Surfactants and Endocrine Disruption

The Surfactants
As discussed in chapter three, surfactants are surface-active chemicals that are very important to the cleaning process. Their concentrations in aqueous cleaners are deceptively low (> 10%),

given that they are the power horses of the cleaner's formulation. It should, therefore, come as no surprise that some of these surface agents may exhibit the kinds of effects described above at very low concentrations.

The proven health hazards associated with organo-chlorinated cleaning solvents were described in detail in chapter two. The suspected health hazards involving some surfactants in some aqueous/semi-aqueous cleaners, acting as endocrine disruptors, were only briefly mentioned in chapter three and again in chapter eight, since more investigative work needs to be done.

The Endocrine System

The endocrine (or hormonal) system is made of glands throughout the body that synthesize and secrete hormones into the bloodstream and various receptors in target tissues that recognize and respond to hormones. The endocrine system controls a complex interplay between the sex hormones of the oestrogens and androgens, and other hormones, such as those of the thyroid system. The immune and nervous systems are also affected by hormonal regulation. It is precisely because of the systems' complexities that it is extremely difficult to accurately predict the behavior of a single chemical compound or its metabolites on the body's organs.

Oestrogens, like oestradiol, pictured in Figure 9.8, influence the development and maintenance of female sex characteristics, and the maturation and function of the sex organs. Chemicals that can imitate an oestrogen are known as oestrogenic chemicals. Androgens such as testosterone serve a similar purpose in males.

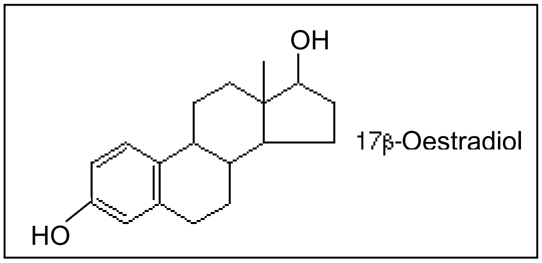

Figure 9.8 THE STRUCTURE OF THE OESTROGEN, *OESTRADIOL*

Chemicals can disrupt the endocrine system in several ways, with the degree of disruption being influenced by timing, especially with regard to the stages of the recipient organ's development and that of the organism. The main mechanisms include binding or activating the oestrogen receptor or other receptors, modifying the production or metabolism of natural hormones and modifying the number of hormone receptors. Terms used to describe these chemicals include xenoestrogens, oestrogenic (estrogenic), hormone mimicking and endocrine disrupting.

Man-made substances implicated as oestrogenic include the alklyphenols (and their derivatives) used in industrial detergents for wool washing and metal finishing, various laboratory detergents, including Triton X-100 and some liquid laundry detergents. The alkylphenols nonylphenol and octylphenol are mainly used to make alkylphenol ethoxylate (APE) surfactants.

Alkylphenols were first thought to be oestrogenic in the 1930s and more evidence of such effects was published in the 1970s.[89,90] However, it was not until 1991 that publication of the effects of nonylphenol on cultured human breast cells led to human health concerns.[91] As reported by A. M. Warhurst <http://website.lineone.net/~mwarhurst/policy.html>: other research has shown that the growth of these cells is increased by alkylphenols at concentrations 1000 to 10000 times higher than the oestradiol levels required to produce the same growth. Oestrogenic effects have also been shown on rainbow trout hepatocytes, chicken embryo fibroblasts and a mouse oestrogen receptor.[92,93] Oestrogenic effects are present at tissue concentrations of 0.1 μM for octylphenol and 1 μM for nonylphenol.[94] A recombinant yeast screen, using the human oestrogen receptor, has shown similar results.[95] Recent research shows oestrogenic effects of nonylphenol at still lower concentrations and levels of 0.05 mg/L were sufficient to increase the number of eggs produced by minnows, as well as an increase in vitellogenin levels (this research also suggested that nonylphenol may lead to an increase in natural oestrogen levels).[96]

Alkylphenol ethoxylate surfactants are not effectively degraded in sewage treatment plants or in the environment, tending instead to lose some of their ethoxylate groups and to also bio-accumulate up the food chain. The resultant alkylphenols, alkylphenols with one or two ethoxylate groups and alkylphenoxy carboxylic acids (APEC), persist even longer. Alkylphenols accumulate where there is inadequate oxygen (e.g., in sediments) and APEC persist in rivers and effluents (e.g., sewage).

Human exposure to these chemicals can occur by (1) absorption through skin from shampoos, cosmetics, spermicidal lubricants and domestic and industrial detergents (2) contaminated drinking water, (3) inhalation and ingestion from pesticide sprays and (4) contamination of food from fields treated with sewage sludge. Nonylphenol has been detected in human umbilical cords at concentrations up to 2 ppt, wet weight, which may or may not be correlated to the predisposition of the infant's sex as a consequence of exposure. The author of this thesis was unable to document worker exposure effects to these detergent-related chemicals in Micromedex's collection of databases.

9.2.3 Enzymatic/Protein Cleaners

Another interesting category in the future of hard-surface cleaning is the group of enzymatic cleaners. Enzymes are proteins that perform certain biological functions. These cleaners depend on microbial processes to digest oily substances, after the contaminant is removed by the surfactant that is present in the cleaner. Used first as drain cleaners and some laundry detergents, enzyme products are being used for industrial parts cleaning and wastewater treatment in a procedure known as bioremediation. A number of these systems require bioreactors. Microbial growth is controlled as the feedstock of the hydrocarbon is utilized.

Several enzymatic cleaners are based on kelp (seaweed). While most vendors are quick to point out what is *not* in their products, ingredient information is most often listed as proprietary. Enzymatic cleaners have a history of safe usage but new formulations require better scrutiny, especially with regard to life cycle and environmental fate. In addition, some people have allergic responses to enzymes in detergents. The biochemical causes behind the appearance/disappearance of these allergies is currently unknown.

Enzymatic cleaners are not widely tested in the SCL because of three primary factors: increased chemical costs over other aqueous cleaners, increased labor issues (some formulations are in two-phases, a liquid and a powder component) and the increased equipment cost and floor space needed for a bioreactor. Advances in nanotechnology (section 9.1.1) may make possible the bio-inspired design or 'mimicking' of enzymatic cleaners at the molecular level cost effective.

9.3 Status of Related Public Policy

The U.S. EPA formed the Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) to develop recommendations for a screening program, which were finalized in August 1998. As a result, an "Endocrine Disruptor Screening Program," was designed with a focus "on providing methods and procedures to detect and characterize the endocrine activity of pesticides, commercial chemicals and environmental contaminants." By the agency's own admission, however, "there currently is not enough scientific data available on most of the estimated 87,000 chemicals in commerce to allow us to evaluate all potential risks," with the exception of some pesticides.[97] A number of papers from the research initiative of the National Science and Technology Council's (NSTC) Committee on the Environment and Natural Resources (CENR) can be found at http://www.epa.gov/endocrine/pubs.html.

9.3.1 The Precautionary Principle: the European Model

The "precautionary principle" may be defined as the approach whereby lack of full scientific certainly is not used as a reason for postponing pollution prevention measures to prevent environmental degradation. It was first endorsed in 1987 by European environmental leaders concerned with toxic discharges into the North Sea. They reasoned that releases of chemicals should be reduced/eliminated if they are *suspected* to be harmful, even before there is clear scientific proof, hence the term *precautionary*. In a 1992 report, the John Snow Institute, Center for Environmental Health Studies, reported that a number of factors contribute to this scientific uncertainty.[98] These factors are listed in Table 9.3.

Reasons for Uncertainty
I. The complexity of dose and exposure relationships
II. The unknown cumulative effects of exposure
III. The unknown effects of combined exposures to multiple chemicals
IV. The vast number of chemicals about which we have little or no health effects information
V. Individual differences among humans in their receptivity and propensity for diseases
VI. Limitations of scientific knowledge
VII. Delays between exposure and occurrence of disease

Source: John Snow Institute, Center for Environmental Health Studies

Table 9.3 FACTORS INFLUENCING SCIENTIFIC UNCERTAINTY[98]

That same year, the United Nations Conference on Environment and Development (UNCED) adopted Principle 15, which states that "where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." A version of this principle was also incorporated into the Cartagena Protocol on Biosafety under the Convention of Biological Diversity. At the International Conference on Biotechnology in the Global Economy held at

Harvard in September 2000 (Cambridge, Massachusetts), a discussion was facilitated by the University's Center for International Development (CID) that "supported efforts to better understand the institutions of precaution through which governments move from science to policy… highlighting the institutional differences among OECD (Organization for Economic Cooperation and Development) countries, sub–Saharan countries and international institutions." The precautionary principle is important to industrial cleaning since its implementation in Europe has led to a ban of some surfactants while the U.S. continues to allow these chemicals in cleaners; many scientists believe that the safer, albeit more expensive alcohol ethoxylate (Figure 9.2) is as effective and readily available as the suspect alkylphenol-ethoxylated surfactants. The computer program or tool, *The Aqueous Way to Go* can be used to 'screen' nonylphenol ethoxylate from potential solvent substitutes in much the same way, as illustrated in Table 8.4. An overview of current policies covering chemical usage throughout the world, in particular, suspect endocrine disrupters, is presented in Table 9.4.

European Union (EU)	The European Commission (EC) published its strategy on endocrine disruption in Dec. 1999. Originally expected to include a list of 20-30 suspected endocrine disrupters, the list was postponed to April 2000. In March 1999 the EC's Scientific Committee on Toxicity, Ecotoxicity and the Environment published the report, "Opinion on Human and Wildlife Health Effects of Endocrine Disrupting Chemicals, with Emphasis on Wildlife and on Ecotoxicology Test Methods." The EU also published a communication on the precautionary principle in February 2000. Several endocrine disrupters are under review as part of Existing Substances process. The EU's chemicals policy in under review as well, having been accepted that it is not currently effective enough.
United Kingdom (UK)	The UK Government published its new chemicals strategy in December 1999. The Environment Agency of England and Wales is currently reviewing its policy towards endocrine disrupters.
United Nations (UN) and NGOs	The OECD has a programme on endocrine disrupters, mainly focusing on the development of testing procedures. The UN is currently negotiating a global treaty covering certain persistent organic pollutants (POPs), including PCBs, dioxin and DDT, with criteria for adding new chemicals. A similar agreement, the POPs Protocol, has already been negotiated among the UN Economic Commission for Europe. The International POPs Elimination Network is a non-governmental organization (NGO) coalition against POPs.
United States (US)	No signs yet of any new controls on existing chemicals, even on the alkylphenols, which are already being phased out in Europe. The US National Academy of Sciences published the report, "Hormonally Active Agents in the Environment" in July 1999.
Chemical Industry	Most relevant industry associations have issued statements about hormone disrupting chemicals relaying their concerns, but calling for more research before any action is taken. Industry claims that effects are not likely to be as significant as those of phytoestrogens. Some companies have stopped using suspect chemicals while others will continue to use them unless they are banned, viewing endocrine disruption as an hypothesis.

Source: A. M. Warhurst and the Friends of the Earth, London at http://website.lineone.net/~mwarhurst/policy.html

Table 9.4 OVERVIEW OF GLOBAL POLICIES EFFECTING SUSPECT ENDOCRINE DISRUPTING CHEMICALS[99]

The author suggests that the *pro*active stance of the precautionary principle, rather than a variety of *re*active policies, should form the basis of technical innovation and resultant world trade. This is especially true in areas such as the production of genetically-modified organisms (GMOs) and the development of solvent alternatives, where the risks are so high for so many. More information on hormone disrupting chemicals and chemicals policy can be found at Tulane University's web site, http://www.tmc.tulane.edu/ecme/eehome/ in "Environmental Estrogens and Other Hormones."

9.3.2 The Effects of a Recent Policy Change: the United States

In a different, but related matter, a recent change in U.S. regulations has led to a loosening of the use of an important solvent chemical, the de-listing of acetone as a VOC. This may lead to an increase in the use of acetone and other hydrocarbons as cleaning agents, even though the quantity and quality of safer and greener alternatives continues to rise (section 6.2.3).

In fact, consultants to the U.S. space agency have recommended the use of butane (lighter fluid) in some part-cleaning operations since this policy change. It would appear that as older scientists retire and/or are replaced by younger, inexperienced researchers/contractors, there is a lack of a common understanding of the past lessons learned from the misuse of these solvents. This may cause American society to repeat some of the same mistakes made earlier. In other words, the U.S. public may be facing a retreat to increased exposure to hydrocarbon products, and their associated health hazards, used for cleaning prior to the discovery of the destruction of the ozone layer by CFCs. These developments are especially troubling in light of the United States' active opposition to the Kyoto Protocol to decrease global-warming (i.e., carbon-based) emissions. The re-introduction of brominated cleaners (chapter two), notably n-propyl bromide (nPB), is likewise a concern. UNEP's STOC considers nPB to be ozone depleting and is not recommending it as a solvent substitute since "non-ozone-depleting solutions exist for all cleaning applications for which nPB is being promoted."

Mentoring, the practice by which an older, experienced researcher acts as a trusted counselor or guide to an apprenticed scientist in the more mature European culture may be counteracting these effects. The methodology, *Critical Thinking for Cleaning Alternatives,* developed for this thesis, may help to counteract the above effects as well.

Aberrations in legal structures, especially liability issues, are no doubt at the root cause of how some societies approach environmental decision-making for cleaning applications. Consumerism, (i.e., the educated consumer) and organized labor (i.e., trade unions representing various segments of the workforce performing cleaning duties) also have roles to play. Various chemical formulators have become more adept in addressing worker safety and the environment due to these concerns. Partly because of these advances, the lines separating parts, precision and institutional (i.e., maintenance and janitorial) cleaning have blurred and are illustrated in Figure 9.9. As workplaces approach the safety of households in cleaning operations, overlaps among cleaning standards and performance guidelines may become more commonplace. Ironically, these same developments may also tend to increase multiple chemical sensitivities to certain, at-risk, individuals within a given population.

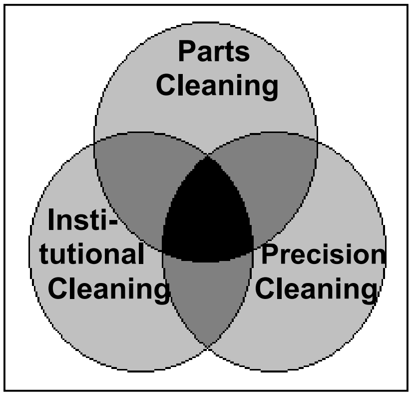

Figure 9.9
ILLUSTRATION OF THE THREE PRINCIPAL CLEANING FIELDS[o]

[o] Electronics is considered a subset of precision cleaning, and maintenance cleaning is considered its own focus. This model differs from UNEP's description of cleaning fields (chapter three).

A Provocative Scenario Involving the Semiconductor Industry

In no industry is the efficacy of cleaning/rinsing cycles more essential than in the semiconductor industry. Cleanrooms, maintained at various levels of cleanliness under U.S. Standard 209E according to the number and size of airborne particulates, generally require cleanliness levels many times greater than surgical fields. This is because the semiconductor, a silicon wafer with diodes and transistors, must act as a circuit at near atomic levels. Contamination is the primary cause of product failure. Moreover, the increased storage capacity of computer chips has caused the adherence to ultraclean conditions to increase exponentially. Figure 9.11 contains the water quality guidelines for chip manufacture and blood dialysis as a means to compare each system's level of desired contamination control.

CONTAMINANT	MAXIMUM CONCENTRATION*
SUSPENDED SOLIDS: RESIDUE / PARTICULATES	0.1 PPM / 500 COUNTS PER LITER
DISSOLVED SOLIDS: ORGANIC (TOC)	0.020 PPM
IONIC: RESISTIVITY / DISSOLVED SILICA (SIO$_2$)	18.3 MEGOHM-CM / 3 PPB
ALUMINUM (AL) CATIONS	0.2 PPB
AMMONIUM (NH$_4$) CATIONS	0.3 PPB
CHROMIUM (CR) CATIONS	0.02 PPB
COPPER (CU) CATIONS	0.002 PPB
IRON (FE) CATIONS	0.02 PPB
MANGANESE (MN) CATIONS	0.05 PPB
POTASSIUM (K) CATIONS	0.1 PPB
SODIUM (NA) CATIONS	0.05 PPB
ZINC (ZN) CATIONS	0.02 PPB
BROMIDE (BR) ANIONS	0.1 PPB
CHLORIDE (CL) ANIONS	0.05 PPB
NITRITE (NO$_2$) ANIONS	0.05 PPB
NITRATE (NO$_3$) ANIONS	0.1 PPB
PHOSPHATE (PO$_4$) ANIONS	0.2 PPB
SULFATE (SO$_4$) ANIONS	0.05 PPB
BACTERIA	0 COUNTS PER 100 ML

A

CONTAMINANT	mg/L*
ALUMINUM (AL)	0.01
ARSENIC (AR)	0.005
BARIUM (BA)	0.1
CADMIUM (CD)	0.001
CALCIUM (CA)	2.0
CHORAMINES	0.1
CHLORINE (CL)	0.5
CHROMIUM (CR)	0.014
COPPER (CU)	0.1
FLUORIDE (F)	0.2
LEAD (PB)	0.005
MAGNESIUM (MG)	4.0
MERCURY (HG)	0.0002
NITRATE (AS N)	2.0
POTASSIUM (K)	8.0
SELENIUM (SE)	0.09
SILVER (AG)	0.005
SODIUM (NA)	70.0
SULFATE (SO$_4$)	100.0
ZINC (ZN)	0.1

B

*Measurement system chosen by industry. Conversion factor: parts/million X 1 = mg/L

Figure 9.10 WATER QUALITY GUIDELINES FOR SEMICONDUCTORS (A) AND HEMODIALYSIS (B)[77]

The goal of this treatise is not to expose the semiconductor industry's over-dependence on energy and water resources. Other researchers such as Ted Smith, the founder and director of the non-profit Silicon Valley Toxics Coalition, are far more familiar with the industry and have documented this with certainty. The purpose here is to reflect on (1) the sheer unsustainable nature of the product that is being manufactured (computers are considered obsolete within eighteen months, perhaps deliberately, because of monopolistic business practices), (2) the emergence of Singapore, a country with a less-than-perfect record on human rights as the semiconductor capital of the world, and, in particular, (3) the unhealthy, unnatural conditions that workers are exposed to in cleanrooms.

Hospitals, Cleanrooms and Cleaners: Could There Be a Connection?

"The globalization of infectious diseases is not a new phenomenon. However, increased population movements, whether through tourism or migration or as a result of disasters; growth in international trade in food and biological products; social and environmental changes linked with urbanization, deforestation and alterations in climate; and changes in methods of food processing, distribution and consumer habits have reaffirmed that *infectious disease events in one country are potentially a concern for the entire world <italics added>*." So begins the World Health Organization's (WHO) report by the Secretariat on global health security – epidemic alert and response (November 2000). Some of these topics were addressed in chapter two.

Staphylococcus Aureus[p] has been implicated in hospital-acquired infections since the 1950s when 50% of the organism's strains developed resistance to penicillin. It has been considered a serious bacterial pathogenic threat since that time. Known as a 'super bug,' the organism has also become resistant to newer and more powerful antibiotics such as tertracycline and the aminoglycosides. It is common, *even in the cleanest healthcare facilities*, with the elderly, the seriously ill and those patience with compromised immune systems being at greatest risk.[100] The MRSA (methicillin-resistant *Staphylococcus Aureus*) super bug responds only to the antibiotic vancomycin, whose use is now restricted due, at least in part, to its apparent role in producing the 'super bug' VRE (Vancomycin-Resistant Enterococci[q]), following its application in European cattle, *for which there is no known treatment*. 'Flesh-eating' disease or Necrotizing Fasciitis is another antibiotic-resistant bacterial infection of the Streptococcus Type A variety associated with surgical or wound patients. This variant super bug is more powerful than other strains, with stronger m-protein serotypes.

Benign forms of *Staphylococcus Aureus* are natural habitants of skin and mucus membranes of humans and can be found throughout the environment from dust to door knobs. An infectious disease expert at the American Society for Microbiology's recent annual meeting in Miami, Florida reported that *even personnel who do not come into direct contact with patients can accumulate and spread bacteria, including resistant strains*. Thus, the WHO's concern is justified for the pandemic spread of these infections to the general population, *including apparently young and otherwise health subjects*, as illustrated in the 'mad cow' disease or Bovine Spongiform Encephalopathy (BSE) in its fatal human form called, new variant Creutzfeldt-Jakob Disease (nvCJD). Cannibalism, not an overuse of antibiotics, appears to be the root cause of these infectious mutations. The disease involves prions. Prions are tiny biological bits that may or may not be alive and so are impossible for scientists to 'kill' (in the conventional sense of the term) to prevent the infection's spread. Some of these prions can be viewed three-dimensionally with RosMol/Chime (section 9.1.1) at

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[p] Staphylococci are gram positive bacteria that are typically arranged in clumps or grape-like clusters. They can be distinguished from streptococci in that only the staphylococi are catalase-positive (catalase is an enzyme that liberates oxygen from hydrogen peroxide).

[q] Enterococci are gram-positive bacteria that are widely distributed in nature and are part of the normal flora of the gastrointestinal and genital tracts.

http://www.mad-cow.org/prion_structure_folder/viewers.html.

The Cleaner Connection

Recently, Americans have been introduced to a line of household cleaners, advertised as antibacterial, for applications where no antibacterial activity is warranted. The more popular the cleaners become, the more product varieties that appear on grocers' shelves.[r] Studies at Tufts University's School of Medicine (Boston, Massachusetts) revealed that the antibacterial agent *triclosan,* used in many of these products, acts like an antibiotic to promote bacterial resistance and, potentially, the spread of untreatable infections. Furthermore, the U.S. Food and Drug Administration (FDA) reports that antibacterial soaps kill the beneficial bacteria that live on skin. Unlike their pathogenic counterparts, these bacteria apparently strengthen the immune systems of children.[101]

These seemingly unconnected events or trends have one or two things in common: they are related to the things we chose to clean well or not to be able to keep clean enough. *Meanwhile, microscopic forms of life have been found in Arctic-like conditions and other species such as the archaea have evolved near volcanic emissions under the sea, both environs thought to be uninhabitable by the scientific community not too long ago*. Somehow, life finds a way.

In hospitals, sterility is maintained (most notably for surgery), cleaning is performed and dressings (gowns, masks, gloves) are donned to protect the person from the pathogen. In cleanrooms, sterility is maintained, cleaning is performed and dressings donned to protect the product from the person. Cleanrooms, whose sterile environment routinely outrivals the surgeon's needs, may offer the next best habitat for a super bug, perhaps of prion-nature, to establish a foothold. The technical staff of these high-tech establishments may already have damaged immune systems due to the unnatural conditions in which they work on a daily basis (there is no such thing as a 'good' bacterium is a cleanroom). Regardless, the spread of a hypothetical cleanroom-acquired infection may not require an at-risk host, as has been confirmed by the American Society for Microbiology.

Closing Statement

Several aspects of the search for surface cleanliness are neither simple nor straightforward. The Alliance for the Prudent Use of Antibiotics (Boston, Massachusetts), an international organization with members from more that 90 countries, has been monitoring the worldwide emergence of treatment-resistant microbial strains since 1981. This group, and others in the scientific community such as the U.S. Center for Disease Control (CDC), should be made aware of the developments in the cleaning industry so that other studies, like those conducted at Tufts medical school, can be undertaken.

In the meantime, unless or until the chemical industry provides complete chemical disclosure on

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[r] Some examples include: Joy® Antibacterial Hand Soap by Procter & Gamble of Cincinnati, OH, Lysol® Antibacterial Kitchen Cleaner by Reckett and Colman of Wayne, NJ, Palmolive® Antibacterial Dishwashing Liquid by Colgate-Palmolive of New York, NY and Windex® Antibacterial Glass and Surface Cleaner by SC Johnson & Son of Racine, WI.

a global basis, institutions such as the Massachusetts Toxics Use Reduction's Surface Cleaning Laboratory should assist in formulating green chemical cleaners, in addition to providing education and training programs and state-of-the-art laboratory testing of existing products. This could be accomplished through partnerships with commercial enterprises and/or other research facilities. Remaining pertinent issues, some having nothing to do with cleaning performance, could then be addressed. These include studies on the chemical additives of fragrances (over 80% of the odorants now used are synthetic in origin) and dyes or colorants (often added for worker safety in product recognition). Tighter quality control on percentages of ingredients could also be maintained, since currently the concentrations of a cleaner's components reported on its Material Safety Data Sheet can vary by as much as 400%. Most importantly, chronic, hormetic and synergistic chemical-exposure tests that are humane need to be developed and implemented before cleaners are marketed.

The development of the tool, *The Aqueous Way to Go* and its educational counterpart, *Critical Thinking for Cleaning Alternatives* revealed many of these trends and potential hazards in cleaning processes and chemicals. The use of this management information system within the cleaning industry should further contribute to this future work.

Epilogue

I have been unable to watch the movie version of *A Civil Action*,[s] the book by the same name mentioned in the Foreword. Released in 1999, I have thus far chosen not to listen to the movie's ads or reviews on TV and on the radio. I suppose what I fear most is Hollywood's depiction of the narrative. Was the movie true to the *real* story's focus? Or, was this just another missed opportunity to educate the public about how things can and do go terribly wrong, despite our scientific knowledge.

No doubt this thesis will be read by only a few. Nevertheless, it is one researcher's attempt to bring clarity to the choices we make that really matter; both to the quality of life for ourselves and for the countless other creatures with whom we share this wonderful planet.

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[s] *A Civil Action*, a Touchstone Picture starring John Travolta as the prosecuting attorney, documents the litigation process involving two giant U.S. corporations accused of polluting the water supply of a Massachusetts community, and the families who hold the companies responsible for the deaths of their children and other family members.

Glossary

ACRONYMS

APE	Alkylphenol ethoxylate
ASTM	American Society for Testing and Materials
BACT	Best Available Control Technology
CAA	U.S. Clean Air Act of 1970, also CAAA (Amendments)
CAS No.	Chemical Abstract Service Number
CERCLA	U.S. Comprehensive Environmental Response, Compensation and Liability Act of 1980
CFCs	Chlorofluorocarbons
CMA	Chemical Manufacturers' Association
CNS	Central Nervous System
CSMA	Chemical Specialties Manufacturers Association
DDT	2,2-bis(*p*-chlorophenyl)-1,1,1,-trichloroethane, toxic insecticide
DEP	Department of Environmental Protection
DfE/DFE	Design for the Environment
DI	Deionized (water)
DoD/DOD	Department of Defense
DU	Dobson Units (for measuring ozone)
ETC	TURI/SCL Effective Test Conditions
EMAS	Ecological Management and Auditing System
EMS	Environmental Management System; EMAS is European example
EPA	Environmental Protection Agency
EPP	Environmentally Preferable Purchasing
EPCRA	U.S. Emergency Planning and Community Right to Know Act of 1986
FTIR	Fourier Transform Infrared (Spectroscopy)
GC	Gas Chromotography
GWP	Global Warming Potential
HAPs	Hazardous Air Pollutants
HCFCs	Hydrchlorofluorocarbons
HMIS	Hazardous Materials Information System
HSDB	Hazardous Substance Data Bank (a TOMES database)
IPA	Isopropyl alcohol, can be used for cleaning
IR	Infrared
ISO	International Standards Organization: 9000-Quality Standard; 14000-Environmental Standard
LCA	Life Cycle Assessment/Analysis
MACT	Maximum Achievable Control Technology (see also, NESHAPs)
MCF	Methyl chloroform, also known as TCA
MEK	Methyl ethyl ketone, a solvent cleaner
MSDS	Material Safety Data Sheet
NASA	U.S. National Aeronautics and Space Administration

NESCAUM	U.S. Northeast States for Coordinated Air Use Management
NESHAPs	U.S. National Emission Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Asssociation
NGOs	Non-governmental Organizations
NIOSH	U.S. National Institute for Occupational Safety and Health
NVR	Non-volatile residue
ODP/ODS	Ozone Depletion Potential/Substance
OSEE	Optically Stimulated Electron Emission
OSHA	U.S. Occupational Safety and Health Administration
OTA	Massachusetts Office of Technical Assistance
P_2	Pollution Prevention
PARIS	U.S. EPA’s Program for Assisting the Replacement of Industrial Solvents
PCBs	Polychlorinated Biphenyls (a group of carcinogenic, i.e., cancer-causing industrial chemicals)
POPs	Persistent Organic Pollutants
QA/QC	Quality Assurance/Quality Control
RCRA	U.S. Resource Conservation and Recovery Act of 1976 (cradle-to-grave chemical responsibility)
RACT	Reasonably Available Control Technology
RO	Reverse Osmosis
RTI	Research Triangle Institute
SAGE	Solvent Alternatives Guide of RTI
SARA	U.S. Superfund Amendments and Reauthorization Act of 1986
SCL	TURI Surface Cleaning Laboratory
SEM	Scanning Electron Microscopy
SNAP	U.S. EPA’s Significant New Alternatives Policy
SOP	Standard Operating Procedure
TACT	Cleaning Parameters of Temperature, Agitation, Concentration and Time
TCA	Total Cost Accounting; also a solvent, trichloroethane known as methyl chloroform of MCF
TCE	Trichloroethylene or trichloroethene, a solvent cleaner
TEM	Transmission Electron Microscopy
TOMES	Toxicology, Occupational Medicine and Environmental Series, a Micromedex database
TQ(E)M	Total Quality (Environmental) Management
TRI	U.S. Toxics Release Inventory
TTC	TURI Technology Transfer Center
TUR	Toxics Use Reduction
TURA	Massachusetts Toxics Use Reduction Act of 1989
TURI	Massachusetts Toxics Use Reduction Institute
UNEP	United Nations Environment Programme
UV	Ultraviolet
VOC	Volatile Organic Compound
WHO	World Health Organization

TURI Glossary of Terms Related to Aqueous Cleaning

The chief ingredients of aqueous chemical cleaners are:

Water
Tap (i.e., municipal) or treated by deionization or distillation.

Surfactants
Substances with both hydrophilic (water soluble) and lipophilic (oil soluble) groups that may be cationic (+ charge), anionic (- charge) or nonionic depending on the charge of the hydrophilic end. Cationic surfactants are generally poor cleaners because of their positive charge. Anionic or negatively charged surfactants are usually emulsifiers that are water-soluble and commonly used in immersion cleaning (examples: organic sulfates and carboxylates and in particular sodium dodecylbenzene sulfonate). Nonionic surfactants with no electrical charge are used for surface cleaning when a lower-foaming detergent is required (examples: alcohol and alkylphenol ethoxylates). Synthetic nonionic surfactants may be prepared by attaching ethylene oxide molecules to water-insoluble polymers but are usually biodegradable in aqueous cleaners. In addition to wetting, surfactants can also enhance the emulsifying and dispersing properties of a cleaner.

Builders
Inorganic salts that provide alkalinity and buffering capacity common to almost all aqueous cleaners. Alkalinity may be provided by hydroxides, carbonates, borates, silicates, phosphates or zeolites (crystalline hydrated aluminosilicates). Many builders also soften water or help with saponification or deflocculation (examples: sodium hydroxide and sodium polyphosphate).

Emulsifiers
Surfactants that disperse soils (e.g., oil and grease) that do not dissolve in water by lowering the interfacial tension between them to form an oil-in-water emulsion containing micelles. Emulsifiers are useful for low soil loading but their concentration in a detergent limits bath life. Separation of soil and cleaner may be accomplished by making the emulsion unstable by lowering the pH and/or temperature. They are chemically similar to semi-aqueous cleaners described in sections 2.2.2 and 3.2.

Saponifiers
Alkalis that react with fatty acids in oils (esters) to form soaps. This converts the insoluble ester into a water-soluble oil that in turn acts as an emulsifier. These chemicals may be mineral (sodium or potassium)- or organic (solutions of monoethanol amine)-based. (Examples: potassium hydroxide and sodium hydroxide).

Solvents
Aqueous or organic substances designed to enhance the removal of oily soils by dissolving them, e.g., glycol ethers, ethylene (butyl cellusolve) and propylene compounds.

Additives
Chemicals that may overlap builders in function. They act primarily as contaminant dispersants, water softening agents, anti-foaming or defoaming agents, detergent fillers and corrosion inhibitors. Examples include ethylene diamine tetraacetic acid (EDTA), amine compounds and various polymers. Some common additives follow:

Sequestering Agents are produced as powders or liquids to combine with calcium (Ca), magnesium (Mg) and other heavy metals in hard water. They form molecules in which these ions are held securely, or *sequestered*, so that they can no longer react undesirably with other species in solution. Orthophosphate and orthosilicate are commonly used.

Chelating Agents are employed to solubilize Ca, Mg, iron (Fe) and related ions so that they remain in solution. Produced in both powdered and liquid forms, they do not degrade or loose their potency at elevated temperatures which make them ideal for aqueous cleaning. However, they can interfere with the ability of other chemicals to remove emulsified oils and dissolved metals from solution, which can lead to waste disposal problems. In addition to EDTA, nitrilo tri acetate (NTA) is also used.

Inhibiting Agents are often added to aqueous cleaners to minimize their effect on metal substrates. They are used for cleaning non-ferrous products at high pH and as rust inhibitors to prevent the rusting or oxidation of cleaned parts (or cleaning equipment that is not constructed of stainless steel).

Appendices

Appendix A. TOMES® HSDB Report on Sodium Hydroxide (NaOH)

0.0 ADMINISTRATIVE INFORMATION

Hazardous Substances Data Bank Number: 229
Last Revision Date: 19990129
Review Date: Reviewed by SRP on 9/23/1986
Update History: Refer to full TOMES text

1.0 SUBSTANCE IDENTIFICATION

Name of Substance: SODIUM HYDROXIDE
CAS Registry Number: 1310-73-2
Related HSDB Records: [POTASSIUM HYDROXIDE]
Synonyms:

1. CAUSTIC SODA [Peer Reviewed]
2. Caustic Soda, Bead (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
3. Caustic Soda, Dry (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
4. Caustic Soda, Flake (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
5. Caustic Soda, Granular (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
6. Caustic Soda, Solid (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
7. HYDROXYDE DE SODIUM [Peer Reviewed] [FRENCH]
8. NATRIUMHYDROXID [Peer Reviewed] [GERMAN]
9. NATRIUMHYDROXYDE [Peer Reviewed] [DUTCH]
10. SODA LYE [Peer Reviewed]
11. Soda, caustic [Peer Reviewed]
12. Soda, hydrate [Peer Reviewed]
13. Sodium Hydrate [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
14. Sodium Hydroxide, Bead (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
15. Sodium Hydroxide, Dry (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects Medicine's current MEDLARS file.]
16. Sodium Hydroxide, Flake (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
17. Sodium Hydroxide, Granular (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
18. Sodium Hydroxide, Solid (DOT) [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.]
19. Sodium(hydroxide de) [Peer Reviewed] [French]

Molecular Formula: H-Na-O [Peer Reviewed]
Wiswesser Line Notation: NA Q [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.,p. 86/8604]

RTECS Number: NIOSH/WB4900000
OHM-TADS Number: 7216900
Shipping Name/Number - DOT/UN/NA/IMCO:

1. IMO 8.0 -
2. UN 1823 - Sodium hydroxide, solid
3. UN 1824 - Sodium hydroxide, solution

STCC Number:

1. 49 352 35 - Dry
2. 49 352 40 - Liquid
3. 49 352 43 - 52% Solution

2.0 MANUFACTURING/USE INFORMATION

Methods of Manufacturing:

1. Electrolysis of sodium chloride brines, which yield sodium hydroxide and the coproducts chlorine and hydrogen [peer reviewed] [sri]
2. By reacting calcium hydroxide with sodium carbonate; from sodium chloride by electrolysis; from sodium metal & water vapor @ low temp. description of indust processes: faith, keyes, & clark's industrial chemicals (john wiley, ny, 4th ED, 1975) PP 737-745. [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
3. High purity 50% caustic soda is obtained directly from the amalgam decoposers in mercury cells, and requires only filtration to remove graphite particles and mercury to yield a commercial product. "Regular grade" 50% caustic soda is produced by evaporation of diaphragm-cell effluent and is less pure, containing about 1% sodium chloride and 0.1% sodium chlorate. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:831]
4. Electrolytic production of caustic soda using the diaphagm cell (predominant in the US); Mercury cell (Europe & Far East) and the membrane cell. [Peer Reviewed] [kirk-othmer encyc chem tech 3rd ed 1978-present v1 p.806]

1) Major impurities are sodium chloride, sodium carbonate, sodium sulfate, sodium chlorate, iron, and nickel. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:860]
2) Potential impurities: Na2O; Na2CO3; NaCl; NaClO3; Fe, Hg, Na2SO4; SiO2; Al2O3; CaO; MgO; Mn; Ni; Cu [Peer Reviewed] [considine. chemical and process technol encyc 1974 p.230]

Formulations/Preparations:

1. 50% and 73% aqueous solution. grades: commercial; ground; flake; beads; fcc; granulated (60% and 76% na2o); rayon (low in iron, copper, and manganese); purified by alcohol (sticks, lumps, and drops); reagent;

highest purity: CP, USP. [Peer Reviewed] [Hawley, G.G. The Condensed Chemical Dictionary. 10th ed. New York: Van Nostrand Reinhold Co., 1981. 942]

2. When kept in tight containers, the usual grades contain 97-98% sodium hydroxide. [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc.1983. 1236]
3. Anhydrous (Rayon Grade) 99.0% minimum; Rayon Grade: 50% liquid; Regular Grade: 50% liquid, 47.7-51% purity. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.1 (1981)]
4. Sodium hydroxide (96%), sodium carbonate (0.5-2.5%), sodium chloride (0.01-2.1): Sodium sulfate (0.02-0.1); Potassium, calcium, magnesium (0.1%); Silicon dioxide (0.03%); And other metals (0.01). [Peer Reviewed] [General Electric Co; Material Safety Data Sheet MSDS #3 (1984)]
5. 50% solution of sodium hydroxide in water: Sodium hydroxide (48.5%) carbonate (<0.25%), chloride (<1.15%), chlorate (<0.25%), sulfate (0.03%), silica (<0.01%), and water (balance). [Peer Reviewed] [General Electric Co; Material Safety Data Sheet MSDS #3 (1984)]
6. AETZNATRON [Peer Reviewed]
7. ASCARITE [Peer Reviewed]
8. COLLO-GRILLREIN [Peer Reviewed]
9. COLLO-TAPETTA [Peer Reviewed]
10. FUERS ROHR [Peer Reviewed]
11. Lewis - Red Devil Lye [Peer Reviewed] [U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety Health. Registry ofToxic Effects of Chemical Substances (RTECS). National Library of Medicine's current MEDLARS file.,p. 86/8604]
12. ROHRPUTZ [Peer Reviewed]
13. ROHRREINIGER ROFIX [Peer Reviewed]
14. SODIO(IDROSSIDO DI) [Peer Reviewed] [ITALIAN]
15. WHITE CAUSTIC [Peer Reviewed] Manufacturers:

1. Akzo America, Inc, Akzo Chemicals Inc, Hq, 111 West 40th St, New York, NY 10018, (212) 382-5500; Akzo Chemical Division, 300 South Riverside Plaza, Chicago, IL 60606; Production site: Le Moyne, AL 36505 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
2. Dow Chemical USA, Hq, 2020 Dow Center, Midland, MI 48674, (517) 636-1000; Production sites: Freeport, TX 77541; Pittsburg, CA 94565; Plaquemine, LA 70764 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - International, 1989. 954]
3. Formosa Plastics Corp USA, Hq, 66 Hanover Rd, Florham Park, NJ 07932, (201) 966-6980; Production site: Baton Rouge, LA 70821 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
4. Fort Howard Corp, Hq, 1919 S Broadway, PO Box 19130, Green Bay, WI 54307-9130, (414) 435-8821; Production sites: Green Bay, WI 54305; Muskogee, OK 74401 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
5. General Electric Co, Hq, 3135 Easton Turnpike, Fairfield, CT 06431, (203) 373-2211; GE Plastics, One Plastics Ave, Pittsfield, MA 01201; Production sites: Burkville, AL 36725; Lexan Ln, Mount Vernon, IN 47620 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
6. Georgia Gulf Corp, Hq, 4800 Perimeter Center Terrace, Suite 595, PO Box 105197, Atlanta, GA 30348, (404) 395-4500; Production site: Plaquemine, LA 70764 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
7. Georgia-Pacific Corp, Hq, 133 Peachtree St NE, Atlanta, GA 30303, (404) 521-4000; Chemical Division; Production sites: 300 Laurel St, Bellingham, WA 98225; Brunswick, GA 31521 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
8. The BFGoodrich Co, Hq, 3925 Embassy Parkway, Akron, OH 44313, (216) 374-2000; BFGoodrich Chemical Group, 6100 Oak Tree Blvd, Cleveland, OH 44131; Production site: Calvert City, KY 42029 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
9. Hanlin Group, Inc, LCP Chemicals Division, Raritan Plaza II, Raritan Center CN3106, Edison, NJ 08817, (201) 225-4840; LCP Chemicals Plants; Production sites: Acme, NC 28456; Brunswick, GA 31520; Moundsville, WV 26041; Orrington, ME 04474; Syracuse, NY 13201 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
10. La Roche Holdings Inc, Hq, La Roche Chemicals Inc, PO Box 1031, Baton Rouge, LA 70821, (504) 355-3341; Production site: Gramercy, LA 70052 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
11. Niachlor Inc, Hq, PO Box 787, Niagara Falls, NY 14304, (716) 278-5100; Production site: Niagara Falls, NY 14302 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
12. Occidental Petroleum Corporation, Hq, 10889 Wilshire Boulevard, Suite 1500, Los Angeles, CA 90024, (213) 879-1700; Subsidiary: Occidental Chemical Corporation, 5005 LBJ Freeway, Dallas, TX 75244, (214) 404-3800; Electrochemicals, Detergent & Specialty Products Division; Electrochemicals Group; Production sites: TX 77536; Delaware City, DE 19706; La Porte, TX 77571; Muscle Shoals, AL 35661; Buffalo Ave at 47th St, Niagara Falls, NY 14303; Tacoma, WA 98401; Taft, LA 70057 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
13. Olin Corporation, Hq, 120 Long Ridge Road, Stamford, CT 06904, (203) 356-2000; Olin Chemicals (address same as Hq); Production sites: Augusta, GA 30903; Lower River Rd, Charleston, TN 37310; McIntosh, AL 36553; Niagara Falls, NY 14302 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
14. Pennwalt Corporation, Hq, Pennwalt Building, Three Parkway, Philadelphia, PA 19102, (215) 587-7000; Chemicals Group; Inorganic Chemical Division; Production sites: 6400 NW Front Ave, Portland, OR 97208; 2901 Taylor Way, Tacoma, WA 98401 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
15. Pioneer Chlor Alkali Co, Hq, 4200 NCNB Center, 700 Louisiana St, Houston, TX 77002; Production sites: Henderson, NV 89015; St Gabriel, LA 70776 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
16. Vulcan Materials Co, Hq, PO Box 7497, Birmingham, AL 35253, (205) 877-3000; Vulcan Chemicals, division, PO Box 7689, Birmingham, AL 35253; Production sites: Geismar, LA 70734; Port Edwards, WI 54469; Wichita, KS 67277 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA:

SRI International, 1989. 955]

17. Weyerhaeuser Co, Hq, Tacoma, WA 98477, (206) 924-2345; Production site: Longview, WA 98632 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 955]
18. PPG Industries, Inc, Hq, One PPG Place, Pittsburgh, PA 15272, (412) 434-3131; Chemicals Group; Production sites: Lake Charles, LA 70601; New Martinsville, Natrium, WV 26155 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]
19. The Proctor and Gamble Co, Hq, 301 E Sixth St, PO Box 599, Cincinnati, OH 45201, (513) 983-5607; Subsidiary: Richardson-Vicks, Inc, One Far Mill Crossing, Shelton, CT 06484, (203) 929-2500; JT Baker, Inc, subsidiary, (201) 859-2151; Production site: 222 Red School Lane, Phillipsburg, NJ 08865 [QC Reviewed] [SRI. 1989 Directory of Chemical Producers - United States of America. Menlo Park, CA: SRI International, 1989. 954]

Other Manufacturing Information:

Caustic soda reacts with all the mineral acids to form the corresponding salts. It also reacts with weak-acid gases, such as hydrogen sulfide, sulfur dioxide, and carbon dioxide. Caustic soda reacts with amphoteric metals and their oxides to form solublesalts. All organic acids also react with sodium hydroxide to form soluble salts. Another common reaction of caustic soda is dehydrochlorination. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:850]

1. In making plastics to dissolve casein; in soln to hydrolyze fats and form soaps; soln precipitate alkaloids (bases) & most metals (as hydroxides) from water soln of their salts; soln used to neutralize acids & make sodium salts; in petroleum refining to remove sulfuric & organic acids; to treat cellulose in making viscose rayon & cellophane; in reclaiming rubber to dissolve out fabric. [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
2. in explosives & dyestuffs; electrolytic extraction of zinc; in tin plating, oxide coating; in laundering, bleaching. [Peer Reviewed] [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 116]
3. Medication (Vet): [QC Reviewed]
4. Medication [QC Reviewed]
5. Vegetable oil refining; regenerating ion exchange resins; organic fusions; peeling of fruits and vegetables in food industry; etching and electroplating [Peer Reviewed] [Hawley, G.G. The Condensed Chemical Dictionary. 10th ed. New York: Van Nostrand Reinhold Co., 1981. 943]
6. Sodium hydroxide is commonly used when moisture and carbon dioxide or hydrogen sulfide must be removed simultaneously. Fused sticks or solutions of the alkali hydroxides are frequently used. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 8:118]
7. When used as a disinfectant/, it kills many common bacterial pathogens such as those causing fowl cholera & pullorum disease. lye can be used to kill domestic animals parasites ... high concn of lye kill the spores of anthrax bacillus but do not kill mycobacterium tuberculosis. lye for disinfectant purposes ... applied as 2% soln in hot or boiling water. for disinfection against anthrax, 5% soln ... used. ... effectiveness of lye soln ... incr by addition of 2.5 lb water-slaked (not air-slaked) LIME. [Peer Reviewed] [Jones, L.M., et al. Veterinary Pharmacology & Therapeutics. 4th ed. Ames: Iowa State University Press, 1977. 866]
8. Chemical & metal processing agent, particularly for aluminum; agent in pulp & paper mfr; textile processing agent; laboratory reagent. [Peer Reviewed] [SRI]
9. A compound containing Na hypochlorite, SiO2 as a thickener, and NaOH as a stain remover is an antimildew and fungicidal agent for household use. [Peer Reviewed] [Jpn Kokai Tokkyo Koho Patent No. 85 32704 02/19/85 (Apex Kansai K K)]
10. Fluorocarbons containing H are treated with alkali or alkaline earth metal bases, and the reaction products are separated from the fluorocarbons not containing H atoms. ... The purified fluorocarbons are useful as blood substitutes. [Peer Reviewed] [Jpn Kokai Tokkyo Koho Patent No. 85112724 06/19/85 (Suntech, Inc)]
11. Elution of activated sludge by sodium hydroxide solution. [Peer Reviewed] [Shioyama M, Toriyama A; Gesuido Kyokaishi 22 (254): 22-8 (1985)]

Consumption Patterns:

1. 51% is consumed in chemical processing and metal processing; 18% is used in paper and pulp manufacture; 13% is used in the petroleum, textile, soap, and food industries; 4% is used in rayon and cellophane production; 8% is used in other applications (1974). [peer Reviewed] [SRI]
2. Organic Chemicals, 30%; Inorganic Chemicals, 20%; Pulp & Paper, 20%; Exports, 10%; Soaps and Detergents, 5%; Petroleum, 5%; Textiles, 4%; Alumina, 3%; Other, 3% (1986). [Peer Reviewed] [chemical profile: Caustic Soda, 1986]
3. Chemical profile: Caustic soda. Pulp and paper, 22%; organic chemicals, 20%; inorganic chemicals, 11%; soaps and detergents, 7%; petroleum, 7%; water treatment, 7%; textiles, 5%; alumina, 4%; other, 9%; exports, 8%. [Peer Reviewed] [Kavaler AR; Chemical Marketing Reporter 235 (25): 50 (1989)]
4. Chemical profile: Caustic soda. Demand: 1988: 12.3 million tons (33,700 tons per day); 1989: 12.5 million tons (34,250 tons per day); 1993 /projected/: 13.4 million tons (36,700 tons per day). (Includes exports, but not imports, which totaled 858,000 tons last year.) [Peer Reviewed] [Kavaler AR; Chemical Marketing Reporter 235 (25): 50 (1989)]

U.S. Production:

1. (1972) 9.27X10+12 GRAMS [Peer Reviewed] [SRI]
2. (1975) 8.7X10+12 GRAMS [Peer Reviewed] [SRI]
3. (1985) 9.24X10+12 g [Peer Reviewed] [Chem Eng News 64(16): 13(1986)]
4. (1990) 24.06 billion lb [Peer Reviewed] [Chem & Engineering News 70 (15): 17 (4/13/92)]
5. (1991) 23.43 billion lb [Peer Reviewed] [Chem & Engineering News 71 (15): 11 (4/12/93)]
6. (1992) 24.50 billion lb [Peer Reviewed] [Chem & Engineering News 72 (15): 13 (4/11/94)]
7. (1993) 25.71 billion lb [Peer Reviewed] [Chem & Engineering News 72 (15): 13 (4/11/94)]

U.S. Imports:

1. (1972) 9.53X10+10 GRAMS [Peer Reviewed] [SRI]
2. (1975) 9.8X10+10 GRAMS [Peer Reviewed] [SRI]
3. (1984) 4.78X10+11 g [Peer Reviewed] [bureau of the census. u.s. imports for consumption and general imports 1984 p.1-351]

U.S. Exports:

1. (1972) 1.1X10+12 GRAMS [Peer Reviewed] [SRI]
2. (1975) 1.00X10+12 GRAMS [Peer Reviewed] [SRI]
3. (1984) 1.14X10+12 g [Peer Reviewed] [bureau of the census. U..S. exports, schedule , 1984 p.2-92]

3.0 CHEMICAL AND PHYSICAL PROPERTIES

Color/Form:

1. Lumps, chips, pellets, sticks [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]

2. White flakes or cake [Peer Reviewed] [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 116]
3. Fused solid with cryst fracture [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
4. Colorless to white solid (flakes, beads, granular form). [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical D.C.: U.S. Government Printing Office, June 1994. 284]

Odor:
1. No odor. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.1 (1981)]
2. Odorless. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

Taste: Detection - the minimum physical intensity detection by a subject where he or she is not required to identify the stimulus but just detect the existence of the stimulus - in water: 8.00x10-3 mol/l. [Peer Reviewed] [ASTM; Compilation of Odor and Taste Threshold Values Data p.150 (1978)]

Boiling Point: 1390 DEG C [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. B-131]

Melting Point: 318.4 DEG C [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. B-131]

Molecular Weight: 40.01 [Peer Reviewed]

Corrosivity: very caustic to aluminum metal in presence of moisture [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]

Critical Temperature and Pressure: SRP4: No relevance [Peer Reviewed]

Density/Specific Gravity: 2.13 @ 25 DEG C [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983.1236]

Dissociation Constants: SRP4: Completely dissociated [Peer Reviewed]

Heat of Combustion: SRP4: Non-combustible [Peer Reviewed]

Heat of Vaporization: SRP4: Negligible (completely ionized) [Peer Reviewed]

Octanol/Water Partition Coefficient: SRP4: Too low to be measured (or possibly virtually 0) [Peer Reviewed]

pH: 0.05% wt/wt soln about 12; 0.5% soln about 13; 5% soln about 14 [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]

Solubilities:
1. 1 g dissolves in 0.9 ml water, 0.3 ml boiling water; 1 g dissolves in 7.2 ml absolute alcohol, 4.2 ml methanol [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
2. sol in glycerol; insol in acetone, ether [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. B-131]

Spectral Properties: index of refraction: 1.3576 [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. B-131]

Surface Tension: At 18 deg C: 74.35 dynes/cm (2.72 wt%), 75.85 dynes/cm (5.66 wt%), 83.05 dynes/cm (16.66 wt%), 96.05 dynes/cm (30.56 wt%), 101.05 dynes/cm (35.90 wt%) [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. F-31]

Vapor Pressure: 1 MM HG @ 739 DEG C [Peer Reviewed] [Sax, N.I. Dangerous Properties of Industrial Materials. 6th ed. New York, NY: Van Nostrand Reinhold, 1984. 2434]

Viscosity: 4.0 cps at 350 deg C. [Peer Reviewed] [General Electric Co; Material Safety Data Sheet MSDS #3 (1984)]

Other Chemical/Physical Properties:
1. 5% soln (wt/wt): density: 1.056, fp: -4 deg c, bp: 102 deg c. 10% soln (wt/wt): density: 1.111, fp: -10 deg c, bp: 110 deg c. 30% soln (wt/wt): density: 1.333, fp: 1 deg c, bp: 115 deg c. 40% soln (wt/wt): density: 1.434, fp: 15 deg c, bp: 125 deg c. 50% soln (wt/wt): density: 1.530, fp: 12 deg c, bp: 140 deg c [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
2. Rapidly absorbs carbon dioxide & water from air [peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
3. Deliquescent [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. B-131]
4. Heat of Formation: -101.723 kcal/mol @ 25 deg C (solid); -49.5 kcal/mol @ 25 deg C (gas); -112.36 kcal/mol @ 25 deg C (in H2O) [Peer Reviewed] [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 67th ed. Boca Raton, FL: CRC Press, Inc., 1986-87.,p. D-84]
5. Heat of transition, alpha to beta, J/G = 103.3. Heat of formation from the elements: Alpha form, kJ/mol = 422.46 C; Beta form, kJ/mol = 426.60 C. Transition temperature, 299.6 C. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 3:748]
6. 70-73 % soln: MP 62 deg C; Den 2.0 at 15.5 deg C. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.1 (1981)]
7. Hygroscopic solid. [Peer Reviewed] [General Electric Co; Material Safety Data Sheet #3 (1984)]

4.0 SAFETY AND HANDLING

EMERGENCY GUIDELINES

DOT Emergency Guidelines:
1. Health: TOXIC, inhalation, ingestion, or skin contact with material may cause severe injury or death. Contact with molten substance may cause severe burns to skin and eyes. Avoid any skin contact. Effects of contact or inhalation may be delayed. Fire mayproduce irritating, corrosive and/or toxic gases. Runoff from fire control or dilution water may be corrosive and/or toxic and cause pollution. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]
2. Fire or explosion: Non-combustible, substance itself does not burn but may decompose upon heating to produce corrosive and/or toxic fumes. Some are oxidizers and may ignite combustibles (wood, paper, oil, clothing, etc.). Contact with metals may evolve flammable hydrogen gas. Containers may explode when heated. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives
3. Public safety: CALL Emergency Response Telephone Number on Shipping Paper first. If Shipping Paper not available or no answer, refer to appropriate telephone number listed on the inside back cover. Isolate spill or leak area immediately for at least 25 to 50 meters (80 to 160 feet) in all directions. Keep unauthorized personnel away. Stay upwind. Keep out of low areas. Ventilate enclosed areas. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium

hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]

4. Protective clothing: Wear positive pressure self-contained breathing apparatus (SCBA). Wear chemical protective clothing which is specifically recommended by the manufacturer. Structural firefighters' protective clothing is recommended for fire situations ONLY, it is not effective in spill situations. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]
5. Evacuation: Spill: See the Table of Initial Isolation and Protective Action Distances for highlighted substances. For non-highlighted substances, increase, in the downwind direction, as necessary, the isolation distance shown under "PUBLIC SAFETY". Fire:If tank, rail car or tank truck is involved in a fire, ISOLATE for 800 meters (1/2 mile) in all directions; also, consider initial evacuation for 800 meters (1/2 mile) in all directions. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]
6. Fire: Small fires: Dry chemical, CO2 or water spray. Large fires: Dry chemical, CO2, alcohol-resistant foam or water spray. Move containers from fire area if you can do it without risk. Dike fire control water for later disposal; do not scatter the material. Fire involving tanks or car/trailer loads: Fight fire from maximum distance or use unmanned hose holders or monitor nozzles. Do not get water inside containers. Cool containers with flooding quantities of water until well after fire is out. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. ALWAYS stay away from the ends of tanks. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]
7. Spill or leak: ELIMINATE all ignition sources (no smoking, flares, sparks or flames in immediate area). Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Stop leak if you can do it without risk. Prevent entry into waterways, sewers, basements or confined areas. Absorb or cover with dry earth, sand or other non-combustible material and transfer to containers. do not get water inside containers. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]
8. First aid: Move victim to fresh air. Call emergency medical care. Apply artificial respiration if victim is not breathing. Do not use mouth-to-mouth method if victim ingested or inhaled the substance; induce artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Administer oxygen if breathing is difficult. Remove and isolate contaminated clothing and shoes. In case of contact with substance, immediately flush skin or eyes with running water for at least 20 minutes. For minor skin contact, avoid spreading material on unaffected skin. Keep victim warm and quiet. Effects of exposure (inhalation, ingestion or skin contact) to substance may be delayed. Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves. /Sodium hydroxide, dry; Sodium hydroxide, bead; Sodium hydroxide, flake/ [QC Reviewed] [U.S. Department of Transportation. 1996 North American Emergency Response Guidebook. A Guidebook for First Responders During the Initial Phase of aHazardous Materials/Dangerous Goods Incident. U.S. Department of Transportation (U.S. DOT) Research and Special Programs Administration, Office of HazardousMaterials Initiatives and Training (DHM-50), Washington, D.C. (1996).,p. G-154]

FLAMMABLE PROPERTIES

Fire Potential:

1. Not combustible but solid form in contact with moisture or water may generate sufficient heat to ignite combustible materials. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 49-83]
2. Crude hydroquinone pumped into sodium hydroxide storage tank by mistake. overflow of tank & evolution of considerable heat resulted. [peer reviewed] [national fire protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 491M-195]

phosphines which may ignite spontaneously in air. addn of caustic to 1,2-dichloroethylene, trichloroethylene, or tetrachloroethane may form monochloroacetylene or dichloroacetylene, both of which are spontaneously flammable in air. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 491M-159]

4. Rags soaked in sodium hydroxide & cinnamaldehyde overheated and ignited when they came into contact in waste bin. accidental contamination of metal scoop with flake sodium hydroxide caused ignition of zinc. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 949]

NFPA Hazard Classification:

1. Health 3, 3 = Materials extremely hazardous to health, but areas may be entered with extreme care. Full protective clothing, including self-contained breathing apparatus, rubber gloves, boots, and bands around legs, arms, and waist should be provided. Noskin surface should be exposed. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association,

1986.,p. 49-83]

2. Flammability 0, 0 = Materials that will not burn. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 49-83]
3. Reactivity 1, 1 = Materials which in themselves are normally stable but which may become unstable at elevated temperatures and pressures or which may react with water with some release of energy but not violently. Caution must be used in approaching the fire and applying water. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 49-83]

Flammable Limits:

SRP4: Non-flammable [Peer Reviewed]

Flash Point:

SRP4: No flashpoint [Peer Reviewed]

Autoignition Temperature:

SRP4: Does not ignite [Peer Reviewed]

FIRE FIGHTING INFORMATION

Fire Fighting Procedures:

1. Wear full protective clothing. flood with water, using care not to splatter or splash this material. [peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 49-83]
2. Extinguish fire using agent suitable for type of surrounding fire. [Peer Reviewed] [Bureau of Explosives; Emergency Handling of Haz Matl in Surface Trans p.469 (1981)]

Toxic Combustion Products:

SRP4: Might form sodium oxides, peroxides and carbonates. [Peer Reviewed]

Other Fire Fighting Hazards:

Sodium hydroxide can melt and flow when heated. [Peer Reviewed] [General Electric Co; Material Safety Data Sheet #3 (1984)]

1. Mixing sodium hydroxide with glacial acetic acid, acetic anhydride, acrolein, chlorohydrin, chlorosulfonic acid, ethylene cyanohydrin, glyoxal, 36% hydrochloric acid, 48.7% hydrofluoric acid, 70% nitric acid, oleum, propiolactone (beta-) or 96% sulfuric acid in closed container caused temp & pressure to incr. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 491M-194]
2. Extremely violent polymerization reaction of acrolein or acrylonitrile results from contact with sodium hydroxide. inadvertent contamination of mixed chloronitrotoluenes by sodium hydroxide in feed line caused exothermic reaction with runaway pressure build-up and eventual explosion of processing apparatus. [peer reviewed] [national fire protection Association. fire protection guide on hazardous materials. 9th ed. boston, ma: national fire protection association, 1986.,p. 491-194]
3. Presence of residue of weak sodium hydroxide solution in a pressure vessel caused maleic anhydride to decompose in runaway explosive reaction. pentol, being fractionated under high vacuum, was accidentally contacted by caustic cleaning solution and violent explosion resulted. [peer reviewed] [national fire protection association. fire protection guide on hazardous materials. 9th ed. boston, ma: national fire protection association, 1986.,p. 491m-195]
4. In mfr of sodium salt of trichlorophenol, sodium hydroxide, methyl alcohol and tetrachlorobenzene were heated. during process, pressure suddenly incr rapidly & explosion occurred. when heated, trichloroethylene and sodium hydroxide form explosive mixtures of dichloroacetylene. [peer reviewed] [national fire protection association. fire protection guide on hazardous materials. 9th ed. boston, ma: national fire protection association, 1986.,p. 491m-195]
5. As benzene extract of allyl benzenesulfonate prepared from allyl alcohol and benzene sulfonyl chloride in presence of aqueous sodium hydroxide under vacuum distillation, residue darkened & exploded. sodium hydroxide reacts with phosphorus pentoxide extremely violently when initiated by local heating. [peer reviewed] [national fire protection association. fire protection guide on hazardous materials. 9th ed. boston, ma: national fire protection association, 1986.,p. 491m-13]
6. Using sodium hydroxide to dry impure tetrahydrofuran, which can contain peroxides, is hazardous. serious explosions can occur. [peer reviewed] [national fire protection association. fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 491M-209]
7. 700 kg of 4-chloro-2-methylphenol, left in contact with concn sodium hydroxide soln for 3 days, decomposed, reaching red heat and evolving fumes which ignited explosively. presence of traces of sodium hydroxide probably caused formation of acetylenic sodium salt of 3-methyl-2-penten-4-yn-1-ol which exploded in metal still. [peer reviewed] [bretherick, l. handbook of butterworths, 1979. 949]
8. Heating mixt of nitrobenzene, flake sodium hydroxide and a little water in autoclave led to explosion. violent explosion occurred during alkaline hydrolysis of tetrachlorobenzene in ethylene glycol @ atmospheric pressure, which was regarded as safe process. [peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 950]
9. During destruction of chemical warfare ammunition, pierced shells containing chloropicrin reacted violently with alcoholic sodium hydroxide. accidental contact of 50% sodium hydroxide soln with residual trichloroethanol in pump caused an explosion. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 950]
10. Chloroform-methanol mixture was put into drum contaminated with sodium hydroxide. vigorous reaction commenced, and drum exploded. addn of sodium hydroxide soln during work-up of reaction mixture of oxime & diborane in tetrahydrofuran is very exothermic, a mild explosion being noted on one occasion. [peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 949]
11. Dry mixtures of sodium tetrahydroborate with sodium hydroxide containing 15-40% of tetrahydroborate liberate hydrogen explosively at 230-270 deg c. explosive reactions occur when zirconium is combined with alkali metal hydroxides. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 950]
12. Interaction of cyanogen azide with 10% alkali forms sodium 5-azidotetrazolide, which explodes violently if isolated. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 950]
13. In sodium hydroxide's reaction with amphoteric metals, hydrogen gas is generated which may form an explosive mixture. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:849]
14. With 1,2,4,5-tetrachlorobenzene: Several serious incidents have been reported about the commercial

preparation of 2,4,5-trichlorophenol by alkaline hydrolysis of methanolic alkali at 125 deg C, reaction went out of control. In one incident the temperature reached 400 deg C after hydrolysis in ethylene glycol solution, the residue from vacuum stripping exploded, probably owing to overheating. In 1968, a violent explosion occurred during hydrolysis in ethylene glycol at atmosphere pressure, which had been regarded as a safe process. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 590]

HAZARDOUS REACTIONS

Reactivities and Incompatibilities:

1. Contact with some metals can generate hydrogen gas. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 49-83]
   acid. [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
3. Crude hydroquinone was pumped into sodium hydroxide storage tank by mistake. the hydroquinone liquor at 85 deg c decomp rapidly in the presence of the sodium hydroxide resulting in overflow of tank & evolution of considerable amount of heat. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 491M-195]
4. Much heat is evolved when the solid material is dissolved in water. Therefore, cold water and caution must be used for this process. [Peer Reviewed] [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 116]
5. Caustic solutions generate heat when further diluted with water. With concentrations of 40% or greater, the heat generated can raise the temperature above the boiling point, resulting in sporadic, dangerous eruptions of the solution. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:848]
6. With aluminum, arsenic trioxide, sodium, and arsenate: An aluminum ladder was used (instead of the usual wooden one) to gain access to a tank containing the alkaline arsenical mixture. Hydrogen produced by alkaline reaction on the ladder generated arsine, which poisoned the three workers involved. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 207]
7. With bromine: A bucket containing 25% sodium hydroxide solution was used to catch and neutralize bromine dripping from a leak. Lack of stirring allowed a layer of unreacted bromine to form below the alkali. Many hours later, a violent eruption occurred when the layers were disturbed during disposal operations. Continuous stirring is essential to prevent stratification of slowly reacting, mutually insoluble, liquids. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 267]
8. With octanol and diborane: Addition of sodium hydroxide solution during work-up of a reaction mixture of oxime and diborane in tetrahydrofuran is very exothermic, a mild explosion being noted on one occasion. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 632]
9. With 4-methyl-2-nitrophenol, sodium carbonate, and methanol: Failure to agitate a large-scale mixture of the reagents caused an eruption due to exothermic action when mixing occurred. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 632]
10. With zinc: Accidental contamination of a metal scoop with flake sodium hydroxide, prior to its use with zinc dust, caused ignition of the latter. A stiff paste prepared from zinc dust and 10% sodium hydroxide solution attains a temperature above 100 deg C after exposure to air for 15 min. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston
11. With zinc and 4-methyl-2-nitrophenol: In preparation of 2,2-dimethoxyazoxybenzene, solvent ethanol was distilled out of the mixture of o-nitroanisole, zinc and sodium hydroxide, before reaction was complete. The exothermic reaction continued unmoderated,and finally exploded. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 633]
12. With 2,2,2-trichloroethanol: Accidental contact of 50% sodium hydroxide solution with residual trichloroethanol in a pump caused an explosion. This was confirmed in laboratory experiments. Chlorohydroxyacetylene, the isomeric chloroketene or chlorooxirene, may have been formed by elimination of hydrogen chloride. [Peer Reviewed] [Bretherick, L. Handbook of Reactive Chemical Hazards. 2nd ed. Boston MA: Butterworths, 1979. 361]
13. Water; acids; flammable liquids, organic halogens; metals such as aluminum, tin, & zinc; nitromethane [Note: Corrosive to metals]. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

Decomposition:

NaOH decomposes to sodium oxide and water. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.4 (1981)]

Polymerization:

SRP4: Not polymerized [Peer Reviewed]

Other Hazardous Reactions:

Corrosion is a problem at temperatures above 60 degrees C, therefore, the use of steel for caustic-handling is not recommended at elevated temperatures. Stress cracking may also occur when caustic soda solution concentrations exceed 20% at temperatures in excess of 60 degrees C. [Peer Reviewed] Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978] -1984.,p. 1:859]

WARNING PROPERTIES

Odor Threshold:

SRP4: None [Peer Reviewed]

Skin, Eye and Respiratory Irritations:

1. Liquid or solid sodium hydroxide is a severe skin irritant. It causes second and third degree burns on short contact and is very injurious to the eyes. [Peer Reviewed] [U.S. Coast Guard, Department of Transportation. CHRIS - Hazardous Chemical Data. Volume II. Washington, D.C.: U.S. Government Printing Office, 1984-5.]
2. HAZARD WARNING: The irritating nature of the aerosol on the mucous membranes is presumed to be adequate warning to maintain air concn at tolerable levels. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.74 (Date)]

PREVENTIVE MEASURES

Protective Equipment and Clothing:

1. Hazards from spills and leaks should be minimized by an adequate supply of water for washing-down. ... Adequate ventilation should be provided in areas where caustic ... soda mist or dust is present. ... For the protection of the eyes, safety goggles should be worn, as well as face shields, if complete face protection is necessary.
   at any location where eye and/or skin contact can occur.

Protection against mist or dust of this compound can be provided by filter or dust-type respiratory protective equipment. ... Safety shoes ... are recommended. [Peer Reviewed] [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 116]

2. Respirator selection: 100 mg/cu m: a) High-efficiency particulate respirator with a full facepiece, b) Supplied air respirator with a full facepiece, helmet, or hood. , c) Self-contained breathing apparatus with a full facepiece. 200 mg/cu m: a) Powered air-purifying respirator with a high-efficiency filter with a full facepiece, or b) Type C SA with a full facepiece operated in pressure-demand or other positive pressure mode or with a full facepiece, helmet, or hood operated in continuous- flow mode. . Escape: a) Dust and mist respirator, except single-use respirators with full facepiece, or b) Self-contained breathing apparatus with a full facepiece. [Peer Reviewed] [NIOSH; Pocket Guide to Chemical Hazards p.167 (1981) DHEW (NIOSH) Pub No. 78-210]
3. Sodium hydroxide: Chemical protective clothing composed of natural rubber, neoprene, nitrile, or styrene/butadiene (SBR)-coated fabric is highly recommended, having break through times greater than one hour. Butyl rubber, neoprene and SBR, polyethylene, chlorinated polyurethane, or polyvinyl alcohol may be used but data suggests break through times of approximately an hour or more. [Peer Reviewed] [ACGIH; Guidelines Select of Chem Protect Clothing Volume #1 Field Guide p.67 (1983)]
4. Sodium hydroxide, 30-70%: Chemical protective clothing composed of natural rubber, neoprene, nitrile, or polyvinyl chloride (PVC) is highly recommended, having break through times greater than one hour. Butyl rubber, nitrile/PVC, polyethylene, chlorinated polyethylene, or styrene/butadiene coated approximately an hour or more. Some data for polyvinyl alcohol (usually from immersion tests) suggest break through times greater than one hour are not likely. [Peer Reviewed] [ACGIH; Guidelines Select of Chem Protect Clothing Volume #1 Field Guide p.67 (1983)]
5. Wear appropriate personal protective clothing to prevent skin contact. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]
6. Wear appropriate eye protection to prevent eye contact. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]
7. Eyewash fountains should be provided in areas where there is any possbility that workers could be exposed to the substance; this is irrespective of the recommendation involving the wearing of eye protection. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

provided within the immediate work area for emergency use where there is a possibility of exposure. [Note: It is intended that these facilities should provide a sufficient quantity or flow of water to quickly remove the substance from any body areas likely to be exposed. The actual determination of what constitutes an adequate quick drench facility depends on the specific circumstances. In certain instances, a deluge shower should be readily available, whereas in others, the availability of water from a sink or hose could be considered adequate.] [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

9. Recommendations for respirator selection. Max concn for use: 10 mg/cu m. Respirator Class(es): Any supplied-air respirator operated in a continuous flow mode. Eye protection needed. Any air-purifying, full-facepiece respirator with a high-efficiency particulate filter. Any powered, air-purifying respirator with a dust and mist filter. Eye protection needed. Any self-contained breathing apparatus with a full facepiece. Any supplied-air respirator with a full facepiece. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]
10. Recommendations for respirator selection. Condition: Emergency or planned entry into unknown concn or IDLH conditions: Respirator Class(es): Any self-contained breathing apparatus that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode. Any supplied-air respirator that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive-pressure mode. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]
11. Recommendations for respirator selection. Condition: Escape from suddenly occurring respiratory hazards: Respirator Class(es): Any air-purifying, full-facepiece respirator with a high-efficiency particulate filter. Any appropriate escape-type, self-contained breathing apparatus. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

Other Preventative Measures:

1. Nickel is the preferred metal for handling caustic soda at all concentrations and temperatures. However, the high cost and limited availability of nickel precludes its use for most applications. Mild steel is adequate for almost all caustic-handling applications. Plastics and plastic-lined steel are now available as construction materials. Fiberglass reinforced plastic tanks of Derakane vinyl ester resin are suitable for many applications. Polypropane is commonly used for lining pipe for protection against mechanical damage. [Peer Reviewed] Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:858]
2. Any dilutions of caustic from concentrations greater than 25% should be done cautiously. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:849]
3. Do not handle broken packages without protective equipment. [Peer Reviewed] [Bureau of Explosives; Emergency Handling of Haz Matl in Surface Trans p.469 (1981)]
4. Contact lenses should not be worn when working with this chemical. [Peer Reviewed] [NIOSH. Pocket Guide to Chemical Hazards. 2nd Printing. DHHS (NIOSH) Publ. No. 85-114. Washington, D.C.: U.S. Dept. of Health and Human Services, NIOSH/Supt.of Documents, GPO, February 1987. 209]

5. SRP: The scientific literature for the use of contact lenses in industry is conflicting. The benefit or detrimental effects of wearing contact lenses depend not only upon the substance, but also on factors including the form of the substance, characteristics and duration of the exposure, the uses of other eye protection equipment, and the hygiene of the lenses. However, there may be individual substances whose irritating or corrosive properties are such that the wearing of contact lenses would be harmfulto the eye. In those specific cases, contact lenses should not be worn. In any event, the usual eye protection equipment should be worn even when contact lenses are in place. [Peer Reviewed]
6. A survey of household materials involved in serious poisonings in children aged under 5 yr was conducted to identify substances that would best be packaged with safety closures. The substances identified as causing the most serious side effects and for which safety closures may be indicated included ... sodium hydroxide (caustic soda). [Peer Reviewed] [Craft AW et al; Br Med J 288(Mar 3): 682 (1984)]
7. The worker should immediately wash the skin when it becomes contaminated. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]
8. Work clothing that becomes wet or significantly contaminated should be removed or replaced. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]
9. Workers whose clothing may have become contaminated should change into uncontaminated clothing before leaving the work premises. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

OTHER SAFETY AND HANDLING

Stability/Shelf Life:

containers of lye must be tightly closed to prevent conversion to sodium carbonate by carbon dioxide of air. [Peer Reviewed] [Jones, L.M., et al. Veterinary Pharmacology & Therapeutics. 4th ed. Ames: Iowa State University Press, 1977. 867]

Shipment Methods and Regulations:

material for transportation in commerce unless that person is registered in conformance ... and the hazardous material is properly classed, described, packaged, marked, labeled, and in condition for shipment as required or authorized by ... /the hazardous materials regulations (49 CFR 171-177)./ [QC Reviewed] [49 CFR 171.2 (7/1/96)]

2. The International Air Transport Association (IATA) Dangerous Goods Regulations are published by the IATA Dangerous Goods Board pursuant to IATA Resolutions 618 and 619 and constitute a manual of industry carrier regulations to be followed by all IATA Member airlines when transporting hazardous materials. [QC Reviewed] [IATA. Dangerous Goods Regulations. 38th ed. Montreal, Canada and Geneva, Switzerland: International Air Transport Association, Dangerous Goods Board, January, 1997. 214]
3. The International Maritime Dangerous Goods Code lays down basic principles for transporting hazardous chemicals. Detailed recommendations for individual substances and a number of recommendations for good practice are included in the classes dealing withsuch substances. A general index of technical names has also been compiled. This index should always be consulted when attempting to locate the appropriate procedures to be used when shipping any substance or article. [QC Reviewed] [IMDG; International Maritime Dangerous Goods Code; International Maritime Organization p.8215 (1988)]

Storage Conditions:

1. Containers should be stored in rooms with trapped floor drains towards which floors should be slanted. where floor drains are not provided, curbs or drained gutter, covered with ... grill, should be constructed @ door openings. [Peer Reviewed] [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 116]
2. Volumetric sodium hydroxide soln used in laboratory must be protected from air to avoid formation of carbonate. [Peer Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236]
3. store in dry place ... separate from acids, metals, explosives, organic peroxides and easily ignitable materials. [Peer Reviewed] [National Fire Protection Association. Fire Protection Guide on Hazardous Materials. 9th ed. Boston, MA: National Fire Protection Association, 1986.,p. 49-83]

Cleanup Methods:

1. On/in soil (solid): Construct barriers to convert or divert to impervious surface. Promptly shovel into steel containers. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.2 (1981)]
2. Soil, Liquid: Absorb small amounts of spill with sand, vermiculite or other inert absorbant material; Shovel into steel containers. May also remove material with vacuum equipment. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.2 (1981)]
3. Land spill of sodium hydroxide: Dig a pit, pond, lagoon, or holding area to contain liquid or solid material. Dike surface flow using soil, sand bags, foamed polyurethane, or foamed concrete. Absorb bulk liquid with fly ash of cement powder. Neutralize with vinegar or other dilute acid; Water spill: Neutralize with dilute acid or mist to knock down vapors. /Liquid/ [Peer Reviewed] [Bureau of Explosives; Emergency Handling of Haz Matl in Surface Trans p.469 (1981)]
4. Land spill of sodium hydroxide: Dig a pit, pond, lagoon, holding area to contain liquid or solid material. Cover solids with a plastic sheet to prevent dissolving in rain or fire fighting water; Water spill: Neutralize with dilute acid to remove strong acid. /Solid/ [Peer Reviewed] [Bureau of Explosives; Emergency Handling of Haz Matl in Surface Trans p.469 (1981)]
5. Perlite and Cellosive WP3H (hydroxyethyl cellulose) have been tested and recommended for vapor suppression and/or containment of 50% sodium hydroxide solutions. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.91 (1981)]

Disposal Methods:

1. SRP: At the time of review, criteria for land treatment or burial (sanitary landfill) disposal practices are subject to significant revision. Prior to implementing land disposal of waste residue (including waste sludge), consult with environmental regulatory agencies for guidance on acceptable disposal practices. [Peer Reviewed]
2. Following neutralization either at the spill site or at a waste management facility, the resultant sludge can be disposed of in a secure landfill. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.92 (1981)]
3. Put into large vessel containing water. Neutralize with HCL /hydrochloric acid/. Discharge into the sewer with sufficient water. Recommendable methods: Neutralization & discharge to sewer. Peer review: Dilute greatly (< pH 9) before discharge. (Peer-review conclusions of an IRPTC

expert consultation (May 1985)) [Peer Reviewed] [United Nations. Treatment and Disposal Methods for Waste Chemicals (IRPTC File). Data Profile Series No. 5. Geneva, Switzerland: United Nations Environmental Programme, Dec. 1985. 280]

5.0 TOXICITY/BIOMEDICAL EFFECTS

SUMMARY

Antidote and Emergency Treatment:

1. When caustic soda comes into contact with the skin it does not usually cause immediate pain, but it does start to cause immediate damage. It fails to coagulate protein which would serve to prevent further penetration. Thus, upon contact with eyes, washing with water must be started within 10 seconds and continued for at least 15 minutes to prevent permanent injury. Following contact with skin, washing with water must be started immediately to prevent corrosive chemical burns. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:861]
2. SRP: Experimental/ Alkali-burned corneas were treated with 2% ascorbic acid. Topical applications and subconjunctival injections were given for 32 days. Treatment with ascorbic acid significantly decreased the incidence of corneal ulcerations and perforations compared to the control group that received the vehicle. These results confirm previous studies and strongly suggest that ascorbic acid presents a potential for use in the Pouliguen Y; Ophthalmic Res 16 (4): 185-89 (1984)]
3. SRP: Experimental/ ... The effect of cimetidine administered intraperitoneally in doses of 2.5, 10, and 50 mg/kg, on: (1) The gastric acid secretory responses in 1 and 4 hr pylorous-ligated rats, and (2) the rat gastric mucosal lesions induced by intragastric administration of ... 0.2 M NaOH ... is discussed. It was found that ... all doses of cimetidine significantly prevented the gastric lesion development induced by different necrotizing agents ... (0.2 M NaOH). The cytoprotecting dose of cimetidine was of 2.5 mg/kg. The duration of cimetidine-induced cytoprotection was 1 hr long before the administration of the necrotizing agent. These results suggest a real cimetidine-induced gastric cytoprotection. [Peer Reviewed] [Mor'on F et al; Arch Int Pharmacodyn Ther 265 (2): 309-19 (1983)]
4. SRP: Experimental/ An experimental study on morniflumate, the beta-morpholinoethyl ester of niflumic acid, was undertaken in the rat to test its gastroprotective and "cytoprotective" properties and to assess its effects on gastric secretion and on the prostaglandin contents in the stomach wall. Morniflumate induced intense anad usually dose-dependent inhibition of the ... gastric necrotic lesions caused by ... NaOH 0.2 mol/l. ... Morniflumate also exerted marked inhibition of gastric acid secretion bothin normal and in pylorus-ligated rats. The compound raised the concn of "cytoprotective" prostaglandins in the glandular portion of the stomach but did not reverse the synthesis-block effect of the ulcerogenic nonsteroidal anti-inflammatory drugs whose gastric effects it inhibited. [Peer Reviewed] [Schiantarelli P et al; Arzneimittelforsch 34 (8): 885-90 (1984)]
5. SRP: Experimental/ The gastric damaging effects of necrotizing concn of NaOH were strongly reduced by paracetamol. ... Paracetamol might be protective by stimulating the biosynthesis of prostaglandins in the stomach wall. [Peer Reviewed] [Van Kolfschoten AA et al; Toxicol Appl Pharmacol 69 (1): 37-42 (1983]
6. Protection against damage from locally applied sodium hydroxide has been shown to be possible under exptl conditions in rabbit corneas by injection of animal's serum into cornea to incr its local buffering capacity. [Peer Reviewed] [Grant, W. M. Toxicology of the Eye. 2nd ed. Springfield, Illinois: Charles C. Thomas, 1974. 931]

Medical Surveillance:

The skin, eyes, and respiratory tract should receive special attention in any placement or periodic examination. NIOSH recommends that workers subject to sodium hydroxide exposure have comprehensive preplacement medical examinations. Medical examinationsshall be made available promptly to all workers with signs or symptoms of skin, eye, or upper respiratory tract irritation resulting from exposure to sodium hydoxide. [Peer Reviewed] [Sittig M; Handbook of Toxic and Hazardous Chemicals p.606 (1981)]

TOXICITY EXCERPTS

Human Toxicity Excerpts:

1. Damage of cornea, conjunctiva, & episcleral tissues is usual, but damage of intraocular structures is relatively rare. in one unusual case localized burn of retina ... noted ... [peer reviewed] [grant, w. m. charles c. thomas, 1974. 930]
2. Dusts /and liquid aerosols/ ... irritating to upper respiratory system. ... prolonged exposure to high concn may cause ... ulceration of nasal passages ... [Peer Reviewed] [American Conference of Governmental Industrial Hygienists, Inc. Documentation of the Threshold Limit Values, 4th ed., 1980. Cincinnati, Ohio: American Conference ofGovernmmental Industrial Hygienists, Inc., 1980. 370]
3. Intact /corneal/ epithelium presents ... barrier to penetration of ions ... until ... rendered permeable by injury. ... at ph 10 no incr in permeability of /sodium hydroxide/; @ ph 10.5 ... no incr for @ least an hr ...; ph 10.8 ... resistance to half original ... in about 30 min ...; @ ph 11 to ... 12 BREAKDOWN OF ... BARRIER ... MORE RAPID ... . [Peer Reviewed] [Grant, W. M. Toxicology of the Eye. 2nd ed. Springfield, Illinois: Charles C. Thomas, 1974. 97]
4. In biopsy specimens from the forearm volar surface sodium hydroxide produced intracellular edema & increased numbers of lamellar granules on the outer surface of the uppermost granular cell layer. [peer reviewed] [nagao s et al; acta dermato-venereol 52 (1): 11-23 (1972)]
5. Symptomatology: 1. ingestion of lye causes swallowing to become painful & difficult almost immediately. burning pain extends down esophagus to stomach. contaminated areas of lips, chin, tongue, & pharynx become edematous & covered with exudate. profuse salivation. because of pharyngeal and esophageal edema, it may become impossible after a few hours to swallow even saliva. mucous membranes are at first white but later brown, edematous, gelatinous, and necrotic. 2. vomitus is thick and slimy due to mucus;later it may contain blood and shreds of mucous membrane. /LYE/ [Peer Reviewed] [Gosselin, R.E., R.P. Smith, H.C. Hodge. Clinical Toxicology of Commercial Products. 5th ed. Baltimore: Williams and Wilkins, 1984.,p. II-66]
6. Symptomatology /after ingestion/: 3. pulse ... rapid & feeble; respirations ... fast & shallow; skin is cold & clammy; collapse ensues. 4. death due to shock, asphyxia from glottic edema or intercurrent infection (pneumonia) commonly occurs on 2nd or ...3rd day. aspiration pneumonitis ... described. 5. convalescence may be interrupted during first week by esophageal perforation or perhaps even gastric perforation. mediastinitis may present as severe substernal pain with fever. 6. if complications do notappear, liquid and soft food can be swallowed with comparative ease within 5 to 7 days. within 5 to 7 days. ... in most cases this absence of

distress marks latent period and that esophageal strictures will develop within weeks or months unless effectivetreatment is instituted. /LYE/ [Peer Reviewed] [Gosselin, R.E., R.P. Smith, H.C. Hodge. Clinical Toxicology of Commercial Products. 5th ed. Baltimore: Williams and Wilkins, 1984.,p. II-66]

7. Contact with the eyes causes disintegration and sloughing of conjunctival and corneal epithelium, corneal opacification, marked edema, and ulceration; After 7 to 13 days either gradual recovery begins, or there is progression of ulceration and corneal symblepharon (adhesion of the lid to the eyeball) with overgrowth of the cornea by a vascularized membrane, progressive or recurrent corneal ulceration, and permanent corneal opacification. [Peer Reviewed] [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2]
8. On the skin, solutions of about 25 to 50% cause the sensation of irritation within about 3 minutes; With solutions of 4% this does not occur until after several hours. If not removed from the skin, severe burns with deep ulceration will occur; Exposure to the dust or mist may cause multiple small burns, with temporary loss of hair. [Peer Reviewed] [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2]
9. Cases of squamous cell carcinoma of the esophagus have occurred with latent periods of 12 to 42 years after ingestion; These cancers may have been sequelae of tissue destruction and possibly scar formation rather than from a direct carcinogenic action ofsodium hydroxide itself. [Peer Reviewed] [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2]
10. Skin contact; Levels of toxic effect: (1) There is not necessarily an immediate sensation of irritation or pain. (2) Primary irritant dermatitis. (3) Multiple small burns with temporary loss of hair. (4) Deterioration of keratin material. (5) Intracellular edema. (6) Severe burns, corrosion of tissue, and deep ulcerations. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.81 (1981)]
11. Eye contact; Levels of toxic effect: (1) Irritation. (2) Conjunctivitis, corneal burns. (3) Photophobia. (4) Disintegration and sloughing of conjunctival and corneal epithelium. (5) Corneal edema, ulceration, and opacefication. (6) Symlbepharon. (7) Overgrowth of the cornea by a vascularized membrane. (8) Permanent corneal opacification. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.81 (1981)]
12. A 28-year old member of an oil-well drilling crew sustained extensive splash burns of the left eye from NaOH and received emergency care from a general physician prior to being hospitalized. At the hospital, initial examination showed vision limited to light perception, corneal clouding to such an extent that iris markings were not discernable, necrosis of most of the bulbar conjunctiva, some sloughing in the masal area of the cornea, blanched and necrotic cul-de-sac, and some involvement of the lids andadjacent skin. The treatment of the patient at the hospital consisted of daily debridement of necrotic areas, local atropine, antibiotics, steroids, systematic ACTH, vitamins, produced some improvement with time so that usual, late sequelae such as vascular invasion and symblepharon did not occur, and the cornea cleared sufficiently within 7 weeks that vision returned to near normal. [Peer Reviewed] [Horowitz ID; Am J Ophthalmol 61: 340-341 (1966) as cited in NIOSH; Criteria Document: Sodium Hydroxide p.29 (1975) DHEW Pub. NIOSH 76-105]
13. A micropolarographic system was used as a quantitative means of monitoring the healing course of corneal epithelium following a 10 second exposure to 0.20 N sodium hydroxide solution. Concn of less than that strength produced inconsistent flux baselines due to incomplete damage to the epithelium, while higher concn commonly involved the stroma as well. Virtually complete epithelial destruction (down to the basement membrane) and reproducible flux baselines were found, however, with the 0.20 N induced lesion studied in detail here. The healing course following those exposures consisted of two well defined phases: an initial period of hypoflux lasting some 48 hr before rising back up to the pre-lesion baseline, followed then by a period of hyperflux lasting about 7 days before decreasing once again down to the pre-lesion baseline. [Peer Reviewed] [Mauger TF, Hill RM; Acta Ophthalmol (Copenh) 63 (3): 264-7 (1985)]
14. An in-plant case-control study of 26 renal cancer deaths was conducted to determine whether an occupational exposure may be related to an apparent increase in mortality from this disease observed among a sample of employees at a multiple process chemicalproduction facility. None was found that explained the excess. Elevated odds ratios were identified for employment in the cell maintenance area of chlorine production and with those presumptive exposures considered to occur in this job, asbestos and caustic, but not chlorine. While an association between renal cancer and asbestos has been previously reported, an association with caustic, per se, is not consistent with prior observations made by others. ... Both the increased and decreased risks, while statistically significant, are based on small numbers of exposed subjects and may be spurious owing to the problem of multiple comparisons. [Peer Reviewed] [Bond GG et al; Am J Ind Med 7 (2): 123-39 (1985)]
15. Ocular blood flow was determined using radioactive S 85 microspheres after an alkali NaOH burn to the eye. With 20 mul NaOH, blood flow was significantly increased in the iris, ciliary processes, and choroid from 2 through 4 hr. This correlated well withthe sustained increase in intraocular pressure (IOP) seen after a 20-mul burn. A 50-mul burn increased blood flow 1 hr, but it returned toward normal levels beyond 2 hr. ... There appeared to be a meaningful correlation between IOP changes and altered blood flow following ocular alkali burns. The blood flow changes paralleled those occurring after the topical application of prostaglandins and supported the concept that ocular blood flow dynamics are mediated by prostaglandins. [Peer Reviewed] [Green K et al; Arch Ophthalmol (Chicago) 103 (4): 569-71 (1985)]
16. 200 patients with suspected caustic ingestation were examined. No steroids were administered to the patients involved. Lesions in the esophagus were found in 93 had nasogastric tubes inserted immediately. Of these patients, 2 developed esophageal strictures, but subsequent dilatation was successful. No stricture formation was observed in the group of patients with noncircular lesions. This low percentage of stricture

formation is due to the use of nasogastric tubes. Since neither the presence nor the severity of esophageal burns is predictable, an endoscopy should be performed in all suspected cases. In the absence of severe pharyngeal lesions, the use of a flexible fiberoptic endoscope is preferablebecause it also allows examination of the stomach and proximal part of the duodenum. [Peer Reviewed] [Wijburg FA et al; Ann Otol Rhinol Laryngol 94 (4 Part 1): 337-41 (1985)]

17.Has a marked corrosive action upon all body tissue. Dangerous. [Peer Reviewed] [Sax, N.I. Dangerous Properties of Industrial Materials. 6th ed. New York, NY: Van Nostrand Reinhold, 1984. 2435]

18. In terms of total dose caustic alkalis have killed adult humans who ingested less than 10 g. [Peer Reviewed] [Gosselin, R.E., R.P. Smith, H.C. Hodge. Clinical Toxicology of Commercial Products. 5th ed. Baltimore: Williams and Wilkins, 1984.,p. III-246]

19. Corrosive to all tissues upon contact, ingestion or inhalation. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.1 (1981)]

20. During the tissue regeneration process in the alimentary tract, some squamous cell carcinomas have developed. [Peer Reviewed] [Sittig M; Handbook of Toxic and Hazardous Chemicals p.606 (1981)]

21. The irritating nature of the aerosol on the mucous membranes is presumed to be adequate warning to maintain air concn at tolerable levels. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.74 (Date)]

22. Various climates and skin textures may influence the seriousness of skin injury. [Peer Reviewed] [NIOSH; Criteria Document: Sodium Hydroxide p.32 (1975) DHEW Pub. NIOSH 76-105]

23. There is a latent period between contact of NaOH with the skin and the sensation of irritation. [Peer Reviewed] [NIOSH; Criteria Document: Sodium Hydroxide p.62 (1975) DHEW Pub. NIOSH 76-105]

Non-Human Toxicity Excerpts:

1. Ingestion of any caustic agent ... /causes/ corrosion of mucous membranes of upper part of digestive tract. vomiting, colic, & purgation may follow, with prostration & death from acute shock. ... corrosion of mouth. /caustic agents/ [Peer Reviewed] [Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall, 1981. 25]
2. Species differences in response to contamination of eye demonstrated in comparison of action of 1% soln on rabbits & monkeys, showing much faster recovery by monkey eyes. [Peer Reviewed] [Grant, W. M. Toxicology of the Eye. 2nd ed. Springfield, Illinois: Charles C. Thomas, 1974. 931]
3. Admin caustic soda in a barium meal to dogs & followed the gastrointestinal progress of this fluid mass by fluoroscopy. it followed the magenstrasse to the corrosive at that site. autopsy confirmed that this was the locus of the greatest necrotic damage. subsequent investigations have confirmed that lye admin to erect dog produces hemorrhagic gastritis ... [Peer Reviewed] [Gosselin, R.E., R.P. Smith, H.C. Hodge. Clinical Toxicology of Commercial Products. 5th ed. Baltimore: Williams and Wilkins, 1984.,p. III-246]
4. Within the first min after topical application of sodium hydroxide to guinea pigs, blockade of resp enzymes in dermal cells and swelling of dermal collagenic fibers occurred. [peer reviewed] [panchenko ki; vestn dermatol venerol (2): 28-32 (1977)]
5. Chronic exposure of guppies to sodium hydroxide (greater than or equal to 25 mg/l) decr their survival rate and wt gain, and caused either late or premature sexual maturity resulting in decr fertility. [peer reviewed] [rustamova sa; gidrobiol zh 13 (3): 96-9 (1977)]
6. Rats admin 0.2 ml of 0.1 n sodium hydroxide demonstrated immediate necrosis of dermal tissue. marked reductions in glycogen & total lipid were observed. [peer reviewed] [sanyal s et al; indian j med res 63 (11): 1609-19 (1975)]
7. Concn 20-100 mg/l in water kills some species of aquatic wildlife due to increase in pH. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.1 (1981)]
8. The clipped backs of anesthetized A/He and C57 black adult mice weighing 25-35 g were painted with 50% NAOH on a 3 sq cm area. The animals were treated in various manners .... All mice, except those treated immediately /by irrigating the area to prevent toxic effects of sodium hydroxide/ developed rapidly progressive burn in both extent and depth. The severity of the burns increased with delay in treatment. Two hr after application, 2 untreated mice were dead, and after 24 hr a hard, dark brown eschar had developed in both the untreated group and in the group treated 2 hr after the burn. The group irrigated 30 min after the burn showed a rather limited, spotty, superficial burns compared to the burns of untreated animals. Groups irrigated 1 and 2 hr after being burned developed progressive changes in both the depth and extent of their burns, with severity increasing with time of treatment. The group irrigated 2 hr after NaOH application exhibited changes similar to those of the untreated group, but with less local edema in the area peripheral to the burned zone. Biopsy sections obtained 24 hr after application exhibited some edema and cellular infiltration in the mice given immediate irrigation. In biopsy of untreated mice, severe necrosis was found. [Peer Reviewed] [Bromberg BE et al; Plast Reconstr Surg 35: 85-95 (1965) as cited in NIOSH; Criteria Document: Sodium Hydroxide p.39 (1975) DHEW Pub. NIOSH 76-105]
9. 0.05 ml of 0.123N (0.5%), 0.5N (2.0%), and 2.0N (8.0%) NaOH were applied into the eyes of 3 anesthetized albino rabbits. The intraocular pressure increased 5, 18, and 37 mm Hg, respectively, within 2.5 min. [Peer Reviewed] [Chiang TS et al; Invest Ophthamol 10: 270-273 (1971) as cited in NIOSH; Criteria Document: Sodium Hydroxide p.43 (1975) DHEW Pub. NIOSH 76-105]
10. 27 white rats died within a month, mostly from aerosol of unknown airborne concn generated from an aqueous 40% NaOH solution. When exposed to an aerosol generated from aqueous 20% NaOH solution, the septa were emphymatously (sic) dilated and cracked, the bronchi were dilated and their epithelial cover was thin and frequently desquamated, and a light roundcell infiltration of the submucus membrane tissue occurred. Other rats were exposed to aerosols generated from 10% and 5% solutions of NaOH. In the group exposed to aerosols from 10% NaOH, little change occurred. In the group exposed to aerosols from 5% NaOH, rats had dilation of the bronchi and a slight degeneration of the mucus membrane and thickenedstrata of the lymphadenoid tissue surrounding the bronchi. [Peer Reviewed] [Vyskocil J et al; Scripta Med 40: 25-29 (1966) as cited in NIOSH; Criteria Document: Sodium Hydroxide p.46 (1975) DHEW Pub. NIOSH 76-105]
11. Damage to the gastric fundic mucosa was produced in rats by intragastric administration of 1 ml 0.2 M NaOH, ... a control group received 1 ml saline solution. The animals were killed 1 hr later, and the number and severity of

ulcers (lesions) noted. The gastric fundic mucosa were excised and frozen, and assayed enzymatically for adenosine triphosphate (ATP), adenosine diphosphate (ADP), adenosine monophosphate (AMP) and lactate, while the tissue level of cyclic adenosine monophosphate (cAMP) was estimated by radioimmunoassay. It was found that: (1) The number and severity of gastric lesions (ulcers) increased significantly in all groups treated by the necrotizing agent; (2) The extent of ATP breakdown into ADP increased significantly, while the ATP transformation into cAMP by adenylate cyclase, and of cAMP into AMP by phosphodiesterase, decreased. ... It was concluded that: (1) The mucosal damage develops as a consequence of a very active metabolic adaption of the rat gastric fundic mucosa, notably the significantly increased ATP transformation into ADP, which is not the consequence of hypoxaemia; (2) The feed-back mechanism system between the membrane-bound ATP-dependent energy systems is broken as the mucosal damage develops, the main changes being significantly decreased ATP transformation into cAMP, and significant alterations by neural, hormonal, and pharmacological influences in the membrane-bound ATP-dependent energy systems. [Peer Reviewed] [Mor'on F et al; Int J Tissue React 5(4): 357-362 (1983)]

12. Animal tissue respiration is enhanced by topically applying a NaOH solution followed by an HCl solution. Solution A was prepared by dissolving 5 g NaOH in 200 ml H2O, and adding 10 ml glycerin. Solution B was prepared by adding 1 ml HCl gradually to 10 ml H2O, followed by 2 ml glycerin. Solution B was diluted to 1 l with H2O immediately before use. To stimulate systemic tissue respiration, solution A was applied to the skin, and about 1 min later solution B was applied repeatedly to the same locationfor approximately 10-30 min. [Peer Reviewed] [Jpn Kokai Tokkyo Koho PATENT NO 85 01131 01/07/85 (Okabe, Genji)]
13. The efficacy of various disinfectants was tested against cultures from rabbit feces containing coccidian parasites (Eimeria intestinalis, E. magna, E. media, E. ... suppressed oocyte development, but /was/ not lethal. ... The most effective treatment (96-98% efficient) was achieved using a mixture of 2% CCl4, 2% NaOH, 5% ammonia water, and 5% NaCl. [Peer Reviewed] [Abramova VF, Karare MV; Profil Parazit Bolezn Zhivotn 30-3 (1985)]
14. Selenium deficient barley ... was treated with sodium hydroxide to deplete it of vitamin E. Housed cattle fed a complete diet based on this treated barley developed nutritional degenerative myopathy, showing that spontaneous myopathy in yearling cattle can be the result of vitamin E and selenium deficiency alone. The diet used is as effective and cheaper than others presently in use for inducing degenerative myopathy. [Peer Reviewed] [Rice DA, McMurray CH; Vet Rec 118 (7): 173-6 (1986)]

TOXICITY VALUES

Ecotoxicity Values:

1. LC100 cyprinus carpio 180 ppm/24 hr @ 25 deg c [peer reviewed] [nishiuchi y; suisan zoshoku 23: 132 (1975)]
2. TLm mosquito fish 125 ppm/96 hr (fresh water) [Peer Reviewed] [U.S. Coast Guard, Department of Transportation. CHRIS - Hazardous Chemical Data. Volume II. Washington, D.C.: U.S. Government Printing Office, 1984-5.]
3. TLm Bluegill 99 mg/L/48 hr (tap water) [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.61 (1981)]

Pharmacokinetics

Absorption, Distribution and Excretion:

Alkalis penetrate skin slowly. [Peer Reviewed] [Dreisbach, R.H. Handbook of Poisoning. 9th ed. Los Altos, California: Lange Medical Publications, 1977. 202]

Metabolism/Metabolites:

SRP4: Not relevant (engages in acid base reaction) [Peer Reviewed]

Biological Half-Life:

SRP4: Not relevant [Peer Reviewed]

Mechanism of Action:

Keratin material in the skin underwent rapid decomposition in NaOH above pH 9.2. Aliquots of washed human hair and fingernails were mixed with various amounts of NaOH solution and the extent of keratin breakdown was measured by estimating the cystine produced. The cystine portion of the keratin complex of human hair or nails was readily cleaved by NaOH in the S-S bond. After 20 hr of contact with 0.1N or 0.25N NaOH, 61.4% and 97.6%, respectively, of the nail keratin were decomposed. Thus, a high degree of destruction of tissue even by a dilute NaOH solution can occur from prolonged contact. [Peer Reviewed] [Chiego B and Silver H; J Invest Dermatol 5: 95-103 (1942) as cited in NIOSH; Criteria Document: Sodium Hydroxide p.30 (1975) DHEW Pub. NIOSH 76-105

Interactions:

SRP4: Interacts with acid salts to form bases. [Peer Reviewed]

6.0 PHARMACOLOGY

Bionecessity:

SRP 4: None [Peer Reviewed]

Therapeutic Uses:

1. Vet: disinfectant [QC Reviewed] [Jones, L.M., et al. Veterinary Pharmacology & Therapeutics. 4th ed. Ames: Iowa State University Press, 1977. 866]
2. Vet: Dehorning of calves [QC Reviewed] [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1236] to induce vitamin E and selenium deficiency in yearling cattle /resulting in degenerative myopathy/. [QC Reviewed] [Rice DA, McMurray CH; Vet Rec 118 (7): 173-6 (1986)]

7.0 ENVIRONMENTAL FATE/EXPOSURE POTENTIAL

ENVIRONMENTAL FATE

Aquatic: In the case of a solid, anhydrous NaOH spill on soil, ground water pollution will occur if precipitation occurs prior to clean up. Precipitation will dissolve some of the solid (with much heat given off) and create an aqueous solution of NaOH, which then would be able to infiltrate the soil. However, prediction of the concn and properties of the solution produced would be difficult. [Peer Reviewed] [Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) p.24 (1981)]

ENVIRONMENTAL TRANSFORMATIONS

Biodegradation:

BOD: none [Peer Reviewed] [U.S. Coast Guard, Department of Transportation. CHRIS - Hazardous Chemical Data. Volume II. Washington, D.C.: U.S. Government Printing Office, 1984-5.]

HUMAN EXPOSURE

Probable Routes of Human Exposure:

1. Inhalation of dust or mist, ingestion, and skin or eye contact. [Peer Reviewed] [Sittig M; Handbook of Toxic and Hazardous Chemicals p.606 (1981)]
2. 536,498 employees (102,011 female employees) (est) have been exposed from actual observed occupational use of sodium hydroxide. [Peer Reviewed] [NIOSH; National Occupational Exposure Survey (5/18/85)]
3. Over a six-month period, the New Jersey Poison Information System received 61 calls related to exposures to alkaline corrosives. Seven of these calls related to a new oven-cleaner product, oven-cleaner pads. These pads are sealed in a protective plastic wrap and contain lye in excess of 5%. ... Five of the callers sustained injuries from their exposure, and three of these sustained burns, one in the oral cavity and one in the eye. None suffered permanent sequelae, but the potential for such is

considerable. The method of application, concn of base, and prolonged exposure to a widely covered area may make this product particularly hazardous. [Peer Reviewed] [Vilogi J et al; Am J Emerg Med 3 (5): 412-4 (1985)]

8.0 EXPOSURE STANDARDS AND REGULATIONS

STANDARDS AND REGULATIONS

Immediately Dangerous to Life or Health: 10 mg/cu m [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

OCCUPATIONAL PERMISSIBLE LEVELS

OSHA Standards:

1. Permissible Exposure Limit: Table Z-1 8-hr Time Weighted Avg: 2 mg/cu m. [QC Reviewed] [29 CFR 1910.1000 (7/1/98)]
2. Vacated 1989 OSHA PEL Ceiling limit 2 mg/cu m is still enforced in some states. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 97-140. Washington, D.C. U.S. Government Printing Office, 1997. 371]

NIOSH Recommendations:

exposure to sodium hydroxide if environmental levels, as determined on the basis of an industrial hygiene survey or by the judgement of a compliance officer, do not exceed half of the workplace environmental limit. Records of these surveys, including the basis for concluding that airborne concn of sodium hydroxide are not above half of the workplace environmental limit, shall be maintained until a new survey is conducted. Surveys shall be repeated when any process change indicates a need for reevaluation or at the discretion of the compliance officer. ... Sampling and analysis of airborne sodium hydroxide shall be accomplished within 30 days after installation of a new process or process change. [Peer Reviewed] [NIOSH; Criteria Document: Sodium Hydroxide p.18 (1975) DHEW Pub. NIOSH 76-105]

2. (15-min) Ceiling value: 2 mg/cu m. [QC Reviewed] [NIOSH. NIOSH Pocket Guide to Chemical Hazards. DHHS (NIOSH) Publication No. 94-116. Washington, D.C.: U.S. Government Printing Office, June 1994. 284]

Threshold Limit Values:

Ceiling Limit 2 mg/cu m [QC Reviewed] [American Conference of Governmental Industrial Hygienists. Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents Biological Exposure Indices for 1998. Cincinnati, OH: ACGIH, 1998. 62]

Other Occupational Permissible Levels:

Ceiling Limits: Finland 2 mg/cu m; West Germany 2 mg/cu m; Yugoslavia 2 mg/cu m. [Peer Reviewed] [NIOSH; Criteria Document: Sodium Hydroxide p.62 (1975) DHEW Pub. NIOSH 76-105]

OTHER STANDARDS AND REGULATIONS

Clean Water Act Requirements:

Designated as a hazardous substance under section 311(b)(2)(A) of the Federal Water Pollution Control Act and further regulated by the Clean Water Act Amendments of 1977 and 1978. These regulations

apply to discharges of sodium hydroxide. [40 CFR 116.4 (7/1/85)]

CERCLA Reportable Quantities:

Persons in charge of vessels or facilities are required to notify the National Response Center (NRC) immediately, when there is a release of this designated hazardous substance, in an amount equal to or greater than its reportable quantity of 1,000 lb or454 kg. The toll free telephone number of the NRC is (800) 424-8802; In the Washington metropolitan area (202) 426-2675. The rule for determining when notification is required is stated in 40 CFR 302.6 (section IV. D.3.b). [Peer Reviewed] [50 FR 13456 (4/4/85)]

FDA Requirements:

section number 121.101; limitations: gras, miscellaneous &/or general-purpose food additive. [peer reviewed] [furia, t.e. (ed.). CRC Handbook of Food Additives. 2nd ed. Cleveland: The Chemical Rubber Co., 1972. 942]

9.0 MONITORING AND ANALYSIS METHODS

SAMPLING PROCEDURES:

1. Analyte: sodium hydroxide; matrix: air; procedure: filter collection, extraction with aqueous acid. [Peer Reviewed] [U.S. Department of Health, Education Welfare, Public Health Service. Center for Disease Control, National Institute for Occupational Safety Health. NIOSH Manual ofAnalytical Methods. 2nd ed. Volumes 1-7. Washington, DC: U.S. Government Printing Office, 1977-present.,p. V4 S381-1]
2. Workplace monitoring: Sampling and analysis may be performed by collection of sodium hydroxide in a glass subsequent titration. [Peer Reviewed] [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2]
3. Detector tubes certified by NIOSH under 42 CFR part 84 or other direct-reading devices calibrated to measure sodium hydroxide may be used. [Peer Reviewed] [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2]

Analytical Laboratory Methods:

1. colorimetric determination of caustic alkalis in air. [peer reviewed] [fedotova la; gig sanit 10: 65 (1976)]
2. analyte: sodium hydroxide; matrix: air; procedure: filter collection, extraction with aqueous acid, back titration with sodium hydroxide; range: 0.76-3.9 mg/cu m. [Peer Reviewed] [U.S. Department of Health, Education Welfare, Public Health Service. Center for Disease Control, National Institute for Occupational Safety Health. NIOSH Manual ofAnalytical Methods. 2nd ed. Volumes 1-7. Washington, DC: U.S. Government Printing Office, 1977-present.,p. V4 S381-1]
3. Caustic soda solutions are normally tested for total alkalinity and the major impurities. To test for the total alkalinity of sodium hydroxide, a titration is performed using a standard acid. [Peer Reviewed] [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 1:860]
4. Workplace monitoring: Sampling and analysis may be performed by collection of sodium hydroxide in a glass bubble containing hydrochloric acid, followed by subsequent titration. [Peer Reviewed] [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2]
5. Determination of sodium hydroxide in boiler water by a linear titration plot method. [Peer Reviewed] [Midgley D; Microchem J 32 (3): 354-66 (1985)]

10.0 ADDITIONAL REFERENCES

Special Reports:

1. Environment Canada; Tech Info for Problem Spills: Sodium Hydroxide (Draft) (1981)
2. NIOSH; Criteria Document: Sodium Hydroxide (1975) DHEW Pub. NIOSH 76-105

Your answers to the following questions will assist in determining those solvent/process alternatives most likely to work for your particular circumstances.

The "More Info..." symbol: will provide additional explanations for particular questions. Select the response that most closely matches the particular part(s) that you are dealing with.

After you press the "Send Data" button, you should immediately save the page that SAGE returns to you in a local file. This page is generated "on the fly" and does not exist with an URL that can be retrieved later. Do not bookmark the page, you won't get it back. To save the page, use the "Save As" function built in to your Web browser. For example, in Netscape you would click on "Save As" and then rename the file (or use the existing name) with either a *.txt (for ASCII text) or *.htm (for HTML) file extension.

Report Header Information
Your Name Part/Process Name
State of Residence

Physical Properties
Select from each column
(Hold down the control key while using the mouse to select multiple items)

Metallic Materials
None
300 Series Stainless
400 Series Stainless
Other Stainless Steels
Cast Iron
High Carbon Steel
Low Carbon Steel
Other Iron
Aluminum
Copper
Nickel
Zinc
Magnesium
Precious Metals
Titanium
Berylium
Zirconium
Brass
Other Non-ferrous metal

Nonmetallic Materials
None
Acrylonitrile/Butadiene/Styrene (ABS)
Epoxies
Fluoropolymers
Phenolics
Poly(amide/imide)
Polyesters
Polypropylene
Polystyrene
Polyvinyl Chloride (PVC)
Polyether ketones
Silicone rubber
Nitrile rubber
Acrylics
Glass
Polycarbonates
Nylon (Polyimide)
Polyurethanes
Other nonmetallic

If the part is metallic, is it sintered or made from powdered metal:
Yes No NA

Does the part have any polished, lapped, or ground surfaces that must be protected:
Yes No

Is the part an assembly or a single piece part:
Assembly Single piece part

Size/Shape Characteristics

Is the part volume:
less than 1 ft3 between 1 and 9 ft3 more than 9 ft3

Is the longest rigid length of the part:
less than 1 ft between 1 and 5 ft more than 5 ft

Does the part have a complex shape:
Yes No

Does the part have blind holes:
Yes No

Coatings

Does the part have any type of coating:
Yes No

Do you want to remove the coating:
Yes No NA

Is the coating:
A plating
A phosphate prep
A paint or powder coat
Some other coating
A thin film deposition
Not applicable

Cleanliness Requirements

Please select the type of contaminant or soil you are removing:
(Hold down the control key while using the mouse to select multiple items)

Water soluble process fluids
Particles
Non-water soluble process fluids
Adhesive residues
Drawing compounds
Rust
Carbonaceous materials
Fibers
Fingerprints
Grease
Oxidation
Metal chips and fines
Silicones
Packaging debris
Oil
Organics
Dyes or inks
Plasticizers
Salts
Scale
Tapping compounds
Wax
Waterbase paint
Non-waterbase paint
Water soluble mold release
Non-water soluble mold release
Some other contaminant

Is your part subject to cleanliness inspection per a national, internal, or customer specification:
Yes No

Is your part inspected per MIL-STD-1246C:
Yes No

Will your part be used in a Class 100 or better clean room:
Yes No

What is the next process step your product will see:
Packaging for shipment
More processing, with the same fluids
Coating
Assembly into another part
Grinding, lapping, or polishing
Some other step not listed

More processing, with different fluids Assembly or test in a clean room
Does the part need to be dry after this cleaning step:
Yes No

Miscellaneous Process Information
What kind of cleaning equipment are you currently using:
Vapor degreaser
Ultrasonic vapor degreaser, with spray and/or heaters
Cold immersion tank
Hot immersion tank
Power washing machine
Some other type of equipment

What type of chemicals are you currently using:
(Select only one)
Methyl chloroform (1,1,1-trichloroethane, TCA)
CFC-113 (trichlorotrifluoroethane)
Methylene chloride
Methyl ethyl ketone (MEK)
Trichloroethylene (TCE)
Kerosene
Stoddard solvent
Mineral spirits
Xylene
Perchloroethylene
Alcohol (ethanol, methanol, isopropanol, isopropyl alcohol, IPA)
Acetone
Toluene
Some other solvent

Do you currently have DI (deionized) or tap water available:
DI water Tap water Neither

How many parts per hour do you need to clean:
More than 100 Between 10 and 100
Less than 10 per hour Production rate varies widely

Is the part a high dollar value part:
Yes No

Will ultrasonic vibrations hurt your part:
Yes No Don't know

Can your part withstand high atmospheric pressure:
Yes No

Can your part withstand high pressure sprays:
Yes No Don't know

Glycol Ethers

Glycol ethers are organic solvents. Many different glycol ethers are used for cleaning. They are often found under the trade names Cellosolve™ and Carbitol™. Glycol ethers are volatile organic compounds (VOCs) and may be regulated in your area. They are also combustible or flammable and must be handled accordingly.

Glycol ethers are used in the semiconductor industry to strip photo-resist. They also remove flux, solder paste, inks, greases, and oils. They are often blended with other solvents for specific cleaning applications.

The terms E-series and P-series are often used to refer to ethylene glycol ethers and propylene glycol ethers, respectively. E-series members generally are more toxic. A semiconductor industry study has linked two E-series glycol ethers to an increase in miscarriages among assembly line workers. The two specific compounds studied were diethylene glycol dimethyl ether and ethylene glycol monoethyl ether acetate. The time weighted average (TWA) for ethylene glycol methyl ether acetate is 5 ppm, but miscarriage increases have been linked to lower exposure levels.

Glycol ethers tend to emulsify well for cleaning and separate easily during recovery. One method for disposal is to burn the solvent in an approved chemical incinerator.

N-methylpyrollidone

NMP is an organic solvent. It is a volatile organic compound (VOC) and has a low vapor pressure of 0.29 mm Hg at 68°F (0.39 mbar at 20°C). It is combustible, with a flash point of 199°F (93°C). Its threshold limit value (TLV) is 100 ppm.

NMP cleans heavy oil and carbon deposits from engine parts. It is an excellent solvent for many coatings, including polyurethanes, printing inks, epoxy resins, polyamidimide-based wire enamels, and water-based coatings. Many plastics, including polystyrene, polyesters, and polyvinyl chloride are soluble in NMP. NMP also can strip paint.

NMP is acceptable for use in both immersion and ultrasonic processes. Pure NMP is commonly used, but it is available blended with surfactants or other solvents. It is also combined with a water rinse in semiaqueous processes.

Many oils become soluble in NMP only when the solvent is above 145°F (63°C). The oils can be separated from the solvent after the cleaning step by lowering the NMP temperature. The solvent can then be reused and the oil can be recycled.

NMP is listed under SARA 313 Title III (EPCRA), section 313(d)(2)(B), serious or irreversible chronic health effects. The effective date was January 1, 1995. First reports are due July 1, 1996. The full discussion can be found in the Federal Register dated November 30, 1994, Vol. 59, No. 229, pp. 61432-61485.

Plasma

A plasma is a mixture of positive ions, negative ions, and electrons produced by an electrostatic or electromagnetic field. The ions or charged molecules (excited radicals) remove contaminants by physically sputtering them from the surface or reacting with them chemically. In chemical removal, the plasma breaks the contaminant molecules into water vapor, carbon dioxide gas, and small, volatile organic molecules. These are then exhausted from the area. Most plasma cleaning processes are done in vacuum chambers with argon or oxygen plasmas.

Plasmas are effective for removal of very thin organic layers. Plasma cleaning is common in the semiconductor industry. It often improves wire bonding on hybrid microcircuits. Plasma cleaning can strip wire insulation from coils and magnetic assemblies. It is also used to prepare surfaces before plating on plastics.

Plasmas are best suited for line-of-sight cleaning. Some work has been done to develop atmospheric pressure plasmas, which may expand the applications for this technique.

UV/Ozone

This process uses short wave ultraviolet (UV) light, combined with ozone, to decompose organic materials. The ozone may be generated by the UV light or may be injected from another source. This process depends entirely on line-of-sight exposure to the UV light and works best on simple, flat surfaces.

The process is best for removing very thin organic films and for producing higher cleanliness levels. It is very dependent on the thickness of the soil; the thicker the soil, the longer it will take to clean. It will not remove particles or salts.

The UV light may cause oxidation of some metals, depending on the metal and length of exposure.

Commercial equipment is inexpensive.

Safety is an issue with this process due to the intense shortwave UV light. In addition, the presence of ozone is a safety and environmental issue. The UV lamps may contain mercury, which would be a safety hazard if the lamps were broken.

Xenon Flash Lamp

Xenon flash lamp cleaning uses light energy from a flash tube to burn off layers of coating materials. It is used to remove coatings from aircraft skins and has been used on both composite and metallic materials.

The process has been combined with carbon dioxide pellet cleaning and used for paint stripping on aircraft. Strip rates of 1 square foot/minute have been achieved. The process may allow the removal of coatings to a certain depth instead of all the way to bare substrate.

The process generates a small waste stream consisting of burnt coating materials. The process is still under development and is expensive.

Original Questionnaire for Vendors of Cleaning Chemicals, 1995

1. Who is the product manufactured by and where is the product manufactured?
2. What is the classification of your cleaning product?
   Saponified Aqeuous
   Semi-Aqueous
   Petroleum Distillates
   Alkaline Aqueous Solution
   Acidic Aqueous Solution
   Terpenes
   Other (please specify):
3. Give a Chemical/Generic description of your product?
4. What contaminants is your product most effective in removing?
5. Is there a recommended process or type of equipment associated with this product? If so, please describe it:
6. Is there a separation process associated with using this cleaning solution?
7. What concentration of cleaning solution is typically used?
8. Is your product designed to be recycled? If so, how is it recycled?
9. What is the cost of your cleaner?
10. Are there any constituents in your cleaner which are listed under SARA 313 or CERCLA? Please include any MSDS sheets and any other information that would assist potential customers in evaluating the applicability of your product to their needs (e.g., a typical process flow diagram, waste stream constituents, special handling equipment).

Original Questionnaire for Vendors of Cleaning Equipment, 1995

1. Which of the following industries does this product target?
   Metal Fabrication/Finishing Parts
   Electronics/Printed Circuit Boards
   Electronics/Semiconductor
   General Electronics
   Precision Instruments
   Medical Devices
   Other (please specify):
1. Please describe the type of equipment you offer.
2. Is your equipment Batch or In-line?
3. Is your equipment typically provided as standard model or custom made?
4. Which of the following cleaners are compatible with your equipment?
   Saponified aqueous
   Semi-aqueous emulsion
   Alkaline aqueous solution
   Acidic aqueous solution
   Hot water/steam
   Petroleum distillates
   Terpenes
   Other (please specify):
   Are the following items included in your equipment or are they available as options?
   Drying Equipment
   Oil Skimmers
   Filtration/Recycling Equipment
   Bath Maintenance
   Automation
5. Do you provide closed-loop aqueous cleaning equipment?
6. What is the selling price for your equipment?
7. Who installs your equipment? What is the average cost of installation?
8. What are the average operating and maintenance costs?
9. Please provide any information that would assist potential customers in evaluating the applicability of your equipment to their nedds (e.g., a schematic diagram, power requirements, physical dimensions, estimated energy usage, average life span).

Original Questionnaire for Vendors of Recycling Equipment, 1997

1. Please give a brief description of the product you offer.
2. Is your product used in either a batch or continuous mode?
3. Which of the following chemicals can your product be used to recycle or treat?
   Alkaline Aqueous Solutions
   Caustic Aqueous Solutions
   Acidic Aqueous Solutions
   Organic Solvents
   Terpenes
   Semi-aqueous Solutions
   Petroleum Distillates
   Alcohols
   Other (please specify):
4. What pH range is your product compatible with?
5. What temperatures is your product compatible with?
6. What flow rates or volumes can your product process?
7. What is the price range of your product?
8. What is the average operating cost of your product?

Example TURI Directory Entries of Cleaning Chemical Vendors, 1995

Company Name Trade Name Classification Cost	Description	Contaminants Removed	Compatible Process and/or Equipment	Percent Volatile pH Vapor Pressure Flash Point Boiling Point
A.W. Chesterton 181 Low Alkaline Cleaner Alkaline Aqueous	A low-alkaline, water-based degreaser that contains Isodecyloxy-Propyliminodipropionic Acid and Dodecylthioethoxylate.	Non-polar soils from aluminum. Contains special yellow metal inhibitors to prevent base metal attack.	Can be used in all types of equipment, except where foam is undesirable.	88 8.0 None 212° F
A.W. Chesterton 217 Pressure Wash Alkaline Aqueous	A moderate alkaline degreaser that contains Dipropylene Glycol Monomethyl Ether and Sodium Carbonate.	Non-polar soils like machining fluids, light oils, dirt, etc.	Spray booths and other equipment where foam generation is undesirable.	>95 10.5 None 212° F
A.W. Chesterton 278 Super Solve Petroleum Distillates	A solvent blend of aliphatic hydrocarbons and a proprietary solvent.	Polar soils like uncured epoxies, resins, adhesives, inks, styrene, etc. Electronic precision cleaning.	Can be safely heated to 175F to enhance cleaning. Mainly used in dip tanks / aerosol.	100 0.9 mm Hg 225° F 200° F
A.W. Chesterton 803 Industrial & Marine Solvent II Alkaline Aqueous	A high alkaline-based degreaser containing no phosphates or butyls. Contains Potassium Hydroxide and Sodium Carbonate.	Non-polar soils, machining fluids.	Compatible with any equipment where foam is acceptable.	89 13.4 >212° F 212° F
A.W. Chesterton KPC 820N Alkaline Aqueous	A mild alkaline-based degreaser containing no phosphates. Contains Carbonic Acid and Sodium Salt.	Mostly non-polar soils, but some polar.	For all types of equipment except high-Pressure spray where foam is undesirable.	90 9.8 None 212° F
Advanced Chemical Design Borothene Vapor-Degreasing Solvent Halogenated Hydrocarbon $2.49 US/lb.	Non-flammable chlorine and bromine chemical.	Fluxes, oils, greases and other hydrocarbon soluble materials.	Vapor degreasing.	 None 161° F
Aerocote Corporation Aerocote DN 30 Alkaline Aqueous $4.90-11.00 US/gal.	Liquid, alkaline cleaner/degreaser.	Greases, shop dirt. Machine, cutting and drawing oils, buffing compounds, etc.	Cleaning carpets, machinery, boats and vehicles.	0 12.65 N/A N/A 212° F
Aerocote Corporation Aerosolv 2000 Emulsifiable Degreaser $7.16-16.00 US/Gal.	The product is an emulsifiable degreaser that contains detergent range Alcohol Ethoxylate and Propylene Glycol T-Butyl Ether.	Greases, drilling muds, smoke tracks, inks, shop dirt.	Removal of carbonized deposits from aircraft/trucks. Cold cleaning of tubular goods, oil rigs, Machinery, etc. and concrete floors. Not for electronics.	N/A Neutral N/A 142° F N/A

*Example TURI Directory Entries of Cleaning Chemical Vendors, 1997

Product Trade Name Company Name Product Classification Approx. Cost	Product Description	Industrial Uses	Contaminants Removed	Equipment Compatibility	Physical Properties	Chemicals Listed in MSDSs
181 Low Alkaline Cleaner A.W. Chesterton Alkaline Aqueous	Low alkaline, water-based degreaser containing Isodecyloxypropyliminodi propionic Acid and Dodecylthioethoxylate.	MFF PCBs SEC GEL MIL PRT PI MED ✓ GCM CHM	ADH BPL CD CC FLX Inks ✓ GRS MR ✓ Oil PAC Rust Scale SI Wax	HPS ✓ IMM ✓ LPS ✓ SC ✓ ULT VPD	% Vol: 88 FP: None pH: 8.0	Isodecyloxypropyliminodipropionic Acid, Dodecylthioethoxylate and monosodium salt
217 Pressure Wash A.W. Chesterton Alkaline Aqueous	Moderate alkaline degreaser containing Dipropylene Glycol Mono-methyl Ether and Sodium Carbonate.	✓ MFF PCBs SEC GEL MIL PRT PI MED ✓ GCM CHM	ADH ✓ BPL CD CC FLX Inks ✓ GRS MR ✓ Oil PAC Rust Scale SI Wax	✓ HPS ✓ IMM ✓ LPS ✓ SC ✓ ULT VPD	% Vol: >95 FP: None pH: 10.5	Dipropylene Glycol Monomethyl Ether and Sodium Carbonate
218 HDP A.W. Chesterton Alkaline Aqueous		✓ MFF PCBs SEC GEL MIL PRT PI MED ✓ GCM CHM	ADH ✓ BPL ✓ CD CC FLX Inks ✓ GRS MR ✓ Oil PAC Rust Scale SI Wax	✓ HPS ✓ IMM ✓ LPS ✓ SC ✓ ULT VPD	% Vol: 90 FP: 225^{o} F pH: 13.4	Dipropylene Glycolmethyl Ether, Potassium Hydroxide and Sodium Carbonate
278 Super Solv A.W. Chesterton Petroleum Distillates	Solvent blend of aliphatic hydrocarbons and a proprietary solvent.	MFF PCBs SEC ✓ GEL MIL ✓ PRT PI MED ✓ GCM CHM	✓ ADH ✓ BPL CD CC ✓FLX ✓ Inks ✓ GRS ✓ MR ✓ Oil ✓ PAC Rust Scale ✓ SI ✓ Wax	HPS ✓ IMM LPS SC ULT VPD	% Vol: 100 FP: 225^{o} F VP: 0.9 mm Hg	Aliphatic Hydrocarbon
803 Industrial & Marine Solvent II A.W. Chesterton Alkaline Aqueous	High alkaline, water-based degreaser contains Potassium Hydroxide and Sodium Carbonate but no phosphates or butyls.	✓ MFF PCBs SEC GEL ✓ MIL PRT PI MED ✓ GCM CHM	ADH ✓ BPL ✓ CD CC FLX Inks ✓ GRS MR ✓ Oil PAC Rust Scale SI Wax	HPS ✓ IMM ✓ LPS ✓ SC ✓ ULT VPD	% Vol: 89 FP: >212^{o} F pH: 13.1-13.7	Potassium Hydroxide and Sodium Carbonate
KPC 820N A.W. Chesterton Alkaline Aqueous	Mild Alkaline-based degreaser contains Carbonic Acid and Sodium Salt but no phosphates.	✓ MFF PCBs SEC GEL ✓ MIL PRT PI MED ✓ GCM ✓ CHM	ADH ✓ BPL ✓ CD CC FLX Inks ✓ GRS MR ✓ Oil PAC Rust Scale SI Wax	HPS ✓ IMM ✓ LPS ✓ SC ✓ ULT VPD	% Vol: 90 FP: None pH: 9.8 VOCs: 0	Carbonic Acid and sodium salt
New PWC ADF Systems, Inc. Alkaline Aqueous $2.95 US/lb.		✓ MFF ✓ PCBs SEC ✓ GEL ✓ MIL ✓ PRT ✓ PI ✓ MED ✓ GCM CHM	✓ ADH ✓ BPL CD CC ✓FLX ✓ Inks ✓ GRS ✓ MR ✓ Oil PAC Rust Scale ✓ SI ✓ Wax	✓ HPS ✓ IMM ✓ LPS ✓ SC ✓ ULT VPD	pH: 12.7 @ 5% Conc.	Sodium Metasilicate and Ethylene Glycol Monobutyl Ether

*Refer to Table 6.7 for meaning of abbreviations used.

*Example TURI Directory Entries of Cleaning Equipment Vendors, 1995

Company Name Trade Name Equipment Type Model	Industrial Uses	Description	Cleaning Chemistry Compatibility	Drying Equip. Oil Skimmer Bath Maint. Filtration	Equipment Cost Installation By
A.W. Chesterton Chesterton Parts Washer Batch Standard	Metals ☒ PCBs ☐ Semi ☐ Elec ☐ PI ☐ MD ☐ Other-Maint.	Heated, water-based parts degreaser. Compatible with aqueous cleaners with pH under 12.5.	Sap. A ☒ SAE ☐ Alk. A ☒ Ter ☐ Ac. A ☒ HW/S ☐ PD ☐ Other-	Included	$735 US Vendor
ACCEL Corp. Microcel/2 Centrifugal Cleaning System Batch Standard & Custom	Metals ☐ PCBs ☒ Semi ☒ Elec ☒ PI ☒ MD ☒ Other-	Centrifugal energy provides superior washing, rinsing, drying of circuit boards, hybrid circuits inside sealed chamber.	Sap. A ☒ SAE ☒ Alk. A ☒ Ter ☒ Ac. A ☒ HW/S ☒ PD ☒ Other-	Included N/A Included Option	$125,000 US Vendor
ACMEFAB Division A-F Industries IMAC System Batch & Inline Custom	Metals ☒ PCBs ☐ Semi ☐ Elec ☐ PI ☐ MD ☐ Other-	Aqueous parts washers, ovens, complete furnishing systems.	Sap. A ☐ SAE ☐ Alk. A ☒ Ter ☐ Ac. A ☒ HW/S ☐ PD ☐ Other-	Included Option Option Option	$75,000+ US Customer/Vendor
Abar Ipsen Industries Ecovac & Varioclean Batch & Semi co Standard & Custom	Metals ☒ PCBs ☐ Semi ☐ Elec ☐ PI ☐ MD ☐ Other-	Ecovac: Applies mild heat / vacuum to vaporize liquids on metal parts. Vario: Combines tech. for precision cleaning.	Sap. A ☐ SAE ☒ Alk. A ☒ Ter ☒ Ac. A ☐ HW/S ☐ PD ☐ Other-	Included Included Option Option	$150-250,000 US Vendor
Aichelin-Stahl Inc. Flexiclean Parts Washer Batch Standard	Metals ☒ PCBs ☐ Semi ☐ Elec ☐ PI ☐ MD ☐ Other-	Precision cleaning for blind holes, vacuum drying, prior to 'clean-room' assembly, vacuum heat treating and plating.	Sap. A ☒ SAE ☒ Alk. A ☒ Ter ☐ Ac. A ☐ HW/S ☐ PD ☐ Other-	Included Included N/A Option	$150-200,000 US Customer
American Metal Wash, Inc. Industrial Spray Washing Machines Batch & Inline Standard & Custom	Metals ☒ PCBs ☐ Semi ☐ Elec ☐ PI ☐ MD ☐ Other-	Cabinet and inline spray washers using biodegradable detergents in heated water.	Sap. A ☒ SAE ☐ Alk. A ☒ Ter ☐ Ac. A ☒ HW/S ☒ PD ☐ Other-	Included/Option Included/Option Included/Option Included/Option	$10-100,000 US Customer
American Metal Wash, Inc. Industrial Wastewater Evaporator Batch Standard	Metals ☐ PCBs ☐ Semi ☐ Elec ☐ PI ☐ MD ☐ Other-Wastewater	Evaporate water portion of any water-based cleaning solution. Reduces disposal waste by 95-98%. No flocculation/ filtration needed.	Sap. A ☒ SAE ☒ Alk. A ☒ Ter ☐ Ac. A ☒ HW/S ☐ PD ☐ Other-		$6650 US Customer

*Refer to Table 6.7 for meaning of abbreviations used.

*Example TURI Directory Entries of Cleaning Equipment Vendors, 1997

Product Trade Name **Company Name** **Batch or Inline** **Standard or Custom** **Approx. Cost**	**Product Description**	**Industrial Uses**	**Compatible Chemicals**	**Equipment Options** Drying Equipment Oil Skimmer Bath Maint. Automation Filtration/Recycling	**Equip-ment Dimen-sions**
Chesterclean Parts Washer A.W. Chesterton Batch Standard	Heated, water-based parts degreaser. Compatible with aqueous cleaners, PH < 12.5	✓ MFF PCBs SEC GEL MIL PRT PI MED ✓ GCM CHM CLP	✓ SPA SMA ✓ ALA TER ✓ ACA CAU PD ORG ALC HCF	Included	36” x 22” x 10”
Miicrocel/2 Centrifugal System ACCEL Corporation Continuous Standard and Custom	Centrifugal energy provides superior washing, rinsing and drying of printed circuit boards and hybrid circuits inside sealed chamber.	MFF ✓ PCBs ✓ SEC ✓ GEL MIL PRT ✓ PI ✓ MED GCM CHM CLP	✓ SPA ✓ SMA ✓ ALA ✓ TER ✓ ACA CAU ✓ PD ORG ✓ ALC HCF	Included N/A Included Optional	
Microline Unline System ACCEL Corporation Continuous Standard and Custom	Fully automated washing, rinsing, drying and fluids recycling in a stainless steel footprint of only 84” x 49” .	MFF ✓ PCBs ✓ SEC ✓ GEL ✓ MIL PRT ✓ PI ✓ MED GCM CHM CLP	✓ SPA ✓ SMA ALA ✓ TER ACA CAU PD ORG ALC HCF	Included N/A Included Optional	Varies, No limits.
IMAC System ACMEFAC Div. A-F Industries Batch and Inline Custom Varies	Aqueous parts washers, ovens, complete furnishing systems.	✓ MFF PCBs SEC GEL MIL PRT PI MED GCM CHM CLP	SPA SMA ✓ ALA TER ✓ ACA CAU PD ORG ALC HCF	Included Optional Optional Optional	Varies.
ADF ADF Systems, Ltd. Batch and Continuous Standard and Custom	Rotary basket top and front load models, manual tank type models, pass through, glove box, agitation dip tanks, drawer type and conveyor washers.	✓ MFF ✓ PCBs SEC GEL ✓ MIL ✓ PRT ✓ PI ✓ MED ✓ GCM CHM ✓ CLP	SPA SMA ✓ ALA TER ACA CAU PD ORG ALC HCF	Optional Optional Optional Optional	
Ecovac and Varioclean Abar Ipsen Industries Batch and semi co Standard and Custom Minimal	Ecovac applies mild heat and vacuum to vaporize liquids on metal parts. Varioclean combines aqueous / vacuum tech. for precision cleaning.	✓ MFF PCBs SEC GEL MIL PRT PI MED GCM CHM CLP	SPA ✓ SMA ✓ ALA ✓ TER ACA CAU PD ORG ALC HCF	Included Included Optional Optional	

*Refer to Table 6.7 for meaning of abbreviations used.

*Example TURI Directory Entries of Recycling Equipment Vendors, 1997

Product Trade Name Company Name Batch or Continuous Approx. Cost	**Product Description**	**Compatible Chemicals**	**pH Range Temp. Range**	**Throughput Operating Costs**
Vapor Degreasing Equipment with Recovery Stills Alexy Associates Inc	1)Vapor Degreasing Equipment cleans parts with approved chlorinated or replacement solvenrs. 2) Recovery Stills reclaim approved chlorinated or replacement solvents.reduces usage and waste generation. 3) Rebuilt Equipment updated to save money.	ALA TER CAU SA ACA PD ✓ ORG ALC Other: Chlorinated Solvents	117° – 260° F	Any Varies with size.
American Metal Wash Evaporators American Metal Wash	Evaporates the water portion of any water-based cleaning solution. Reduces disposal waste 95-98%. Requires no flocculation or filtration.	✓ ALA TER ✓ CAU ✓ SA ✓ ACA PD ORG ALC		Around $0.05 US/gal. evaporated.
Aqualogic Evaporator System Aqualogic, Inc.		✓ ALA TER ✓ CAU SA ✓ ACA PD ORG ALC	1 – 13 160° F Max.	30-45 GPH Varies with energy source.
Aqualogic Microfiltration Systems Aqualogic, Inc.		✓ ALA TER ✓ CAU ✓ SA ✓ ACA PD ORG ALC	2 – 12 165° – 170° F Max.	250 – 1500 GPD Operation of 2-5 hP motor membrane for 3-5 years.
Automatic Batch System (ABS) Aqualogic, Inc.		✓ ALA TER ✓ CAU SA ✓ ACA PD ORG ALC Other: Cyanide Solutions	0.5 – 13.5 140° F Max.	1000 – 2000 gal. Batch Depends on waste concentrations.
AQW-20 Series Water Recyclers Aqueous Technologies	Provides closed-loop operation of various aqueous cleaning applications.	✓ ALA TER CAU ✓ SA ACA PD ✓ ORG ✓ ALC	6 – 12 160° F	4 – 20 GPM N/A
X-Cleaner, Megacleaner Austin American Technology	Rinse water recycling systems for use with Austin American Tech. cleaning equipment.	ALA TER CAU SA ACA PD ✓ ORG ✓ ALC Other: Rinse DI Water	4 – 11 Ambient – 130° F	7 GPM Approx. $800 US/yr.

*Refer to Table 6.7 for meaning of abbreviations used.

Surface-Cleaning Related Conferences

CleanTech International Cleaning Technology Exposition, Chicago, Illinois, USA. Annual in Spring (3 days). Contact: Witter Publishing (908) 788-0343.
International Workshop on Solvent Substitution and the Elimination of Toxic Substances and Emissions, Phoenix, Arizona, USA. Annual in Winter (4 days). Contact: Exchange/Monitor Publications (847) 234-2353.
Mr. Clean Conference, USA location varies (2 days). Annual in Fall or Spring. *Contact, John Dennis, recently deceased.*

Surface-Cleaning Related Journals and Subscriptions

*A2C2: The Journal of Advanced Applications in Contamination Control Vicon Publishing, LLC 62 Route 101A, Ste. 3 Amherst, NH 03031 USA Tel. (603) 672-9997 Fax (603) 672-3028	Free Monthly (Supported by Vendor Advertisements) Circulation: 30,000+ Mostly USA
CleanRooms: The Magazine of Contamination Control Technology PennWell Publishing Company 10 Tara Blvd., 5th Floor Nashua, NH 03062 USA Tel. (603) 891-0123 Fax (603) 891-9200	Free Monthly (Supported by Vendor Advertisements) Circulation: 2,500 USA and Canada
MICRO "Defect Reduction and Yield Enhancement Strategies for Semiconductors and Advanced Microelelectronics" Canon Publications 11444 West Olympic Blvd. Ste. 900 Los Angeles, CA 90064 USA Tel. (310) 392-5509 Fax (310) 445-4299	Free Monthly (Supported by Vendor Advertisements) Circulation: 27,000 Mostly USA
Mr. Clean's Corner: An International Newsletter "Bringing Technical and Business People Together" Publisher John Dennis (*recently deceased*) 15215 Collmer Road Black Forest, CO 80908 USA Tel. (719) 495-3057	Free Monthly (Supported by Vendor Advertisements and Related Businesses) Circulation: 10,000 26 countries
Parts Cleaning: The Magazine of Industrial Metal Cleaning Cleaning Technology Group 84 Park Avenue Flemington, NJ 08822 USA Tel. (908) 788-0343 Fax (908) 788-3782	Free Monthly (Supported by Vendor Advertisements) Circulation: 45,000 USA and Canada
Precision Cleaning: The Magazine of Critical Cleaning Technology Witter Publishing Corporation 84 Park Avenue Flemington, NJ 08822 USA Tel. (908) 788-0343 Fax (908) 788-3782	Free Monthly (Supported by Vendor Advertisements) Circulation: 30,000 USA and Canada
Products Finishing 6915 Valley Avenue Cincinnati, OH 45244-3029 USA Tel. (513) 527-8800 Fax (513) 527-8801	Free Monthly (Supported by Vendor Advertisements) Circulation: 45,000 Mostly USA

*Also publishes the Journal of Cleaning Science. Not supported by vendor advertisements. Premiere Issue, March 2000. Circulation: 5,000 Northeast USA.

Appendix E. Complete List of Hyperlinked ASTM Standards for Cleaning

B322-85 Standard Practice for Cleaning Metals Prior to Electroplating
A380-96 Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
E1971-98 Standard Guide for Stewardship for the Cleaning of Commercial and Institutional Buildings
D6361-98 Standard Guide for Selecting Cleaning Agents and Processes
D5703-95 Standard Practice for Preparatory Surface Cleaning for Clay Brick Masonry
G93-96 Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments
D5533-98 Standard Test Method for Evaluation of Automotive Engine Oils in the Sequence IIIE, Spark-Ignition Engine
D5107-90 Standard Practice for Preparatory Surface Cleaning of Architectural Sandstone
D4488-95 Standard Guide for Testing Cleaning Performance of Products Intended for Use on Resilient Flooring and Washable Walls
D4258-83(1999) Standard Practice for Surface Cleaning Concrete for Coating
D4174-89(1999) Standard Practice for Cleaning, Flushing, and Purification of Petroleum Fluid Hydraulic Systems
G127-95 Standard Guide for the Selection of Cleaning Agents for Oxygen Systems
G122-96 Standard Test Method for Evaluating the Effectiveness of Cleaning Agents
D5343-97 Standard Guide for Evaluating Cleaning Performance of Ceramic Tile Cleaners
D5245-92 Standard Practice for Cleaning Laboratory Glassware, Plasticware, and Equipment Used in Microbiological Analyses
D4261-83(1999) Standard Practice for Surface Cleaning Concrete Unit Masonry for Coating
D800-91 Standard Test Methods of Chemical Analysis of Industrial Metal Cleaning Compositions
F1105-95(1999)e1 Standard Test Method for Preparing Aircraft Cleaning Compounds, Liquid-Type, Temperature-Sensitive, or Solvent-Based, for Storage Stability Testin
D2200-95 Pictoral Surface Preparation Standards for Painting Steel Surfaces
G121-98 Standard Practice for Preparation of Contaminated Test Coupons for the Evaluation of Cleaning Agents
F945-98 Standard Test Method for Stress-Corrosion of Titanium Alloys by Aircraft Engine Cleaning Materials
F91-70(1996) Standard Practice for Testing for Leaks in the Filters Associated With Laminar Flow Clean Rooms and Clean Work Stations by Use of a Condensation Nuclei Detector
F1567-94 Standard Specification for Fabricated or Cast Automatic Self-Cleaning, Fuel Oil and Lubricating Oil Strainers
F1518-94 Standard Practice for Cleaning and Disinfection of Flexible Fiberoptic and Video Endoscopes Used in the Examination of the Hollow Viscera
F318-78(1996) Standard Practice for Sampling Airborne Particulate Contamination in Clean Rooms for Handling Aerospace Fluids
F1409-94 Standard Test Method for Straight Line Movement of Cleaners While Cleaning Carpets
F820-95 Standard Test Method for Measuring Air Performance Characteristics of Central Vacuum Cleaning Systems
E1857-97 Standard Guide for Selection of Cleaning Techniques for Masonry, Concrete, and Stucco Surfaces
D3276-96 Standard Guide for Painting Inspectors (Metal Substrates)
D1374-89 Standard Test Method of Aerated Total Immersion Corrosion Test for Metal Cleaners
D1280-89 Standard Test Method of Total Immersion Corrosion Test for Soak Tank Metal Cleaners
G131-96 Standard Practice for Cleaning of Materials and Components by Ultrasonic Techniques
F1620-96 Standard Practice for Calibrating a Scanning Surface Inspection System Using Monodisperse Polystyrene Latex Spheres Deposited on Polished or Epitaxial Wafer Surfaces
F1471-93 Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air- Filter System
F1284-92 Standard Test Method for Evaluating Carpet Embedded Dirt Removal Effectiveness of Residential Central Vacuum Cleaning Systems
F1104-87(1998) Standard Test Method for Preparing Aircraft Cleaning Compounds, Liquid Type, Water Base, for Storage Stability Testing
F50-92(1996) Standard Practice for Continuous Sizing and Counting of Airborne Particles in Dust-Controlled Areas and Clean Rooms Using Instruments Capable of Detecting Single Sub-Micrometre and Larger Partic
F25-68(1995)e1 Standard Test Method for Sizing and Counting Airborne Particulate Contamination in Clean Rooms and Other Dust-Controlled Areas Designed for Electronic and Similar Applications
E1575-98 Standard Practice for Pressure Water Cleaning and Cutting
D4417-93 Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel
D1825-92 Standard Practice for Etching and Cleaning Copper-Clad Electrical Insulating Materials and Thermosetting Laminates for Electrical Testing
D235-95 Standard Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
C912-93(1997) Standard Practice for Designing a Process for Cleaning Technical Glasses
B614-95 Standard Practice for Descaling and Cleaning Zirconium and Zirconium Alloy Surfaces
B600-91(1997)e1 Standard Guide for Descaling and Cleaning Titanium and Titanium Alloy Surfaces
D2758-94(1998)e1 Standard Test Method for Engine Coolants by Engine Dynamometer
F1428-92(1999) Standard Specification for Aluminum Particle-Filled Basecoat/Organic or Inorganic Topcoat, Corrosion Protective Coatings for Fasteners
F502-93(1998)e1 Standard Test Method for Effects of Cleaning and Chemical Maintenance Materials on Painted Aircraft Surfaces
D1060-96 Standard Practice for Core Sampling of Raw Wool in Packages for Determination of Percentage of Clean Wool Fiber Present
G1-90(1999)e1 Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

F1692-96 Standard Test Method for Life Evaluation of a Turbine-Powered Nozzle for Household Central Vacuum Cleaning Systems

F1601-96 Standard Test Method for Motor Life Evaluation of an Electric Motorized Nozzle for Central Vacuum Cleaning Systems

F1178-88(1994)e1 Standard Specification for Enameling System, Baking, Metal Joiner Work and Furniture

E1837-96 Standard Test Method to Determine Efficacy of Disinfection Processes for Reusable Medical Devices (Simulated Use Test)

D5759-95 Standard Guide for Characterization of Coal Fly Ash and Clean Coal Combustion Fly Ash for Potential Uses

D4262-83(1999) Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces

C756-87 Standard Test Method for Cleanability of Surface Finishes

D5844-98 Standard Test Method for Evaluation of Automotive Engine Oils for Inhibition of Rusting (Sequence IID)

D2986-95a Standard Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test

G136-96 Standard Practice for Determination of Soluble Residual Contaminants in Materials by Ultrasonic Extraction

G120-95 Standard Practice for Determination of Soluble Residual Contamination in Materials and Components by Soxhlet Extraction

G31-72(1995)e1 Standard Practice for Laboratory Immersion Corrosion Testing of Metals

F1310-90 Standard Specification for 65-Gallon Dispensing Tank

F111-96 Standard Practice for Determining Barium Yield, Getter Gas Content, and Getter Sorption Capacity for Barium Flash Getters

E1793-96 Standard Practice for Preparation of Aluminum Alloy for Bonding in Foam and Beam Type Transportable Shelters

E1560-95 Standard Test Method for Gravimetric Determination of Nonvolatile Residue From Cleanroom Wipers

E1548-93(1998) Standard Practice for Preparation of Aerospace Contamination Control Plans

E165-95 Standard Test Method for Liquid Penetrant Examination

D4010-83 Standard Specification for Waterless Hand Cleaner

D3399-81(1992)e1 Standard Specification for General-Purpose Synthetic Detergent Liquid

D2960-98 Standard Test Method of Controlled Laundering Test Using Naturally Soiled Fabrics and Household Appliances

D2356-88e1 Standard Specification for Phosphate and Silica Containing Scouring Powder Compounds

D458-85(1998) Standard Specification for Soda Ash

D457-85(1997) Standard Specification for Modified Soda (Sesquicarbonate Type)

D456-85(1997) Standard Specification for Caustic Soda (Anhydrous)

B879-97 Standard Practice for Applying Non-Electrolytic Conversion Coatings on Magnesium and Magnesium Alloys

A849-97 Standard Specification for Post-Applied Coatings, Pavings, and Linings for Corrugated Steel Sewer and Drainage Pipe

G144-96 Standard Test Method for Determination of Residual Contamination of Materials and Components by Total Carbon Analysis Using a High-Temperature Combustion Analyzer

F1530-94 Standard Test Method for Measuring Flatness, Thickness, and Thickness Variation on Silicon Wafers by Automated Noncontact Scanning

F1449-92 Standard Guide for Care and Maintenance of Flame Resistance and Thermal Protective Clothing

F1280-90(1994)e1 Standard Guide for Ecological Considerations for the Use of Oilspill Dispersants in Freshwater and Other Inland Environments, Impermeable Surface

F1279-90(1994)e1 Standard Guide for Ecological Considerations for the Use of Oilspill Dispersants in Freshwater and Other Inland Environments, Permeable Surface

F1231-89(1994)e1 Standard Guide for Ecological Considerations for the Use of Oilspill Dispersants in Freshwater and Other Inland Environments, Rivers and Creek

F1210-89(1994)e1 Standard Guide for Ecological Considerations for the Use of Oilspill Dispersants in Freshwater and Other Inland Environments, Lakes and Large Water Bodies

F1209-89(1994)e1 Standard Guide for Ecological Considerations for the Use of Oilspill Dispersants in Freshwater and Other Inland Environments, Ponds and Slough

F523-93(1997) Standard Practice for Unaided Visual Inspection of Polished Silicon Wafer Surfaces

E1766-95 Standard Test Method for Determination of Effectiveness of Sterilization Processes for Reusable Medical Devices

E1191-97 Standard Guide for Conducting Life-Cycle Toxicity Tests with Saltwater Mysids

E1022-94 Standard Guide for Conducting Bioconcentration Tests with Fishes and Saltwater Bivalve Mollusks

E864-98 Standard Practice for Surface Preparation of Aluminum Alloys to be Adhesively Bonded in Honeycomb Shelter Panels

E709-95 Standard Guide for Magnetic Particle Examination

D6332-99 Standard Guide for Testing Systems for Measuring Dynamic Responses of Carbon Monoxide Detectors to Gases and Vapors

D6067-96 Standard Test Method for Using the Electronic Cone Penetrometer for Environmental Site Characterization

D5607-95 Standard Test Method for Performing Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force

D5396-94 Standard Specification for Reclaimed Perchloroethylene

D5349-95 Standard Test Method for Determination of the Moisture and Volatile Content of Sulfonated and Sulfated Oils by Hot-Plate Method

D5119-99 Standard Test Method for Evaluation of Automotive Engine Oils in the CRC L-38 Spark-Ignition Engine

D4770-88 Standard Test Method for Evaluation of Man-Made Fiber Batting Used as Filling in Outerwear Apparel

D4389-99 Standard Specification for Finished Glass Fabrics Woven From Rovings

D4285-83(1999) Standard Test Method for Indicating Oil or Water in Compressed Air

D4276-95 Standard Practice for Confined Area Entry
D4029-90 Standard Specification for Finished Woven Glass Fabrics
D3938-96 Standard Guide for Determining or Confirming Care Instructions for Apparel and Other Textile Consumer Products
D1570-95 Standard Test Methods for Sampling and Chemical Analysis of Fatty Alkyl Sulfates
D1113-90ae1 Standard Test Method for Vegetable Matter and Other Alkali-Insoluble Impurities in Scoured Wool
D820-93 Standard Test Methods for Chemical Analysis of Soaps Containing Synthetic Detergents
D584-96 Standard Test Method for Wool Content of Raw Wool-Laboratory Scale
D495-99 Standard Test Method for High-Voltage, Low -Current, Dry Arc Resistance of Solid Electrical Insulation
D460-91(1997) Standard Test Methods for Sampling and Chemical Analysis of Soaps and Soap Products
A829/A829M-95 Standard Specification for Alloy Structural Steel Plates
PS53-97 Provisional Standard Guide for Identification and Management of Lead Hazards in Facilities
G128-95 Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems
F1920-98 Standard Test Method for the Energy Performance of Rack Conveyor, Hot Water Sanitizing, Commercial Dishwashing Machines
F1715-96 Standard Guide for Gravimetric Wear Assessment of Prosthetic Knee Designs in Simulator Devices
F1701-96e1 Standard Specification for Unused Polypropylene Rope with Special Electrical Properties
F1617-98 Standard Test Method for Measuring Surface Sodium, Aluminum, and Potassium on Silicon and EPI Substrates by Secondary Ion Mass Spectrometry
F1531-94 Standard Test Method for Comparing Printer or Copier Cartridges
F1526-95 Standard Test Method for Measuring Surface Metal Contamination on Silicon Wafers by Total Reflection X-Ray Fluorescence Spectroscopy
F1464-93 Standard Specification for Oxygen Concentrators for Domiciliary Use
F1451-92(1999) Standard Test Method for Measuring Sori on Silicon Wafers by Automated Noncontact Scanning
F1438-93(1999) Standard Test Method for Determination of Surface Roughness by Scanning Tunneling Microscopy for Gas Distribution System Components
F1398-93(1999) Standard Test Method for Determination of Total Hydrocarbon Contribution by Gas Distribution System Components
F1397-93(1999) Standard Test Method for Determination of Moisture Contribution by Gas Distribution System Components
F1396-93(1999) Standard Test Method for Determination of Oxygen Contribution by Gas Distribution System Components
F1394-92(1999) Standard Test Method for Determination of Particle Contribution from Gas Distribution System Valves
F1390-97 Standard Test Method for Measuring Warp on Silicon Wafers by Automated Noncontact Scanning
F1376-92(1999) Standard Guide for Metallurgical Analysis for Gas Distribution System Components
F1375-92(1999) Standard Test Method for Energy Dispersive X-Ray Spectrometer (EDX) Analysis of Metallic Surface Condition for Gas Distribution System Components
F1374-92(1999) Standard Test Method for Ionic/Organic Extractables of Internal Surfaces-IC/GC/FTIR for Gas Distribution System Components
F1373-93(1999) Standard Test Method for Determination of Cycle Life of Automatic Valves for Gas Distribution System Components
F1372-93(1999) Standard Test Method for Scanning Electron Microscope (SEM) Analysis of Metallic Surface Condition for Gas Distribution System Components
F1012-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-the Arctic
F1010-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Bird Habitats
F1009-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Offshore
F1008-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Salt Marshes
F999-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Gravel or Cobble Beaches
F991-86 Standard Specification for Docking/Drain Plug and Boss Assemblies
F990-86(1993)e1 Standard Guide for Ecological Considerations for Use of Chemical Dispersants in Oil Spill Response-Sandy Beaches
F973-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response Tidal Flats
F972-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Nearshore Subtidal
F971-86(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response Mangroves
F932-85(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Coral Reefs
F931-85(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response- Seagrasses
F930-85(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Rocky Shores
F929-85(1993)e1 Standard Guide for Ecological Considerations for the Use of Chemical Dispersants in Oil Spill Response-Marine Mammals
F861-94(1998) Standard Specification for Commercial Dishwashing Racks
F657-92(1999) Standard Test Method for Measuring Warp and Total Thickness Variation on Silicon Wafers by Noncontact Scanning
F608-97 Standard Laboratory Test Method for Evaluation of Carpet-Embedded Dirt Removal Effectiveness of Household Vacuum Cleaners
F558-98 Standard Test Method for Measuring Air Performance Characteristics of Vacuum Cleaners
F519-97e2 Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating Processes and Service Environments

F303-78(1989)e1 Standard Practices for Sampling Aerospace Fluids from Components

F289-96 Standard Specification for Molybdenum Wire and Rod for Electronic Applications

F150-98 Standard Test Method for Electrical Resistance of Conductive and Static Dissipative Resilient Flooring

F76-86(1996)e1 Standard Test Methods for Measuring Resistivity and Hall Coefficient and Determining Hall Mobility in Single-Crystal Semiconductors

E1920-97 Standard Guide for Metallographic Preparation of Thermal Sprayed Coatings

E1752-95 Standard Guide for Collection of Multi-Media Field Emission and Discharge Data Associated with Glycol Dehydration Units

E1731M-95 Standard Test Method for Gravimetric Determination of Nonvolatile Residue from Cleanroom Gloves [Metric]

E1611-94 Standard Guide for Conducting Sediment Toxicity Tests with Marine and Estuarine Polychaetous Annelids

E1563-98 Standard Guide for Conducting Static Acute Toxicity Tests with Echinoid Embryos

E1562-94 Standard Guide for Conducting Acute, Chronic, and Life-Cycle Aquatic Toxicity Tests with Polychaetous Annelids

E1498-92(1998) Standard Guide for Conducting Sexual Reproduction Tests with Seaweeds

E1417-99 Standard Practice for Liquid Penetrant Examination

E1367-99 Standard Guide for Conducting 10-day Static Sediment Toxicity Tests with Marine and Estuarine Amphipods

E1295-89 Standard Guide for Conducting Three-Brood, Renewal Toxicity Tests with Ceriodaphnia dubia

E1265-90(1995)e1 Standard Test Method for Measuring Insertion Loss of Pneumatic Exhaust Silencers

E1241-98 Standard Guide for Conducting Early Life-Stage Toxicity Tests with Fishes

E1218-97a Standard Guide for Conducting Static 96-h Toxicity Tests with Microalgae

E1193-97 Standard Guide for Conducting Daphnia magna Life-Cycle Toxicity Tests

E1099-96 Standard Specification for Soda Ash, Anhydrous (Sodium Carbonate, Anhydrous)

E987-88(1994)e1 Standard Test Methods for Deglazing Force of Fenestration Products

E866-96 Standard Specification for Corrosion-Inhibiting Adhesive Primer for Aluminum Alloys to Be Adhesively Bonded in Honeycomb Shelter Panels

E729-96 Standard Guide for Conducting Acute Toxicity Tests on Test Materials with Fishes, Macroinvertebrates, and Amphibians

E724-98 Standard Guide for Conducting Static Acute Toxicity Tests Starting with Embryos of Four Species of Saltwater Bivalve Molluscs

E712-80(1992)e1 Standard Practice for Laboratory Screening of Metallic Containment Materials for Use With Liquids in Solar Heating and Cooling Systems

E271-98 Standard Test Methods for Analysis of Aqueous Hydrofluoric Acid

E3-95 Standard Practice for Preparation of Metallographic Specimens

D6321-98 Standard Practice for the Evaluation of Machine Washable T-Shirts

D6237-98 Standard Guide for Painting Inspectors (Concrete and Masonry Substrates)

D5913-96 Standard Test Method for Evaluation of Cleanability of Paint Brushes

D5862-99 Standard Test Method for Evaluation of Engine Oils in Two-Stroke Cycle Turbo-Supercharged 6V92TA Diesel Engine

D5765-95 Standard Practice for Solvent Extraction of Total Petroleum Hydrocarbons from Soils and Sediments Using Closed Vessel Microwave Heating

D5616-94 Standard Specification for Reclaimed Trichloroethylene

D5544-94 Standard Test Method for On-Line Measurement of Residue After Evaporation of High-Purity Water

D5491-98 Standard Classification for Recycled Post-Consumer Polyethylene Film Sources for Molding and Extrusion Materials

D5369-93(1998) Standard Practice for Extraction of Solid Waste Samples for Chemical Analysis Using Soxhlet Extraction

D5367-94 Standard Practice for Evaluating Coatings Applied Over Surfaces Treated With Inhibitors Used to Prevent Flash Rusting of Steel When Water or Water/Abrasive Blasted

D5354-95 Standard Test Method for Determination of Total Active Ingredients in Sulfonated and Sulfated Oils

D5353-95 Standard Test Method for Determination of Total Desulfated Fatty Matter

D5352-95 Standard Test Method for Determination of Organically Combined Sulfuric Anhydride Ash-Gravimetric, Test Method C

D5350-95 Standard Test Method for Determination of Organically Combined Sulfuric Anhydride by Titration, Test Method A

D5348-95 Standard Test Method for Determination of the Moisture Content of Sulfonated and Sulfated Oils by Distillation with Xylene

D5347-95 Standard Test Method for Determination of the Ash Content of Fats and Oils

D5287-97 Standard Practice for Automatic Sampling of Gaseous Fuels

D5217-91 Standard Guide for Detection of Fouling and Degradation of Particulate Ion Exchange Materials

D5127-99 Standard Guide for Ultra Pure Water Used in the Electronics and Semiconductor Industry

D5030-89(1994)e1 Standard Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit

D5012-89(1994)e1 Standard Guide for Preparation of Materials Used for the Collection and Preservation of Atmospheric Wet Deposition

D4995-89(1995)e1 Standard Specifications for Electronic and Degreasing Grades of 1,1,2-Trichloro 1,2,2,-Trifluoroethane Solvent

D4844-88(1998) Standard Guide for Air Monitoring at Waste Management Facilities for Worker Protection

D4814-99 Standard Specification for Automotive Spark-Ignition Engine Fuel

D4749-87(1994)e1 Standard Test Method for Performing the Sieve Analysis of Coal and Designating Coal Size
D4687-95 Standard Guide for General Planning of Waste Sampling
D4542-95 Standard Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
D4494-95 Standard Test Method for Detecting Residual Odor of Drycleaning Grade Perchloroethylene
D4386-95 Standard Practice for Application of Floor Polishes to Maintain Multilayer Composite Tile or Flooring
D4330-94(1997) Standard Practice for Evaluation of Fiberglass Boat Polish and Wax
D4265-98 Standard Guide for Evaluating Stain Removal Performance in Home Laundering
D3959-91(1997) Standard Test Method for Rubber- and Plastic-Coated Fabrics-Discoloration Sensitivity to Tobacco Smoke
D3790-79(1991)e1 Standard Test Method for Volatile Matter (Moisture) of Leather by Oven Drying
D3692-89 Standard Practice for Selection of Zippers for Care-Labeled Apparel and Household Furnishings
D3673-89(1995)e1 Standard Test Methods for Chemical Analysis of Alpha Olefin Sulfonates
D3564-95 Standard Practice for Application of Floor Polishes to Maintain Vinyl Composition Tile or Flooring
D3514-96 Standard Test Method for Pilling Resistance and Other Related Surface Changes of Textile Fabrics: Elastomeric Pad
D3454-97 Standard Test Method for Radium-226 in Water
D3316-96 Standard Test Method for Stability of Perchloroethylene with Copper
D2985-92 Standard Test Method for Color of Asbestos
D2812-88 Standard Test Method for Non-Lint Content of Cotton
D2784-98 Standard Test Method for Sulfur in Liquefied Petroleum Gases (Oxy-Hydrogen Burner or Lamp)
D2724-87 Standard Test Methods for Bonded, Fused, and Laminated Apparel Fabrics
D2525-90 Standard Practice for Sampling Wool for Moisture
D2251-96 Standard Test Method for Metal Corrosion by Halogenated Organic Solvents and Their Admixtures
D2234-98 Standard Practice for Collection of a Gross Sample of Coal
D2157-94(1999) Standard Test Method for Effect of Air Supply on Smoke Density in Flue Gases From Burning Distillate Fuels
D2156-94(1999) Standard Test Method for Smoke Density in Flue Gases from Burning Distillate Fuels
D2058-87(1992)e1 Standard Test Method for Durability of Finish of Zippers to Drycleaning
D2052-85(1990)e1 Standard Test Method for Colorfastness of Zippers to Drycleaning
D2051-86(1991)e1 Standard Test Method for Durability of Finish of Zippers to Laundering
D2022-89(1995)e1 Standard Test Methods of Sampling and Chemical Analysis of Chlorine-Containing Bleaches
D2013-86 Standard Method of Preparing Coal Samples for Analysis
D1779-98 Standard Specification for Adhesive for Acoustical Materials
D1732-67(1998) Standard Practices for Preparation of Magnesium Alloy Surfaces for Painting
D1730-67(1998) Standard Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting
D1567-89 Standard Test Method for Detergent Cleaners for Evaluation of Corrosive Effects on Certain Porcelain Enamels
D1334-96 Standard Test Method for Wool Content of Raw Wool-Commercial Scale
D1061-95(1999) Standard Specification for Asbestos Lap
D929-85(1997) Standard Specification for Borax
D928-87(1998) Standard Specification for Sodium Bicarbonate
D658-91 Standard Test Method for Abrasion Resistance of Organic Coatings by Air Blast Abrasive
D609-95 Standard Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products
D595-85(1997) Standard Specification for Tetrasodium Pyrophosphate (Anhydrous)
D594-85(1997) Standard Specification for Sodium Sesquisilicate
D538-85(1997) Standard Specification for Trisodium Phosphate
D537-85(1997) Standard Specification for Sodium Metasilicate
D500-95 Standard Test Methods of Chemical Analysis of Sulfonated and Sulfated Oils
D498-74(1990)e1 Standard Specification for Powdered Soap (Nonalkaline Soap Powder)
D497-69(1990)e1 Standard Specification for Ordinary Laundry Bar Soap
D496-74(1990)e1 Standard Specification for Chip Soap
D257-93(1998) Standard Test Methods for DC Resistance or Conductance of Insulating Materials
C1378-97 Standard Test Method for Determination of Resistance to Staining
C1309-97 Standard Practice for Performance Evaluation of In-Plant Walk-Through Metal Detectors

C1265-94 Standard Test Method for Determining the Tensile Properties of an Insulating Glass Edge Seal for Structural Glazing Applications

C675-91(1996) Standard Test Method for Alkali Resistance of Ceramic Decorations on Returnable Beverage Glass Containers

C428-97 Standard Specification for Asbestos-Cement Nonpressure Sewer Pipe

B849-94 Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement

B828-98 Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings

B819-95 Standard Specification for Seamless Copper Tube for Medical Gas Systems

B812-96 Standard Test Method for Resistance to Environmental Degradation of Electrical Pressure Connections Involving Aluminum and Intended for Residential Application

B810-96 Standard Test Method for Calibration of Atmospheric Corrosion Test Chambers by Change in Mass of Copper Coupons

B727-83(1995) Standard Practice for Preparation of Plastics Materials for Electroplating

B253-87 Standard Guide for Preparation of Aluminum Alloys for Electroplating

B242-54(1990) Standard Practice for Preparation of High-Carbon Steel For Electroplating

B183-79(1997) Standard Practice for Preparation of Low-Carbon Steel for Electroplating

A967-96 Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts

A888-98e1 Standard Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications

A650/A650M-98 Standard Specification for Tin Mill Products, Black Plate, Double Reduced

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TURI
SURFACE CLEANING LABORATORY

EXPERIMENTAL PARAMETER LOG

SCL #: 95-409-01-2*
DATE: July 5, 1995
EXPERIMENTEER: Garlotta/ Jankauskas
CLIENT: Electro-Optical Devices
CLASSIFICATION:1st cleaning trial for Electro-Optical Devices
DESCRIPTION OF WORK: Parts were contaminated with wax obtained from Electro-Optical Devices and cleaned with ultrasonics. Gravimetric analysis was used.
SUBSTRATE MATERIAL:Glass
CONTAMINANTS:wax (blanchard #5 stacking wax is comparable)
CONTAMINATING PROCESS USED: applied on with glass rod

EXPERIMENTAL PLAN AND PROCEDURES: The purpose of this trial is to get some cleaners that would be appropriate for Electro-Optical Devices's needs.

Two different cleaners will be used. Since we really don't know how much time will be needed for removal of the wax, we will check the glass parts at 5 minute intervals and remove the part from the cleaning bath when we deem appropriate. The two cleaners are the Oakite Inproclean #3800 and Church & Dwight Armakleen 2002. A 15% solution of each will be used. Cleaning will be done in an ultrasonic tank at 150^{o} F, rinsing will be done at the same temperature in tap water for two minutes. The parts will be dried under air knives for two minutes and then placed in a convection oven set at 190^{o} F for 20 minutes. The parts will then be cooled down for one hour and then analysed gravimetrically.

After the first two trial were ran we decided to do a third in which the Oakite Inproclean #3800 was used at a 5% concentration.

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TURI
SURFACE CLEANING LABORATORY
EXPERIMENTAL PARAMETER LOG

TRIAL #1
SAMPLE NUMBERS: #1
CLEANING PRODUCT: Oakite Inproclean #3800
CONCENTRATION: 15% by Volume

TRIAL #2
SAMPLE NUMBERS: #2
CLEANING PRODUCT: Church & Dwight Armakleen 2002
CONCENTRATION: 15% by Volume

TRIAL #3
SAMPLE NUMBERS: #3
CLEANING PRODUCT: Oakite Inproclean #3800
CONCENTRATION: 5% by Volume

CLEANING CONDITIONS:

	time (min)	Temperature		
		trial #1	trial #2	trial #3
Ultrasonics	5, 15, 10	149	158	150
#1 RINSE/TAP H_2O	2	150	150	150
#2 RINSE/DEIONIZED H_2O				
#3 RINSE H_2O				
DRY air knives	2	room	room	room
DRY convection oven	20	190	190	190
DRY				
DRY				
COOL DOWN	60	room	room	room

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OBSERVATIONS: The Oakite Inproclean #3800 performed the best with outstanding wax removal after just 5 minutes. The one problem which might not be major is that the wax dissolves in the cleaner solution solution so that removal of wax from the cleaner bath can't be accomplished. When using the 5% solution of Inproclean #3800 the wax was easily separated from the cleaning solution, a slightly longer cleaning time was necessary and there seemed to be some kind of cloudiness on the glass.

The Armakleen 2002 was the least sucessful. Quite a bit of wax residue remained on the glass parts and it seems some of the wax dissolved into the cleaning solution. The greater than 100% removal obtained was due to some coating that the Armakleen removed which was on the part prior to weighing.

TURI
SURFACE CLEANING LAB

EXPERIMENTAL DATA LOG

GRAVIMENTRIC ANALYSIS

sample #	clean mass (g)	mass with contamination (g)	mass after cleaning (g)	contaminant removed (g)	Percent Removal
#1	18.5032	19.9066	18.5034	1.4032	99.99%
#2	18.7390	19.9260	18.7318	1.1942	100.61%
#3	18.5032	20.1649	18.5033	1.6616	99.99%

CONCLUSIONS: The Oakite #3800 looks excellent at both concentrations. May want to leave the 5% solution in for 15 minutes instead of 10 and use a DI water rinse to avoid spotting. Although the Armakleen showed good removal this is due to the amount of coating that the Armakleen had removed. A slight amount of wax residue was noticed on the glass.

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TURI
SURFACE CLEANING LABORATORY
EXPERIMENTAL

PARAMETER LOG
SCL #: 95-409-02-2
DATE: July 31, 1995
TEST REPORT NUMBER:
EXPERIMENTER: Jankauskas
CLIENT: Electro-Optical Devices
SUBSTRATE MATERIAL: Soda-Lime Glass
CONTAMINANTS: Blanchard Stacking Wax #5
CONTAMINATING PROCESS USED: melted wax applied w. swab & allowed to set overnight
ANALYTIC METHODS: visual, waterbreak, gravimetric

EXPERIMENTAL PLAN AND PROCEDURES:

The purpose of this trial is to see if stirbar agitation would be suitable for Electro-Optical Devices's needs. Four different cleaners will be tested in a stirbar agitated beaker with and without brushing.

Cleaning was done in a stirbar agitated beaker set at 150° F. Cleaning time will be determined during the trial depending on the cleaner's effectiveness. Two glass samples will be used for each cleaner, one sample will be cleaned solely by the agitation, while the second sample will brushed for a few seconds. The samples will be rinsed in a tap water bath for 1 minute at 150° F and then in a DI water rinse for 1 minute at room temperature. The parts will then be dried under an air knife for 2 minutes and then in a convection oven set at 120° F for 30 minutes.

The samples will be analyzed gravimetrically to get a percent removal. The samples will be observed with a waterbreak test to detect any residual wax. After drying, the samples will be checked for any water spotting that may occur.

Trial #1-
SAMPLE NUMBERS: #1, #2(brushed)
CLEANING PRODUCT: Alconox Alcojet Detergent
CONCENTRATION: 2% solution (20 grams per liter solution)

Trial #2-
SAMPLE NUMBERS: #3, #4(brushed)
CLEANING PRODUCT: International Products Micro
CONCENTRATION: 4% by volume

Trial #3-
SAMPLE NUMBERS: #5, #6(brushed)
CLEANING PRODUCT: Oakite Inproclean #3800
CONCENTRATION: 10% by volume

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Trial #4-
SAMPLE NUMBERS: #7, #8(brushed)
CLEANING PRODUCT: Innovative Organics L-12 cleaner
CONCENTRATION: 10% by volume

CLEANING CONDITIONS:

	time (min)	Temperature trial #1	 trial #2	 trial #3	 trial #4
stirbar agitation	15	152	152	157	149
#1 RINSE/TAP H_2O	1	153	150	149	151
#2 RINSE/DEIONIZED H_2O	1	80	80	80	80
DRY air knives	1	room	room	room	room
DRY convection oven	30	127	136	127	127
COOL DOWN	60	room	room	room	room

OBSERVATIONS:

After cooling down, all the cleaners were ranked in four categories; Percent Removal without brushing, Removal with brushing. Wax separation from cleaner solution, and Spotting. For each category, each cleaners was assigned a number from one to four, one is for the best performer, while four is for the worst.

	Percent Removal	Brushing Removal	Wax Separation	Spotting
Alcojet	1	1	2	1
Micro	3	3	1	3
Inproclean #3800	2	1	3	1
L-12	4	4	4	4

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GRAVIMETRIC ANALYSIS

sample #	clean mass (g)	mass with contamination (g)	mass after cleaning (g)	contaminant removed (g)	Percent Removal
1	14.8777	15.8713	14.8775	0.9938	100.02%
2	16.5521	19.1277	16.5516	2.5761	100.02%
3	**12.3687**	**14.1690**	**12.6813**	**1.4877**	**82.64%**
4	**14.3598**	**16.6013**	**14.3642**	**2.2371**	**99.80%**
5	15.0674	17.3836	15.0732	2.3104	99.75%
6	13.3556	15.6748	13.3559	2.3189	99.99%
7	*14.0975*	*16.1344*	*15.1696*	*0.9648*	*47.37%*
8	*15.7478*	*18.6593*	*15.7907*	*2.8686*	*98.53%*

Normal - Alconox Alcojet
Bold - International Products Group Micro
Underline - Oakite Inproclean #3800
Italic - Innovative Organics L-12

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TURI
SURFACE CLEANING LABORATORY
EXPERIMENTAL
PARAMETER LOG

SCL #: 95-409-03-2
DATE: August 1, 1995
TEST REPORT NUMBER:
EXPERIMENTER: Jankauskas/Garlotta
CLIENT: Electro-Optical Devices
SUBSTRATE MATERIAL: Soda-Lime Glass
CONTAMINANTS: Blanchard Stacking Wax #5
CONTAMINATING PROCESS USED: melted wax applied on with swab and allowed to set overnight
ANALYTIC METHODS: visual, waterbreak

EXPERIMENTAL PLAN AND PROCEDURES:

The purpose of this trial is to determine the effectiveness of ultrasonics for Electro-Optical Devices.

Cleaning was done in beaker ultrasonics set at 150° F. Cleaning time will be determined during the trial depending on the cleaner's effectiveness. Two glass samples will be used for each cleaner. The samples will be rinsed in a tap water bath for 1 minute at 150° F and then in a DI water rinse for 1 minute at room temperature. The parts will then be dried under an air knife for 1 minute and then in a convection oven set at 120° F for 30 minutes.

The samples will be analyzed gravimetrically to get a percent removal. The samples will be observed with a waterbreak test to detect any residual wax. After drying, the samples will be checked for any water spotting that may occur.

Trial #1-
SAMPLE NUMBERS: #1, #2
CLEANING PRODUCT: Alconox Alcojet Detergent
CONCENTRATION: 2% solution (20 grams per liter solution)

Trial #2-
SAMPLE NUMBERS: #3, #4
CLEANING PRODUCT: International Products Micro
CONCENTRATION: 4% by volume

Trial #3-
SAMPLE NUMBERS: #5, #6
CLEANING PRODUCT: Oakite Inproclean #3800
CONCENTRATION: 10% by volume

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Trial #4-
SAMPLE NUMBERS: #7, #8
CLEANING PRODUCT: Innovative Organics L-12 cleaner
CONCENTRATION: 10% by volume

CLEANING CONDITIONS:

	time (min)	Temperature			
		trial #1	trial #2	trial #3	trial #4
Beaker Ultrasonics	15	142			144
Beaker Ultrasonics	10		149	148	
#1 RINSE/TAP H_2O	1	147	151	146	150
#2 RINSE/DEIONIZED H_2O	1	81	81	81	81
DRY air knives	1	room	room	room	room
DRY convection oven	15	131	133	136	135
COOL DOWN	60	room	room	room	room

OBSERVATIONS:

After cooling down, all the cleaners were ranked in three categories; Wax Removal, Wax Separation and Spotting. A number of one to four was assigned for each cleaner's performance, one being the best performer and four being the worst.

	Percent Removal	Wax Separation	Spotting
Alcojet	1	2	1
Micro	3	1	3
Inproclean #3800	2	2	1
L-12	4	4	4

The Innovative Organics L-12 cleaner also had the problem of redeposition during the trial. The wax would be removed and float up on the surface, after a while, the glob of wax would sink in the solution and cling to the glass surface again.

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GRAVIMETRIC ANALYSIS

sample #	clean mass (g)	mass with contamination (g)	mass after cleaning (g)	contaminant removed (g)	Percent Removal
1	14.8772	17.5155	14.8765	2.639	100.03%
2	16.5516	19.2710	16.5513	2.7197	100.01%
3	**12.3678**	**14.6132**	**12.3680**	**2.2452**	**99.99%**
4	**14.3587**	**16.9307**	**14.3591**	**2.5716**	**99.98%**
5	15.0665	18.0461	15.0665	2.9796	100.00%
6	13.3553	16.2423	13.3550	2.8873	100.01%
7	*14.0972*	*17.3542*	*14.2524*	*3.1018*	*95.23%*
8	*15.7449*	*19.4233*	*15.8566*	*3.5667*	*96.96%*

Normal - Alconox Alcojet
Bold - International Products Group Micro
Underline - Oakite Inproclean #3800
Italic - Innovative Organics L-12

CONCLUSIONS:

Immersion: The stirbar agitation appeared to provide sufficient energy for cleaning. The Alcojet and the Oakite Inproclean #3800 were both very sucessful in cleaning the glass samples. Brushing should also be considered to ensure cleanliness (International Products Micro cleaner was successful when brushing was applied).

Ultrasonics: The ultrasonics was successful for all cleaners except the Innovative Organics L-12 cleaner. Results suggest that a lower cleaning temperature can be used as opposed to aggitated immersion. The ultrasonics also provided a better separation of wax from the cleaner solution.

Rinsing: The rinsing procedures used were sucessful in removing residual cleaner from the glass and leaving a spot free surface after drying. A final rinse of cold running DI water may be appropriate (some residual cleaning solution was noticed on the samples when rinsed in a still bath of DI water).

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SURFACE CLEANING LAB
EXPERIMENTAL TEST REPORT

Prepared for:	**Report Prepared By:**
Optical Manufacturer	Jay Jankauskas SCL Technician

Abstract:

The purpose of this trial was to find an alternative cleaning method for Optical Manufacturer that will effectively remove Pexalyn and Hercolyn D resins from optical lenses attached to aluminum holders. Three different options to achieve the desired cleanliness was tested. The first option was test out the possibility of aqueous or semi-aqueous clenaing to perform the cleaning. The second was to find a replacement that will perform the necessary cleaning while minimizing environmental and worker exposure concerns. The final option evaluated was to find a replacement adhesive that would work just as effectively as the Pexalyn and Hercolyn D resins but be easier to remove.

Substrates Used:	**Cleaning Chemicals Tested**	**Contaminants encountered:**
Glass lenses attached to resins. aluminum holders.	Kyzen corp. Ionix FCR Brulin Corp. 815 PCX Church & Dwight Armakleen E-2001 Perchloroethylene Inland Tech. Citra Safe Oxychem OXSOL 100 Twin River Methyl Ester Dow Chem. Dowanol PnB Propylene Glycol Monomethyl Ether Acetate AGA Chem. AK-225 Terpene Tech. HTF-85B	Hercolyn D and Pexalyn

Saponifier Test Results:

The first option tested was to use a water based chemical to remove the resins. Normally a water based chemistry is not appropriate when cleaning tough adhesives like this in a short amount of time, but both the Hercolyn D and Pexalyn resins are rosin based. Although rosin cannot be removed by water and surfactants alone, they can be reacted with alkali and a water miscible solvent to produce a water soluble soap by the following reaction:

$$\text{Base} + C_{19}H_{29}COOH_{.}\ \text{H/Base} + C_{19}H_{29}COO^{-} \quad (1)$$

Insoluble Resin　　　　Water Soluble Rosin Soap

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Three different saponifiers were tested to see if they would be effective. All chemicals were diluted to 20% and tested in a 25 kHz Crest ultrasonic unit at 130 F. Cleaning was performed until the glass lens would dislodge from the aluminum holder or 30 minutes, whichever came first. Chemicals were noted on the effectiveness of the resin removal as well as any cavitational damage that occurred to the lens. The results for the saponification tests are shown below in Table 1:

Table 1: Test Results for Saponifiers

	Chemical Description	*Cleaning Effectiveness*	*Cavitation Effects*
Kyzen Corp. Ionox FCR	A proprietary, low vapor pressure, water miscible alcohol in an alkaline solution.	After 15 minutes, the lens was separated from the holder, a few slight traces of resin was noticed on the lenses.	Some slight scratching of the glass lens.
Brulin Corp. 815 PCX	Alkaline based solution coupled with monoethanolamine.	After 30 minutes, enough of the adhesive was removed so that the lens could be manually removed from the holder.	Glass lens looked pretty scratched due to cavitational erosion.
Church And Dwight Armakleen E-2001	A buffered solution of inorganic salts and low levels of surfactants.	Not much effect in removing the adhesive after 30 minutes.	Not much effect on the resins.

Conclusions:

Due to part configuration and contaminant type, ultrasonics would be the only possibility for a water based solution to work. A few problems would exist from using a water based system for Optical Manufacturers= application:

1) Cavitational erosion - This will increase with the amount of immersion time. The Kyzen Ionox FCR seemed to be the only effective chemistry in removing the lens from the holder, but there was evidence of cavitational erosion. The one way to solve this would be to raise the frequency of the ultrasonics. Although this will reduce cavitational erosion, it will also increase the amount of time needed to clean off these parts.

2) New Equipment- Although Optical Manufacturer=s vapor degreasing equipment could be converted into an ultrasonic cleaning/rinse system, a drying system will still be needed to remove the rinse water. Since the aluminum holders need to be at 250 F to attach new lenses for polishing, a convention heat oven would be appropriate. This would require initial capital expenditure and additional floor space.

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Test results for Solvents:

A couple problems were encountered when searching for a new solvent. The first problem was finding a solvent that had no flash point and a boiling point around 250 F. The no flash solvents that are acceptable to be used in cleaning operations are few and far between. The no flash solvents that exist that I found were AK-225, HFE 7100, Vertrel, 3M=s perfluorocarbons. There are two problems with the solvents listed previously; 1) They are very expensive (up to $10,000 per 55 gal drum), 2) They mostly tend to have low boiling points (less than 150 F), 3) They are not to effective on tough contaminants (low KB values). Due to this an appropriate mixture was not found that would successfully operate in the vapor phase.

Solvents that could possibly be used in an immersion system at 250 F were also sourced out. The one downfall that would occur from this is that drying time would take longer and certain low vapor pressure solvents would need some sort of rinse stage. Also there was a concern for flashpoint.

Seven solvents were compared to perchloroethylene in dissolving the resins. Resins were melted on several 2@ x 2@ glass plates and allowed to cool and solidify. One plate was immersed in each solvent at room temperature for five minutes. The effectiveness of each solvent was compared to perchloroethylene and noted below in Table 2:

Table 2: Solvent Test Results

	Description	*Boiling Point (F)*	*Flash Point (F)*	*Pros & Cons*	*Test results*
Perchloroethylene	Current solvent Used At Optical Manufacturer	250	None	HAP, carcinogenic.	A small amount of adhesives still remained
Citra-Safe	Highly distilled d-limonene terpene	340	132	Low flash point, will need a rinse.	Dissolved the same amount as the PERC
Oxsol 100	Parachloro-benzeotrifluoride	288	228	Not listed as a HAP or VOC but has a 25 ppm exposure limit and not the greatest odor.	Removed all traces of the adhesive within 3 minutes
Methyl Ester	Solvent naturally derived from soybeans	>400	>300	Very safe and non-flammable, very tough to rinse off.	Was not that effective
Glycol Ether DPM	Propylene based glycol ether from Dow Chemical	338	138	Has a low evaporation rate, but will not leave non-volatile residue	Dissolved about the same amount as the PERC
Propylene Glycol Monomethylether Acetate	A commodity propylene based glycol ether			High boiling point, has a pretty bad odor.	Was not that effective
AK-225	Low Boiling HCFC blend.	126	None	Low boiling point, very expensive.	Dissolved the same amount as the PERC
HTF-85B	Terpene derived from turpentine	470-650	>200	Great solvency, also would need a solvent rinse.	Was not that effective

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Conclusions:

From the above results, probably the best solvent for Optical Manufacturer=s needs would be either OXSOL 100 or Glycol Ether DPM. The one problem that would be encountered with these two solvents is the flash point. In order for these solvent to be used safely, they would need to be operated in a closed system with some form of fire-suppression (nitrogen blanketing or reducing oxygen level with carbon dioxide). The OXSOL 100 can also be mixed with OXSOL 10 (Monochlorotoluene) and Perchloroethylene to make a nonflammable blend. Although perchloroethylene would still be used at Optical Manufacturer, a blend with the OXSOL solvents would reduce Perchloroethylene usage by 50-70%.

Sourcing out Replacement Adhesives:

Although some possibilities were found from the above testing, it might be more worthwhile for Optical Manufacturer to look into changing their resin to something that is easier to remove. When talking to a sales rep from Crest Ultrasonics, he informed me that Gerber Optical (a company that design systems to make optical lenses) uses a wax with a melting point of 140 F to attach lenses to the holders during polishing. This wax can be removed by cleaning in a warm ultrasonic bath with an aqueous detergent.

Summary:

From the testing conducted, it appears that Optical Manufacturer=s best bet would be to look into the alternative polishing process from Gerber Optical. A switch in adhesives would allow for a water based cleaning system to be used effectively. From the lab tests, the second best alternative would be to use the OXSOL 100 in an immersion cleaning process with adequate fire suppression or use a mixture of OXSOL 100, OXSOL 10 and Perchloroethylene to achieve a non-flammable solvent immersion cleaner. Contact names and numbers from appropriate companies that Optical Manufacturer may want to contact are listed below in Table 3.

Table 3: Contact Names & Numbers

Company Name	*Contact name*	*Phone Number*
Gerber Optical	Kurt Brey	860-648-6600 x 6652
Gerber Optical	Jeffrey Eisenberg	860-648-6600
Occidental Chemical Corp.	Michael Leathem	800-578-8880, 3, 7253#
Kyzen Corp.	Eric F. Bromley	603-622-2900
Dow Chemical Corp.		1-800-447-4369

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TURI
SURFACE CLEANING LABORATORY
EXPERIMENTAL
PARAMETER LOG

SCL #: 97-550-01-3
DATE: 10/23/97
EXPERIMENTER: Marshall
CLIENT TYPE: Chemical Manufacturer
TRIAL #: 1
SUBSTRATE MATERIAL: Glass and stainless steel
CONTAMINANTS: Teflon grease, metal oxides
CONTAMINATING PROCESS USED: Parts were received contaminated
ANALYTICAL METHODS: Visual

PURPOSE: The purpose of the trial was to find an alternative cleaning system to replace or reduce the amount of acids currently used.

EXPERIMENTAL PROCEDURES: The parts were first place into the Miele parts washer. Alcojet powder cleaner from Alconox was selected for the initial cleaning of the parts. The cleaning at 160^{o}F, rinsing at 150^{o}F and drying cycle approximately thirty minutes. From the parts washer the parts were visually inspected to see what contaminants had been removed. Next, the semi cleaned parts were cleaned in a 40kHz ultrasonic tank also at 160^{o}F. Another Alconox product was used during this step. A 1-2% solution of Citrinox was made in a beaker and suspended in the ultrasonic tank. The parts were placed into the bath. The parts werer cleaned for 5, 15 and 25 minute intervals. At each interval, the parts were removed and inspected.The parts were rinsed with running tap water at 130^{o}F for 10 seconds.

Some parts were also tested in a alkaline cleaner, MacDermid ND-17 at 5%. These parts were cleaned for five minutes in a beaker with no agitation. Then, the parts were observed for any signs of removal. A final cleaning took place in the ultrasonic tank for 5 minutes.

The final cleanliness analysis of all the cleaned parts was to be performed by the client.

RESULTS: The Miele parts washer removed most of the Teflon greases but had little to no effect on the metal oxides. In the ultrasonic tank, the Citrinox removed a small amount of the metal oxides after the five minute period. As the time of the cleaning increased, the level of contaminants removed also increased. At the end of the twenty-five minutes a majority of the metal oxides had been removed. The alkaline cleaner tested proved to be slightly effective in loosening some of the contaminant. Using the ultrasonic aided in more successful removal.

Final analysis will be conducted by the client to determine if the level of cleaning will meet the required efficiency.

CONCLUSIONS: Upon initial visual analysis of the parts cleaned, the cleaning procedure tested appeared to have performed adequately. Additional testing and adjustment will depend upon how the cleaned parts stand up to the client’s examination.

SCL #	Substrate	Contaminant	Mechanism	Cleaner
94-401-01-8	ALUMINUM	CARBON	ULTRASONICS	Brulin Corporation
94-401-01-8	ALUMINUM	CARBON	ULTRASONICS	W.R. Grace & Co.
94-401-01-8	ALUMINUM	LUBRICANT	ULTRASONICS	Brulin Corporation
94-401-01-8	ALUMINUM	LUBRICANT	ULTRASONICS	W.R. Grace & Co.
94-401-01-8	ALUMINUM	OIL	ULTRASONICS	Brulin Corporation
94-401-01-8	ALUMINUM	OIL	ULTRASONICS	W.R. Grace & Co.
94-402-01-8	ALUMINUM	ADHESIVE	IMMERSION	Macdermid
94-402-01-8	STAINLESS STEEL	ADHESIVE	IMMERSION	Macdermid
94-465-01-5	COPPER	OIL	ANALYSIS	OSEE
94-465-01-5	COPPER	OIL	ANALYSIS	Goniometer
94-465-01-5	KOVAR	OIL	ANALYSIS	OSEE
94-465-01-5	KOVAR	OIL	ANALYSIS	Goniometer
94-465-01-5	CERAMIC	OIL	ANALYSIS	OSEE
94-465-01-5	NICKEL	OIL	ANALYSIS	OSEE
94-465-01-5	NICKEL	OIL	ANALYSIS	Goniometer
94-465-01-5	TUNGSTEN	OIL	ANALYSIS	OSEE
94-465-01-5	TUNGSTEN	OIL	ANALYSIS	Goniometer
94-465-01-5	MONEL	OIL	ANALYSIS	OSEE
94-465-01-5	MONEL	OIL	ANALYSIS	Goniometer
94-465-01-5	QUARTZ	OIL	ANALYSIS	OSEE
94-466-01-8	CARBON STEEL	OIL	SPRAY	W.R. Grace & Co.
94-466-01-8	ALUMINUM	OIL	SPRAY	W.R. Grace & Co.
94-468-03-2	PLASTIC	MR AGENT	SPRAY	S & S Industrial
95-454-01-2	ALUMINUM	FLUX	IMMERSION	Calgon Corporation
95-454-01-2	ALUMINUM	ROSIN	IMMERSION	Calgon Corporation
95-454-01-2	ALUMINUM	SOLDER	IMMERSION	Calgon Corporation
95-454-02-2	ALUMINUM	FLUX	IMMERSION	Kyzen Corporation
95-454-02-2	ALUMINUM	ROSIN	IMMERSION	Kyzen Corporation
95-454-02-2	ALUMINUM	SOLDER	IMMERSION	Kyzen Corporation
95-454-02-2	GOLD	FLUX	IMMERSION	Kyzen Corporation
95-454-02-2	GOLD	ROSIN	IMMERSION	Kyzen Corporation
95-454-02-2	GOLD	SOLDER	IMMERSION	Kyzen Corporation
95-403-01-8	TIN	OIL	IMMERSION	W.R. Grace & Co.
95-404-02-2	PLASTIC	FINGERPRINTS	ULTRASONICS	Valtech Corporation
95-404-02-2	PLASTIC	OIL	ULTRASONICS	Valtech Corporation
95-404-03-2	PLASTIC	FINGERPRINTS	ULTRASONICS	Warren Chemical Co.
95-404-03-2	PLASTIC	OIL	ULTRASONICS	Warren Chemical Co.
95-405-04-2*	BRASS	GREASE	IMMERSION	Oakite Products
95-405-04-2*	BRASS	OIL	IMMERSION	Oakite Products
95-406-04-2	COPPER	OIL	ULTRASONICS	Sky Products
95-406-04-2	COPPER	OIL	ULTRASONICS	Oakite Products
95-407-04-2	ALUMINUM	WAX	IMMERSION	Oakite Products
95-407-04-2	BRASS	WAX	IMMERSION	Oakite Products
95-407-04-2	COPPER	WAX	IMMERSION	Oakite Products
95-407-07-2	ALUMINUM	LUBRICANT	IMMERSION	A.W. Chesterton
95-407-07-2	ALUMINUM	OIL	IMMERSION	A.W. Chesterton
95-407-07-2	ALUMINUM	WAX	IMMERSION	A.W. Chesterton
95-407-07-2	BRASS	LUBRICANT	IMMERSION	A.W. Chesterton
95-407-07-2	BRASS	OIL	IMMERSION	A.W. Chesterton
95-407-07-2	BRASS	WAX	IMMERSION	A.W. Chesterton
95-407-07-2	COPPER	LUBRICANT	IMMERSION	A.W. Chesterton
95-407-07-2	COPPER	OIL	IMMERSION	A.W. Chesterton
95-407-07-2	COPPER	WAX	IMMERSION	A.W. Chesterton
95-408-02-2C	FELT	STICKIES	IMMERSION	Brulin Corporation
95-408-02-2C	FELT	STICKIES	IMMERSION	T-Square
95-409-01-2*	GLASS	WAX	ULTRASONICS	Oakite Products
95-409-02-2	GLASS	WAX	IMMERSION	Alconox
95-409-03-2	GLASS	WAX	ULTRASONICS	Alconox
95-409-03-2	GLASS	WAX	ULTRASONICS	Oakite Products
95-410-01-2	STAINLESS STEEL	METAL	ULTRASONICS	W.R. Grace & Co.
95-410-01-2	STAINLESS STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
95-410-03-2	STAINLESS STEEL	METAL	SPRAY	A.W. Chesterton
95-410-03-2	STAINLESS STEEL	OIL	SPRAY	A.W. Chesterton
95-412-01-2	STEEL	OIL	IMMERSION	A.W. Chesterton
95-412-01-2	STEEL	OIL	IMMERSION	Calgon Corporation
95-412-01-2	STEEL	OIL	IMMERSION	Cleaning Systems
95-412-01-2	STEEL	OIL	IMMERSION	Oakite Products
95-467-01-8	STEEL	OIL	SPRAY	W.R. Grace & Co.
95-467-01-8	STEEL	OIL	SPRAY	Brulin Corporation
95-467-01-8	ALUMINUM	OIL	ULTRASONICS	Brulin Corporation
95-467-01-8	STEEL	OIL	ULTRASONICS	Brulin Corporation

SCL #	Substrate	Contaminant	Mechanism	Cleaner
95-467-01-8	ALUMINUM	OIL	IMMERSION	Oakite Products
95-467-01-8	STEEL	OIL	IMMERSION	Oakite Products
95-407-05-2	ALUMINUM	OIL	IMMERSION	Oakite Products
95-407-05-2	ALUMINUM	WAX	IMMERSION	Oakite Products
95-407-05-2	STEEL	OIL	IMMERSION	Oakite Products
95-407-05-2	STEEL	WAX	IMMERSION	Oakite Products
95-407-05-2	BRASS	OIL	IMMERSION	Oakite Products
95-406-01-2	COPPER	OIL	ULTRASONICS	Sky Products
95-406-02-2	COPPER	OIL	ULTRAS0NICS	Sky Products
95-454-02-2	ALUMINUM	FLUX	IMMERSION	Calgon Corporation
95-454-02-2	ALUMINUM	ROSIN	IMMERSION	Calgon Corporation
95-454-02-2	ALUMINUM	SOLDER	IMMERSION	Calgon Corporation
95-454-02-2	GOLD	FLUX	IMMERSION	Calgon Corporation
95-454-02-2	GOLD	ROSIN	IMMERSION	Calgon Corporation
95-454-02-2	GOLD	SOLDER	IMMERSION	Calgon Corporation
95-407-05-2	COPPER	WAX	IMMERSION	Oakite Products
95-407-05-2	COPPER	OIL	IMMERSION	Oakite Products
95-411-01-2	ALUMINUM	OIL	ULTRASONICS	W.R. Grace & Co.
95-410-02-2	STAINLESS STEEL	METAL	ULTRASONICS	W.R. Grace & Co.
95-405-01-1	BRASS	GREASE	COMPATIBILITY	Calgon Corporation
95-405-01-1	BRASS	GREASE	COMPATIBILITY	Oakite Products
95-405-01-1	BRASS	GREASE	COMPATIBILITY	Sky Products
95-405-01-1	BRASS	OIL	COMPATIBILITY	Calgon Corporation
95-405-01-1	BRASS	OIL	COMPATIBILITY	Oakite Products
95-405-01-1	BRASS	OIL	COMPATIBILITY	Sky Products
95-405-05-3*	BRASS	GREASE	IMMERSION	Oakite Products
95-405-05-3*	BRASS	OIL	IMMERSION	Oakite Products
95-408-01-1C	METAL	STICKIES	IMMERSION	T-Square
95-408-01-1C	METAL	STICKIES	IMMERSION	Brulin Corporation
95-412-01-2	STEEL	OIL	SPRAY	Calgon Corporation
95-412-01-2	STEEL	OIL	SPRAY	Cleaning Systems
95-412-01-2	STEEL	OIL	SPRAY	Oakite Products
95-413-02-2C	ALUMINUM	NONE	COMPATIBILITY	Brulin Corporation
95-413-02-2C	ALUMINUM	NONE	COMPATIBILITY	Calgon Corporation
95-413-02-2C	ALUMINUM	NONE	COMPATIBILITY	CSI
95-413-02-2C	ALUMINUM	NONE	COMPATIBILITY	Oakite Products
95-413-02-2C	ALUMINUM	NONE	COMPATIBILITY	W.R. Grace & Co.
95-413-02-2C	CHROME	NONE	COMPATIBILITY	Brulin Corporation
95-413-02-2C	CHROME	NONE	COMPATIBILITY	Calgon Corporation
95-413-02-2C	CHROME	NONE	COMPATIBILITY	CSI
95-413-02-2C	CHROME	NONE	COMPATIBILITY	Oakite Products
95-413-02-2C	CHROME	NONE	COMPATIBILITY	W.R. Grace & Co.
95-413-02-2C	STEEL	NONE	COMPATIBILITY	Brulin Corporation
95-413-02-2C	STEEL	NONE	COMPATIBILITY	Calgon Corporation
95-413-02-2C	STEEL	NONE	COMPATIBILITY	CSI
95-413-02-2C	STEEL	NONE	COMPATIBILITY	Oakite Products
95-413-02-2C	STEEL	NONE	COMPATIBILITY	W.R. Grace & Co.
95-414-01-2C	SILVER	BUFFING	IMMERSION	Calgon Corporation
95-414-01-2C	SILVER	BUFFING	IMMERSION	W.R. Grace & Co.
95-414-03-2C	SILVER	BUFFING	IMMERSION	Matchless
95-414-03-2C	SILVER	BUFFING	IMMERSION	Novamax
95-416-04-2	STAINLESS STEEL	ADHESIVE	MANUAL	A.W. Chesterton & Solvent Kleene
95-416-04-2	STAINLESS STEEL	ADHESIVE	MANUAL	Macdermid & Solvent Kleene
95-454-01-2	GOLD	FLUX	IMMERSION	Calgon Corporation
95-454-01-2	GOLD	ROSIN	IMMERSION	Calgon Corporation
95-454-01-2	GOLD	SOLDER	IMMERSION	Calgon Corporation
95-453-03-5	BRASS	OIL	ANALYSIS	Goniometry
96-404-07-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-404-08-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-404-09-5	STEEL	UNKNOWN	ANALYSIS	FTIR
96-404-09-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-404-10-5	STEEL	UNKNOWN	ANALYSIS	FTIR
96-404-10-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-404-11-5	STEEL	UNKNOWN	ANALYSIS	FTIR
96-404-11-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-414-04-2C	BRASS	NONE	COMPATIBILITY	Calgon Corporation
96-414-04-2C	BRASS	NONE	COMPATIBILITY	W.R. Grace & Co.
96-414-06-2C	BRASS	BUFFING	SPRAY	W.R. Grace & Co.
96-414-06-2C	SILVER	OIL	SPRAY	W.R. Grace & Co.
96-418-02-2	ELECTRONICS	COATING	IMMERSION	Ecolink
96-418-02-2	ELECTRONICS	COATING	IMMERSION	Isp Technologies

SCL #	Substrate	Contaminant	Mechanism	Cleaner
96-419-03-3	STAINLESS STEEL	COATING	IMMERSION	T-Square
96-419-04-2	STAINLESS STEEL	COATING	IMMERSION	US Polychem
96-420-01-2	ELECTRONICS	FLUX	IMMERSION	Church & Dwight Co.
96-421-01-5	STAINLESS STEEL	OIL	ANALYSIS	FTIR
96-421-01-5	STAINLESS STEEL	OIL	ANALYSIS	OSEE
96-422-01-2	ALUMINUM	CARBON	ULTRASONICS	Rochester/Chemex / NaOH Mix
96-422-01-2	STAINLESS STEEL	CARBON	ULTRASONICS	Delta Omega Tech
96-425-01-2	STAINLESS STEEL	GREASE	IMMERSION	Safety Kleene
96-425-01-2	STAINLESS STEEL	GREASE	IMMERSION	Twin River
96-425-01-2	STAINLESS STEEL	OIL	IMMERSION	Safety Kleene
96-425-01-2	STAINLESS STEEL	OIL	IMMERSION	T-Square
96-426-01-2*	STEEL	COATING	BLASTING	Armex
96-427-01-2*	TEFLON	CLAY	BLASTING	Armex
96-428-01-2*C	ALUMINUM	OIL	IMMERSION	Brulin Corporation
96-428-01-2*C	ALUMINUM	OIL	IMMERSION	W.R. Grace & Co.
96-429-01-2	STEEL	GREASE	IMMERSION	Ardrox
96-429-01-2	STEEL	GREASE	IMMERSION	US Polychem
96-429-02-2*	STEEL	GREASE	IMMERSION	Ardrox
96-429-02-2*	STEEL	GREASE	IMMERSION	US Polychem
96-429-02-2*	STEEL	OIL	IMMERSION	Ardrox
96-429-02-2*	STEEL	OIL	IMMERSION	US Polychem
96-429-02-2*	STEEL	TAR	IMMERSION	Ardrox
96-429-02-2*	STEEL	TAR	IMMERSION	US Polychem
96-430-01-8	COATING	SOLDER	ANALYSIS	Goniometer
96-431-01-8	COPPER	OIL	IMMERSION	Oakite Products
96-431-01-8	COPPER	OXIDES	IMMERSION	Oakite Products
96-432-01-8*	ALUMINUM	ASPHALT	IMMERSION	AG Environmental
96-432-01-8*	ALUMINUM	ASPHALT	IMMERSION	Calgon Corporation
96-432-01-8*	COPPER	ASPHALT	IMMERSION	AG Environmental
96-432-01-8*	COPPER	ASPHALT	IMMERSION	Calgon Corporation
96-432-01-8*	IRON	ASPHALT	IMMERSION	AG Environmental
96-432-01-8*	IRON	ASPHALT	IMMERSION	Calgon Corporation
96-433-01-8	BRASS	BUFFING	IMMERSION	Ardrox
96-434-01-9	ELECTRONICS	FLUX	COMPATIBILITY	IPA/Cyclohexane
96-436-01-5	ALUMINUM	WAX	ANALYSIS	Goniometer
96-436-01-5	ALUMINUM	WAX	ANALYSIS	Microphotography
96-449-02-2	STAINLESS STEEL	OIL	IMMERSION	Ardrox
96-449-02-2	STAINLESS STEEL	OIL	IMMERSION	Brulin Corporation
96-449-02-2	STAINLESS STEEL	OIL	IMMERSION	Calgon Corporation
96-452-01-5	STAINLESS STEEL	GREASE	ANALYSIS	OSEE
96-423-02-2	PLASTIC	INK	IMMERSION	Macdermid
96-423-02-2	PLASTIC	INK	IMMERSION	Mirachem
96-424-02-2	STEEL	OIL	IMMERSION	Oakite Products
96-414-05-2C	BRASS	NONE	COMPATIBILITY	W.R. Grace & Co.
96-414-05-2C	BRASS	NONE	COMPATIBILITY	Calgon Corporation
96-419-05-4	STAINLESS STEEL	COATING	IMMERSION	Inland Technolgies
96-419-05-4	STAINLESS STEEL	COATING	IMMERSION	T-Square
96-419-06-4	STAINLESS STEEL	COATING	IMMERSION	US Polychem
96-419-07-4	STAINLESS STEEL	COATING	SPRAY	US Polychem
96-449-01-1	COPPER	OIL	IMMERSION	Calgon Corporation
96-449-01-1	COPPER	OIL	IMMERSION	Ardrox
96-449-01-1	COPPER	OIL	IMMERSION	Buckeye
96-449-01-1	BRASS	OIL	IMMERSION	Calgon Corporation
96-449-01-1	BRASS	OIL	IMMERSION	Ardrox
96-449-01-1	BRASS	OIL	IMMERSION	Buckeye
96-419-05-4	STAINLESS STEEL	COATING	IMMERSION	ISP Tech
96-404-05-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-404-06-5	STEEL	UNKNOWN	ANALYSIS	OSEE
96-419-01-1	STAINLESS STEEL	COATING	LIFT TEST	US Polychem
96-419-01-1	STAINLESS STEEL	COATING	LIFT TEST	Fredrick Gumm
96-427-02-2	TEFLON	CLAY	BLASTING	Armex
96-428-02-2C	ALUMINUM	OIL	IMMERSION	W.R. Grace & Co.
97-435-01-8	GLASS	ROSIN	IMMERSION	Occidental Chemical
97-436-05-4	ALUMINUM	WAX	SPRAY	Steam
97-537-01-4	LIQUID	NONE	FORMULATION	Formulation
97-538-02-2	STAINLESS STEEL	INK	MANUAL	T-Square
97-538-04-2	STAINLESS STEEL	COATING	IMMERSION	Calgon Corporation
97-538-04-2	STAINLESS STEEL	COATING	IMMERSION	Carroll Company
97-538-04-2	STAINLESS STEEL	COATING	IMMERSION	LPS Laboratories Inc.
97-538-04-2	STAINLESS STEEL	COATING	IMMERSION	Quaker Chemical Corp
97-538-04-2	STAINLESS STEEL	COATING	IMMERSION	US Polychem

SCL #	Substrate	Contaminant	Mechanism	Cleaner
97-538-04-2	STAINLESS STEEL	COATING	IMMERSION	Valtech Corporation
97-538-07-3	STAINLESS STEEL	DIRT	IMMERSION	Ecolink
97-538-07-3	STAINLESS STEEL	DIRT	IMMERSION	Oakite Products
97-538-07-3	STAINLESS STEEL	DIRT	IMMERSION	Solvent Kleene
97-538-07-3	STAINLESS STEEL	GREASE	IMMERSION	Ecolink
97-538-07-3	STAINLESS STEEL	GREASE	IMMERSION	Oakite Products
97-538-07-3	STAINLESS STEEL	GREASE	IMMERSION	Solvent Kleene
97-538-07-3	STAINLESS STEEL	METAL	IMMERSION	Ecolink
97-538-07-3	STAINLESS STEEL	METAL	IMMERSION	Oakite Products
97-538-07-3	STAINLESS STEEL	METAL	IMMERSION	Solvent Kleene
97-538-07-3	STAINLESS STEEL	OIL	IMMERSION	Ecolink
97-538-07-3	STAINLESS STEEL	OIL	IMMERSION	Oakite Products
97-539-03-4	STAINLESS STEEL	LUBRICANT	ULTRASONICS	Oakite Products
97-539-03-4	STAINLESS STEEL	LUBRICANT	ULTRASONICS	US Polychem
97-539-03-4	STAINLESS STEEL	LUBRICANT	ULTRASONICS	W.R. Grace & Co.
97-540-01-5	STAINLESS STEEL	UNKNOWN	ANALYSIS	Microphotography
97-540-02-5	STEEL	BUFFING	ANALYSIS	Microphotography
97-540-02-5	STEEL	OIL	ANALYSIS	Microphotography
97-540-03-2	STAINLESS STEEL	BUFFING	ULTRASONICS	W.R. Grace & Co.
97-540-03-2	STAINLESS STEEL	FINGERPRINTS	ULTRASONICS	W.R. Grace & Co.
97-540-03-2	STAINLESS STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
97-541-01-1	PLASTIC	ADHESIVE	MANUAL	Brulin Corporation
97-541-01-1	PLASTIC	ADHESIVE	MANUAL	Loctite
97-541-02-2	PLASTIC	ADHESIVE	MANUAL	Eastern Color
97-541-02-2	PLASTIC	ADHESIVE	MANUAL	Isopropyl Alcohol
97-541-02-2	PLASTIC	ADHESIVE	MANUAL	T-Square
97-542-02-2	CR STEEL	LUBRICANT	SPRAY	Ardrox
97-542-02-2	CR STEEL	LUBRICANT	SPRAY	Calgon Corporation
97-542-02-2	CR STEEL	LUBRICANT	ULTRASONICS	Ardrox
97-542-02-2	CR STEEL	LUBRICANT	ULTRASONICS	Calgon Corporation
97-542-02-2	CR STEEL	METAL	SPRAY	Ardrox
97-542-02-2	CR STEEL	METAL	SPRAY	Calgon Corporation
97-542-02-2	CR STEEL	METAL	ULTRASONICS	Ardrox
97-542-02-2	CR STEEL	METAL	ULTRASONICS	Calgon Corporation
97-543-02-3*	STEEL	DIRT	BLASTING	Armex
97-543-02-3*	STEEL	LUBRICANT	BLASTING	Armex
97-543-02-3*	STEEL	OIL	BLASTING	Armex
97-543-02-3*	STEEL	RUBBER	BLASTING	Armex
97-544-01-2	CR STEEL	OIL	IMMERSION	Calgon Corporation
97-544-01-2	CR STEEL	OIL	IMMERSION	Oakite Products
97-544-01-2	CR STEEL	OIL	IMMERSION	W.R. Grace & Co.
97-544-03-5	LIQUID	OIL	ANALYSIS	Colorimeter
97-545-01-3*	STAINLESS STEEL	CORROSIVE	BLASTING	Armex
97-545-01-3*	STAINLESS STEEL	SALTS	BLASTING	Armex
97-546-01-3	TEFLON	OIL	EXTRACTION	Supercritical CO_2
97-547-01-2	STAINLESS STEEL	OIL	IMMERSION	Fine Organics
97-547-01-2	STAINLESS STEEL	OIL	IMMERSION	W.R. Grace & Co.
97-548-04-2	STAINLESS STEEL	GREASE	SPRAY	Alconox
97-549-01-2	STAINLESS STEEL	OIL	ULTRASONICS	Church & Dwight Co.
97-549-01-2	STAINLESS STEEL	OIL	ULTRASONICS	General Chemical
97-549-01-2	STAINLESS STEEL	OIL	ULTRASONICS	Macdermid
97-549-01-2	STAINLESS STEEL	OIL	ULTRASONICS	Oakite Products
97-549-01-2	STAINLESS STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
97-550-01-3	GLASS	GREASE	SPRAY	Alconox
97-550-01-3	GLASS	OXIDES	ULTRASONICS	Alconox
97-551-01-2	GLASS	PITCH	ULTRASONICS	International Products
97-551-01-2	GLASS	PITCH	ULTRASONICS	LPS Laboratories Inc
97-551-01-2	GLASS	PITCH	ULTRASONICS	Macdermid
97-551-01-2	GLASS	PITCH	ULTRASONICS	Oakite Products
97-551-01-2	GLASS	POLISH	ULTRASONICS	International Products
97-551-01-2	GLASS	POLISH	ULTRASONICS	LPS Laboratories Inc
97-551-01-2	GLASS	POLISH	ULTRASONICS	Macdermid
97-551-01-2	GLASS	POLISH	ULTRASONICS	Oakite Products
97-539-01-2	STAINLESS STEEL	LUBRICANT	IMMERSION	US Polychem
97-539-01-2	STAINLESS STEEL	LUBRICANT	IMMERSION	Warren Chemical Co.
97-539-01-2	STAINLESS STEEL	LUBRICANT	IMMERSION	W.R. Grace & Co.
97-539-01-2	STAINLESS STEEL	LUBRICANT	IMMERSION	Oakite Products
97-539-01-2	STAINLESS STEEL	LUBRICANT	IMMERSION	Macdermid
97-542-01-2	CR STEEL	METAL	IMMERSION	Ardrox
97-542-01-2	CR STEEL	METAL	IMMERSION	Calgon Corporation
97-542-01-2	CR STEEL	OIL	IMMERSION	Adrox

SCL #	Substrate	Contaminant	Mechanism	Cleaner
97-542-01-2	CR STEEL	OIL	IMMERSION	Calgon Corporation
97-538-05-2	STAINLESS STEEL	COATING	IMMERSION	Calgon Corporation
97-435-01-8	GLASS	ROSIN	ULTRASONICS	Occidental Chemical
97-435-01-8	GLASS	ROSIN	ULTRASONICS	Dow
97-436-01-5	ALUMINUM	WAX	ANALYSIS	Goniometry
97-436-01-5	ALUMINUM	WAX	ANALYSIS	Microscopy
97-436-01-5	ALUMINUM	WAX	ANALYSIS	Water Break
97-436-02-5	ALUMINUM	WAX	ANALYSIS	Goniometry
97-537-01-4	LIQUID	NONE	FORMULATION	3M
97-538-03-4	STAINLESS STEEL	INK	MANUAL	Tsquare
97-538-03-4	STAINLESS STEEL	INK	MANUAL	Accurate Manufactured
97-539-05-4	STAINLESS STEEL	LUBRICANT	ULTRASONICS	US Polychem
97-539-05-4	STAINLESS STEEL	LUBRICANT	ULTRASONICS	W.R. Grace & Co.
97-539-05-4	STAINLESS STEEL	LUBRICANT	ULTRASONICS	Oakite Products
97-539-05-4	STAINLESS STEEL	PLASTIC	ULTRASONICS	US Polychem
97-539-05-4	STAINLESS STEEL	PLASTIC	ULTRASONICS	W.R. Grace & Co.
97-539-05-4	STAINLESS STEEL	PLASTIC	ULTRASONICS	Oakite Products
97-542-03-4	CR STEEL	OIL	ULTRASONICS	Calgon Corporation
97-542-03-4	CR STEEL	METAL	ULTRASONICS	Calgon Corporation
97-542-03-4	CR STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
97-542-03-4	CR STEEL	METAL	ULTRASONICS	W.R. Grace & Co.
97-544-02-2	CR STEEL	OIL	IMMERSION	Oakite Products
97-544-04-4	CR STEEL	OIL	IMMERSION	Oakite Products
97-544-05-4	CR STEEL	OIL	IMMERSION	Oakite Products
97-544-06-5	LIQUID	OIL	ANALYSIS	Colorimeter
97-544-07-4	LIQUID	OIL	ANALYSIS	Colorimeter
97-544-07-4	CR STEEL	OIL	IMMERSION	Oakite Products
97-544-08-4	CR STEEL	OIL	IMMERSION	Oakite Products
97-547-02-2	STAINLESS STEEL	OIL	ULTRASONICS	Fine Organics
97-547-02-2	STAINLESS STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
97-547-04-4	STAINLESS STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
97-549-02-4	STAINLESS STEEL	OIL	ULTRASONICS	Macdermid
97-435-01-8	GLASS	ROSIN	IMMERSION	Dow
98-540-04-4	STAINLESS STEEL	BUFFING	ULTRASONICS	W.R. Grace & Co.
98-540-04-4	STAINLESS STEEL	OIL	ULTRASONICS	W.R. Grace & Co.
98-557-01-2	ALUMINUM	OIL	ULTRASONICS	Matchless
98-557-01-2	ALUMINUM	DUST	ULTRASONICS	Matchless
98-557-01-2	ALUMINUM	DIRT	ULTRASONICS	Matchless
98-557-01-2	STEEL	OIL	ULTRASONICS	Matchless
98-557-01-2	STEEL	DUST	ULTRASONICS	Matchless
98-557-01-2	STEEL	DIRT	ULTRASONICS	Matchless
98-557-01-2	ALUMINUM	OIL	ULTRASONICS	US Polychem
98-557-01-2	ALUMINUM	DUST	ULTRASONICS	US Polychem
98-557-01-2	ALUMINUM	DIRT	ULTRASONICS	US Polychem
98-557-01-2	STEEL	OIL	ULTRASONICS	US Polychem
98-557-01-2	STEEL	DUST	ULTRASONICS	US Polychem
98-557-01-2	STEEL	DIRT	ULTRASONICS	US Polychem
98-557-01-2	ALUMINUM	OIL	ULTRASONICS	Oakite Products
98-557-01-2	ALUMINUM	DUST	ULTRASONICS	Oakite Products
98-557-01-2	ALUMINUM	DIRT	ULTRASONICS	Oakite Products
98-557-01-2	STEEL	OIL	ULTRASONICS	Oakite Products
98-557-01-2	STEEL	DUST	ULTRASONICS	Oakite Products
98-557-01-2	STEEL	DIRT	ULTRASONICS	Oakite Products
98-559-01-1	AL-OXIDE	INK	IMMERSION	W.R. Grace & Co.
98-559-01-1	AL-OXIDE	PAINT	IMMERSION	W.R. Grace & Co.
98-559-01-1	AL-OXIDE	INK	IMMERSION	US Polychem
98-559-01-1	AL-OXIDE	PAINT	IMMERSION	US Polychem
98-559-01-1	AL-OXIDE	INK	IMMERSION	Oakite Products
98-559-01-1	AL-OXIDE	PAINT	IMMERSION	Oakite Products
98-559-03-2	AL-OXIDE	INK	ULTRASONICS	W.R. Grace & Co.
98-559-03-2	AL-OXIDE	PAINT	ULTRASONICS	W.R. Grace & Co.
98-559-03-2	AL-OXIDE	INK	ULTRASONICS	Oakite Products
98-559-03-2	AL-OXIDE	PAINT	ULTRASONICS	Oakite Products
98-557-01-2	ALUMINUM	FINGERPRINTS	ULTRASONICS	Matchless
98-557-01-2	STEEL	FINGERPRINTS	ULTRASONICS	Matchless
98-557-01-2	ALUMINUM	FINGERPRINTS	ULTRASONICS	US Polychem
98-557-01-2	STEEL	FINGERPRINTS	ULTRASONICS	US Polychem
98-557-01-2	ALUMINUM	FINGERPRINTS	ULTRASONICS	Oakite Products
98-557-01-2	STEEL	FINGERPRINTS	ULTRASONICS	Oakite Products
98-541-03-2	PLASTIC	ADHESIVE	MANUAL	Oakite Products
98-541-03-2	PLASTIC	ADHESIVE	MANUAL	Inland Technologies

SCL #	Substrate	Contaminant	Mechanism	Cleaner
98-541-03-2	PLASTIC	ADHESIVE	MANUAL	Solvent Kleene
98-541-03-2	PLASTIC	ADHESIVE	MANUAL	EnviroSolutions
98-569-01-5	STAINLESS STEEL	COATING	ANALYSIS	OSEE
98-569-01-5	STAINLESS STEEL	COATING	ANALYSIS	Goniometer
98-569-02-5	STAINLESS STEEL	COATING	ANALYSIS	OSEE
98-569-02-5	STAINLESS STEEL	COATING	ANALYSIS	Goniometer
98-569-03-5	STAINLESS STEEL	COATING	ANALYSIS	Microphotography
98-569-03-5	PAPER	COATING	ANALYSIS	Microphotography
98-559-04-2	PLASTIC	INK	IMMERSION	Oakite Products
98-559-04-2	PLASTIC	PAINT	IMMERSION	Oakite Products
98-559-04-2	PLASTIC	INK	IMMERSION	Brulin Corporation
98-559-04-2	PLASTIC	PAINT	IMMERSION	Brulin Corporation
98-559-04-2	PLASTIC	INK	IMMERSION	Chrisal USA
98-559-04-2	PLASTIC	PAINT	IMMERSION	Chrisal USA
98-549-03-5	STAINLESS STEEL	OIL	ANALYSIS	OSEE
98-549-04-5	LIQUID	NONE	ANALYSIS	Colorimeter
98-549-05-5	LIQUID	OIL	ANALYSIS	Colorimeter
98-549-06-5	STAINLESS STEEL	OIL	ANALYSIS	OSEE
98-549-07-4	STAINLESS STEEL	OIL	ANALYSIS	OSEE
98-549-08-5	LIQUID	OIL	ANALYSIS	Colorimeter
98-532-02-2	GLASS	ADHESIVE	IMMERSION	Alconox
98-532-02-2	GLASS	FRIT	IMMERSION	Alconox
98-537-02-2	ALUMINUM	NONE	IMMERSION	3M
98-559-05-2	ZrO_2	PAINT	IMMERSION	Oakite Products
98-570-01-5	BRASS	OIL	ANALYSIS	OSEE
98-522-02-1	NONE	CARBON	IMMERSION	Buckeye
98-522-02-1	NONE	CARBON	IMMERSION	Safe Cleanup
98-522-03-1	NONE	ADHESIVE	IMMERSION	Finger Lakes
98-561-02-4	ALUMINUM	OIL	IMMERSION	Zep Co.
98-561-02-4	ALUMINUM	OIL	IMMERSION	EnviroSolutions
98-561-02-4	ALUMINUM	OIL	IMMERSION	Safe Cleanup
98-571-02-2	ALUMINUM	INK	MANUAL	AG Environmental
98-571-02-2	ALUMINUM	INK	MANUAL	Oakite Products
98-572-01-2	STEEL	GREASE	IMMERSION	Matchless
98-572-01-2	STEEL	BUFFING	IMMERSION	Matchless
98-572-01-2	STEEL	DIRT	IMMERSION	Matchless
98-572-01-2	STEEL	METAL	IMMERSION	Matchless
98-572-01-2	STEEL	GREASE	IMMERSION	Emkay
98-572-01-2	STEEL	BUFFING	IMMERSION	Emkay
98-572-01-2	STEEL	DIRT	IMMERSION	Emkay
98-572-01-2	STEEL	METAL	IMMERSION	Emkay
98-571-03-2	ALUMINUM	INK	MANUAL	T-Square
98-571-03-2	ALUMINUM	INK	MANUAL	Oakite Products
98-561-04-4	ALUMINUM	OIL	IMMERSION	Safety Kleene
98-561-04-4	ALUMINUM	OIL	IMMERSION	AG Environmental
98-561-04-4	ALUMINUM	OIL	IMMERSION	Envirsolutions
98-561-04-4	ALUMINUM	OIL	IMMERSION	W.R. Grace & Co.
98-561-04-4	ALUMINUM	OIL	IMMERSION	Safe Cleanup
98-561-04-4	ALUMINUM	OIL	IMMERSION	Zep Co.
98-622-04-2	STAINLESS STEEL	RESIN	IMMERSION	Gemtek
98-622-04-2	STAINLESS STEEL	RESIN	IMMERSION	T-Square
98-622-04-2	STAINLESS STEEL	RESIN	IMMERSION	W.R. Grace & Co.
98-622-04-2	STAINLESS STEEL	RESIN	IMMERSION	Chrisal USA
98-622-05-2	NONE	RESIN	IMMERSION	Gemtek
98-622-05-2	NONE	RESIN	IMMERSION	W.R. Grace & Co.
98-674-03-2	ALUMINUM	OIL	IMMERSION	Ecolink
98-674-03-2	ALUMINUM	OIL	IMMERSION	Occidental Chemical
98-675-01-4	NICKEL	OIL	ULTRASONICS	Magnaflux
98-676-01-2	ALUMINUM	SOLVENT	IMMERSION	Solvent Kleene
98-676-01-2	ALUMINUM	PAINT	IMMERSION	Solvent Kleene
98-676-01-2	ALUMINUM	SLUDGE	IMMERSION	Solvent Kleene
98-676-02-4	ALUMINUM	SOLVENT	IMMERSION	Chrisal USA
98-676-02-4	ALUMINUM	PAINT	IMMERSION	Chrisal USA
98-676-02-4	ALUMINUM	SLUDGE	IMMERSION	Chrisal USA
98-676-02-4	ALUMINUM	SOLVENT	IMMERSION	AG Environmental
98-676-02-4	ALUMINUM	PAINT	IMMERSION	AG Environmental
98-676-02-4	ALUMINUM	SLUDGE	IMMERSION	AG Environmental
98-675-02-2	NICKEL	OIL	ULTRASONICS	Valtech Corporation
98-675-02-2	NICKEL	OIL	ULTRASONICS	SWR Corp.
98-675-03-2	NICKEL	COATING	IMMERSION	Fine Organics
98-675-03-2	COPPER	COATING	IMMERSION	Water

SCL #	Substrate	Contaminant	Mechanism	Cleaner
98-675-03-2	COPPER	COATING	IMMERSION	Fine Organics
98-675-04-2	NICKEL	OIL	ULTRASONICS	Valtech Corporation
98-675-04-2	NICKEL	OIL	ULTRASONICS	SWR Corp.
98-675-04-2	NICKEL	OIL	ULTRASONICS	Carroll Company
98-679-01-2	NICKEL	OIL	IMMERSION	Calgon Corporation
98-679-01-2	NICKEL	OIL	IMMERSION	W.R. Grace & Co.
98-679-01-2	COPPER	OIL	IMMERSION	Calgon Corporation
98-679-01-2	COPPER	OIL	IMMERSION	W.R. Grace & Co.
98-679-02-4	NICKEL	OIL	ULTRASONICS	Calgon Corporation
98-679-02-4	NICKEL	OIL	ULTRASONICS	W.R. Grace & Co.
98-679-02-4	COPPER	OIL	ULTRASONICS	Calgon Corporation
98-679-02-4	COPPER	OIL	ULTRASONICS	W.R. Grace & Co.
98-675-05-4	NICKEL	COATING	IMMERSION	Water
98-674-04-2	ALUMINUM	OIL	IMMERSION	Water
98-679-03-4	COPPER	OIL	ULTRASONICS	W.R. Grace & Co.
98-679-03-4	NICKEL	OIL	ULTRASONICS	W.R. Grace & Co.
98-679-03-4	COPPER	OIL	ULTRASONICS	Calgon Corporation
98-679-03-4	NICKEL	OIL	ULTRASONICS	Calgon Corporation
98-679-04-4	COPPER	OIL	ULTRASONICS	Calgon Corporation
98-679-04-4	COPPER	OIL	ULTRASONICS	W.R. Grace & Co.
98-679-04-4	NICKEL	OIL	ULTRASONICS	Calgon Corporation
98-679-04-4	NICKEL	OIL	ULTRASONICS	W.R. Grace & Co.
98-679-05-4	COPPER	OIL	ULTRASONICS	Calgon Corporation
98-679-05-4	NICKEL	OIL	ULTRASONICS	Calgon Corporation
98-680-02-2	ALUMINUM	COATING	IMMERSION	T-Square
98-679-06-4	COPPER	OIL	ULTRASONICS	Calgon Corporation
98-679-06-4	NICKEL	OIL	ULTRASONICS	Calgon Corporation
98-680-03-4	ALUMINUM	COATING	IMMERSION	T Square
98-675-07-4	NICKEL	OIL	ULTRASONICS	Magnaflux
98-676-07-2	ALUMINUM	SOLVENT	IMMERSION	AG Environmental
98-676-07-2	ALUMINUM	SLUDGE	IMMERSION	AG Environmental
98-676-07-2	ALUMINUM	PAINT	IMMERSION	AG Environmental
98-682-01-2	STAINLESS STEEL	INK	MANUAL	Exxon
98-682-01-2	STAINLESS STEEL	INK	MANUAL	AG Environmental
98-682-01-2	STAINLESS STEEL	INK	MANUAL	EnviroSolutions
98-682-01-2	STAINLESS STEEL	INK	MANUAL	Finger Lakes
98-682-01-2	STAINLESS STEEL	INK	MANUAL	Inland Technologies
98-682-01-2	STAINLESS STEEL	INK	MANUAL	T-Square
98-682-02-4	FILM	NONE	COMPATIBILITY	EnviroSolutions
98-682-02-4	FILM	NONE	COMPATIBILITY	W.R. Grace & Co.
98-683-01-4	STEEL	OIL	IMMERSION	Watson
98-683-01-4	STEEL	OIL	IMMERSION	Watson
98-676-08-2	ALUMINUM	SOLVENT	SPRAY	AG Environmental
98-676-08-2	ALUMINUM	PAINT	SPRAY	AG Environmental
98-676-08-2	ALUMINUM	SLUDGE	SPRAY	AG Environmental
98-676-10-4	ALUMINUM	SOLVENT	IMMERSION	AG Environmental
98-676-10-4	ALUMINUM	PAINT	IMMERSION	AG Environmental
98-676-10-4	ALUMINUM	SLUDGE	IMMERSION	AG Environmental
98-682-03-4	FILM	INK	MANUAL	Envirosolution
98-682-03-4	STAINLESS STEEL	COATING	MANUAL	EnviroSolutions
98-682-03-4	FILM	COATING	MANUAL	EnviroSolutions
98-676-12-5	LIQUID	SOLVENT	ANALYSIS	Colorimeter
98-676-12-5	LIQUID	PAINT	ANALYSIS	Colorimeter
98-676-12-5	LIQUID	SLUDGE	ANALYSIS	Colorimeter
98-541-04-2	PLASTIC	ADHESIVE	MANUAL	EnviroSolutions
98-541-04-2	PLASTIC	ADHESIVE	MANUAL	Solvent Kleene
98-561-03-4	ALUMINUM	OIL	IMMERSION	W.R. Grace & Co.
98-561-03-4	ALUMINUM	OIL	IMMERSION	Safe Cleanup
98-632-03-4	GLASS	ADHESIVE	IMMERSION	Alconox
98-632-03-4	GLASS	FRIT	IMMERSION	Alconox
98-632-04-4	GLASS	ADHESIVE	IMMERSION	Alconox
98-632-04-4	GLASS	FRIT	IMMERSION	Alconox
98-632-05-4	GLASS	ADHESIVE	IMMERSION	Alconox
98-632-05-4	GLASS	FRIT	IMMERSION	Alconox
98-675-06-4	NICKEL	OIL	ULTRASONICS	Valtech Corporation
98-675-06-4	NICKEL	OIL	ULTRASONICS	SWR Corp
98-676-04-4	ALUMINUM	NONE	ANALYSIS	Gravimetric
98-676-04-4	ALUMINUM	NONE	ANALYSIS	Visual
98-676-04-4	ALUMINUM	NONE	ANALYSIS	Wipe
98-676-06-4	ALUMINUM	NONE	ANALYSIS	Gravimetric
98-676-06-4	ALUMINUM	NONE	ANALYSIS	Visual

SCL #	Substrate	Contaminant	Mechanism	Cleaner
98-676-06-4	ALUMINUM	NONE	ANALYSIS	Wipe
98-676-09-4	ALUMINUM	SOLVENT	SPRAY	AG Environmental
98-676-09-4	ALUMINUM	PAINT	SPRAY	AG Environmental
98-676-09-4	ALUMINUM	SLUDGE	SPRAY	AG Environmental
98-676-11-4	ALUMINUM	SOAP RESIDUE	IMMERSION	Alconox
98-676-11-4	ALUMINUM	SOAP RESIDUE	IMMERSION	W.R. Grace & Co.
98-676-11-4	ALUMINUM	SOAP RESIDUE	IMMERSION	Watson
98-676-13-5	ALUMINUM	SOLVENT	IMMERSION	AG Environmental
98-676-13-5	ALUMINUM	PAINT	IMMERSION	AG Environmental
98-676-13-5	ALUMINUM	SLUDGE	IMMERSION	AG Environmental
98-677-02-1	ALUMINUM	NONE	SPRAY	Water
98-677-03-4	ALUMINUM	NONE	SPRAY	Water
98-677-04-4	ALUMINUM	NONE	SPRAY	Water
99-695-01-2	MONEL	OIL	IMMERSION	ITW Fluid Products
99-688-04-2	TEFLON	OIL	IMMERSION	Ecolink
99-683-02-2	ALUMINUM	OIL	IMMERSION	Watson
99-683-02-2	CR STEEL	OIL	IMMERSION	Watson
99-688-03-2	TEFLON	OIL	IMMERSION	AG Environmental
99-688-03-2	TEFLON	OIL	IMMERSION	Ecolink
99-688-03-2	TEFLON	OIL	IMMERSION	T-Square
99-688-03-2	TEFLON	OIL	IMMERSION	Florida Chemical
99-695-01-2	MONEL	OIL	IMMERSION	US Polychem
99-695-01-2	MONEL	OIL	IMMERSION	Calgon Corporation
99-695-01-2	MONEL	OIL	IMMERSION	Star Cleaning Products
99-695-01-2	MONEL	OIL	IMMERSION	Ardrox
99-695-02-2	MONEL	OIL	SPRAY	US Polychem
99-695-02-2	MONEL	OIL	SPRAY	Ardrox
99-695-02-2	MONEL	OIL	SPRAY	Emkay
99-695-03-3	STAINLESS STEEL	OIL	SPRAY	US Polychem
99-695-03-3	STAINLESS STEEL	LUBRICANT	SPRAY	US Polychem
99-695-03-3	STAINLESS STEEL	COATING	SPRAY	US Polychem
99-695-03-3	MONEL	OIL	SPRAY	US Polychem
99-695-03-3	MONEL	LUBRICANT	SPRAY	US Polychem
99-695-03-3	MONEL	COATING	SPRAY	US Polychem
99-695-03-3	BRONZE	OIL	SPRAY	US Polychem
99-695-03-3	BRONZE	LUBRICANT	SPRAY	US Polychem
99-695-03-3	BRONZE	COATING	SPRAY	US Polychem
99-695-03-3	SILICONE	OIL	SPRAY	US Polychem
99-695-03-3	SILICONE	LUBRICANT	SPRAY	US Polychem
99-695-03-3	SILICONE	COATING	SPRAY	US Polychem
99-692-02-2	CARBON STEEL	OIL	IMMERSION	Twin Rivers
99-692-02-2	CARBON STEEL	OIL	IMMERSION	Solvent Kleene
99-692-02-2	CARBON STEEL	OIL	IMMERSION	Oakite Products
99-692-02-2	CARBON STEEL	OIL	IMMERISON	Ecolink
99-692-02-2	STAINLESS STEEL	OIL	IMMERSION	Twin Rivers
99-692-02-2	STAINLESS STEEL	OIL	IMMERSION	Solvent Kleene
99-692-02-2	STAINLESS STEEL	OIL	IMMERSION	Oakite Products
99-692-02-2	STAINLESS STEEL	OIL	IMMERSION	Ecolink
99-696-02-2	ALUMINUM	OIL	BLASTING	Armex
99-696-02-2	ALUMINUM	DIRT	BLASTING	Armex
99-696-02-2	ALUMINUM	GREASE	BLASTING	Armex
99-6100-01-5	MOLYBDENUM	OIL	ANALYSIS	OSEE
99-6100-01-5	AL-OXIDE	OIL	ANALYSIS	OSEE
99-6100-01-5	STAINLESS STEEL	OIL	ANALYSIS	OSEE
99-6100-01-5	MACOR	OIL	ANALYSIS	OSEE
99-6100-01-5	TITANIUM-AL	OIL	ANALYSIS	OSEE
99-6101-01-2	BRASS	BUFFING	IMMERSION	Calgon Corporation
99-6101-01-2	BRASS	BUFFING	IMMERSION	Oakite Products
99-6101-02-2	BRASS	BUFFING	IMMERSION	Oakite Products
99-6101-02-2	BRASS	BUFFING	IMMERSION	Calgon Corporation
99-6101-02-2	BRASS	BUFFING	IMMERSION	Chrisal USA
99-6101-02-2	BRASS	BUFFING	IMMERSION	US Polychem
99-6101-03-2	BRASS	BUFFING	ULTRASONICS	Oakite Products
99-6101-03-2	BRASS	BUFFING	ULTRASONICS	Calgon Corporation
99-6102-01-2	BRASS	OIL	IMMERSION	Oakite Products
99-6102-01-2	BRASS	OIL	IMMERSION	US Polychem
99-6101-04-3	BRASS	BUFFING	IMMERSION	Oakite Products
99-6101-04-3	BRASS	BUFFING	IMMERSION	Calgon Corporation
99-622-07-1	NONE	ADHESIVE	IMMERSION	Savogran
99-622-08-1	NONE	RESIN	IMMERSION	Savogran
99-622-09-2	NONE	RESIN	IMMERSION	Gemtek

SCL #	Substrate	Contaminant	Mechanism	Cleaner
99-6100-02-2	STAINLESS STEEL	OIL	IMMERSION	Branson
99-6100-02-2	STAINLESS STEEL	OIL	IMMERSION	Matchless
99-6100-02-2	STAINLESS STEEL	OIL	IMMERSOIN	Warren Chemical Co.
99-6100-02-2	STAINLESS STEEL	OIL	IMMERSION	Gemtek
99-6100-02-2	STAINLESS STEEL	OIL	IMMERSION	Savogran
99-6100-02-2	STAINLESS STEEL	OIL	IMMERSION	Water
99-622-10-4	NONE	RESIN	IMMERSION	Gemtek
99-696-01-1	ALUMINUM	DIRT	MANUAL	Hotsy Corp.
99-696-01-1	ALUMINUM	OIL	MANUAL	Hotsy Corp.
99-696-01-1	ALUMINUM	GREASE	MANUAL	Hotsy Corp.
99-696-01-1	ALUMINUM	DIRT	MANUAL	Bo Chem Co.
99-696-01-1	ALUMINUM	OIL	MANUAL	Bo Chem Co.
99-696-01-1	ALUMINUM	GREASE	MANUAL	Bo Chem Co.
99-696-01-1	ALUMINUM	DIRT	MANUAL	Gemtek
99-696-01-1	ALUMINUM	OIL	MANUAL	Gemtek
99-696-01-1	ALUMINUM	GREASE	MANUAL	Gemtek
99-6100-3-4	STAINLESS STEEL	OIL	IMMERSION	Branson
99-6100-03-4	STAINLESS STEEL	OIL	IMMERSION	Warren Chemical Co
99-6100-03-4	STAINLESS STEEL	OIL	IMMERSION	Matchless
99-6100-04-4	METAL	OIL	ULTRASONICS	Branson
99-6100-04-4	METAL	OIL	ULTRASONICS	Mathcless
99-6102-02-4	BRASS	OIL	IMMERSION	Calgon Corporation
99-6102-02-4	BRASS	OIL	IMMERSION	US Polychem
99-6102-02-4	BRASS	OIL	IMMERSION	W.R. Grace & Co.
99-6102-02-4	BRASS	OIL	IMMERSION	SWR Corp
99-6102-02-4	BRASS	OIL	IMMERSION	Gemtek
99-6102-02-4	STEEL	OIL	IMMERSION	Calgon Corporation
99-6102-02-4	STEEL	OIL	IMMERSION	US Polychem
99-6102-02-4	STEEL	OIL	IMMERSION	W.R. Grace & Co.
99-6102-02-4	STEEL	OIL	IMMERSION	SWR Corp
99-6102-02-4	STEEL	OIL	IMMERSION	Gemtek
99-6102-02-4	STEEL	DIRT	IMMERSION	Calgon Corporation
99-6102-02-4	STEEL	DIRT	IMMERSION	US Polychem
99-6102-02-4	STEEL	DIRT	IMMERSION	W.R. Grace & Co.
99-6102-02-4	STEEL	DIRT	IMMERSION	SWR Corp
99-6102-02-4	STEEL	DIRT	IMMERSION	Gemtek
99-6100-05-4	STAINLESS STEEL	OIL	IMMERSION	Brulin Corporation
99-6102-03-4	STEEL	OIL	IMMERSION	US Polychem
99-6102-03-4	STEEL	DIRT	IMMERSION	Gemtek
99-6100-06-5	MOLYBDENUM	OIL	ANALYSIS	OSEE
99-6100-06-5	MOLYBDENUM	DIRT	ANALYSIS	OSEE
99-6101-05-4	BRASS	BUFFING	IMMERSION	Calgon Corporation
99-6101-05-4	SILVER	BUFFING	IMMERSION	Calgon Corporation
99-6101-05-4	BRASS	BUFFING	IMMERSION	Oakite Products
99-6101-05-4	BRASS	OIL	IMMERSION	Oakite Products
99-6101-05-4	BRASS	OIL	IMMERSION	Calgon Corporation
99-622-11-2	NONE	ADHESIVE	IMMERSION	EnviroSolutions
99-622-11-2	NONE	ADHESIVE	IMMERSION	AG Environmental
99-622-11-2	NONE	ADHESIVE	IMMERSION	Savogran
99-6100-07-4	MOLYBDENUM	OIL	ULTRASONICS	Branson
99-6100-07-4	TITANIUM	OIL	ULTRASONICS	Branson
99-6100-07-4	MACOR	OIL	ULTRASONICS	Branson
99-6100-07-4	MOLYBDENUM	OIL	ULTRASONICS	Brulin Corporation
99-6100-07-4	ALUMINA	OIL	ULTRASONICS	Brulin Corporation
99-6100-07-4	MACOR	OIL	ULTRASONICS	Brulin Corporation
99-6100-07-4	MOLYBDENUM	OIL	ULTRASONICS	Valtech Corporation
99-6100-07-4	ALUMINA	OIL	ULTRASONICS	Valtech Corporation
99-6100-07-4	TITANIUM	OIL	ULTRASONICS	Valtech Corporation
99-6100-07-4	MACOR	OIL	ULTRASONICS	Valtech Corporation
99-6104-01-5	LIQUID	OIL	ANALYSIS	Surfactant Titration
99-6103-02-2	STEEL	OIL	IMMERSION	Safe Cleanup
99-6103-02-2	STEEL	OIL	IMMERSION	EnviroSolutions
99-6103-02-2	STEEL	OIL	IMMERSION	AG Environmental
99-6103-02-2	STEEL	OIL	IMMERSION	Gemtek
99-6103-03-4	STEEL	OIL	IMMERSION	Forbest
99-6107-01-2	ALUMINUM	COATING	IMMERSION	Brulin Corporation
99-6107-01-2	ALUMINUM	COATING	IMMERSION	Fine Organics
99-6107-01-2	ALUMINUM	COATING	IMMERSION	T-Square
99-6107-01-2	ALUMINUM	COATING	IMMERSION	Gemtek
99-6107-01-2	ALUMINUM	COATING	IMMERSION	Kyzen Corporation
99-6107-01-2	ALUMINUM	COATING	IMMERSION	Loctite

SCL #	Substrate	Contaminant	Mechanism	Cleaner
99-6107-02-4	ALUMINUM	COATING	IMMERSION	Brulin Corporation
99-6107-02-4	ALUMINUM	COATING	IMMERSION	EnviroSolutions
99-6107-02-4	ALUMINUM	COATING	IMMERSION	Oakite Products
99-622-13-2	STAINLESS STEEL	RESIN	IMMERSION	EnviroSolutions
99-6107-03-3	ALUMINUM	COATING	IMMERSION	EnviroSolutions
99-6107-03-3	ALUMINUM	COATING	IMMERSION	Brulin Corporation
99-6107-03-3	ALUMINUM	COATING	IMMERSION	Oakite Products
99-6109-01-2	ALUMINUM	LUBRICANT	IMMERSION	Oakite Products
99-6109-01-2	ALUMINUM	LUBRICANT	IMMERSION	US Polychem
99-6109-01-2	ALUMINUM	LUBRICANT	IMMERSION	W.R. Grace & Co.
99-6109-01-2	ALUMINUM	LUBRICANT	IMMERSION	Calgon Corporation
99-6109-01-2	ALUMINUM	LUBRICANT	IMMERSION	Gemtek
99-6109-01-2	ALUMINUM	LUBRICANT	IMMERSION	Forbest
99-6109-02-4	ALUMINUM	LUBRICANT	IMMERSION	Oakite Products
99-6109-02-4	ALUMINUM	LUBRICANT	IMMERSION	Calgon Corporation
99-6109-02-4	ALUMINUM	LUBRICANT	IMMERSION	US Polychem
99-6107-04-4	STAINLESS STEEL	COATING	IMMERSION	EnviroSolutions
99-6107-04-4	PLASTIC	COATING	IMMERSION	EnviroSolutions
99-6109-03-4	ALUMINUM	LUBRICANT	IMMERSION	Oakite Products
99-6109-03-4	ALUMINUM	LUBRICANT	IMMERSION	US Polychem
99-6109-03-4	ALUMINUM	LUBRICANT	IMMERSION	Calgon Corporation
99-6109-03-4	ALUMINUM	LUBRICANT	IMMERSION	Mix
99-609-09-4	ALUMINUM	WAX	IMMERSION	EnviroSolutions
99-7108-02-1C	ALUMINA	ALCOHOL	IMMERSION	Chem-Tech Internationl
99-7108-02-1C	ALUMINA	ALCOHOL	IMMERSION	Oakite Products
99-7108-02-1C	ALUMINA	ALCOHOL	IMMERSION	SWR Corp.
99-7108-02-1C	ALUMINA	ALCOHOL	IMMERSION	Alconox
99-7108-02-1C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-7108-02-1C	ALUMINA	ALCOHOL	IMMERSION	Water
99-707-10-3	ALUMINUM	WAX	ULTRASONICS	EnviroSolutions
99-707-10-3	ALUMINUM	OIL	ULTRASONICS	EnviroSolutions
99-707-10-3	ALUMINUM	FLUX	ULTRASONICS	EnviroSolutions
99-707-10-3	BRASS	WAX	ULTRASONICS	EnviroSolutions
99-707-10-3	BRASS	DIRT	ULTRASONICS	EnviroSolutions
99-707-10-3	BRASS	OIL	ULTRASONICS	EnviroSolutions
99-707-10-3	STAINLESS STEEL	WAX	ULTRASONICS	EnviroSolutions
99-707-10-3	STAINLESS STEEL	DIRT	ULTRASONICS	EnviroSolutions
99-707-10-3	STAINLESS STEEL	OIL	ULTRASONICS	EnviroSolutions
99-707-10-3	STAINLESS STEEL	FLUX	ULTRASONICS	EnviroSolutions
99-7108-03-4C	ALUMINA	ALCOHOL	IMMERSION	Gemtek
99-7109-04-4	ALUMINUM	LUBRICANT	IMMERSION	Bcs Company
99-7109-05-4	ALUMINUM	LUBRICANT	IMMERSION	Oakite Products
99-7109-05-4	ALUMINUM	LUBRICANT	IMMERSION	US Polychem
99-7109-05-4	ALUMINUM	LUBRICANT	IMMERSION	Calgon Corporation
99-607-09-4	ALUMINUM	WAX	IMMERSION	EnviroSolutions
99-607-09-4	ALUMINUM	WAX	ULTRASONICS	EnviroSolutions
99-7107-05-3	ALUMINUM	COATING	IMMERSION	EnviroSolutions
99-7104-02-5	LIQUID	OIL	ANALYSIS	Surfactant Titration
99-7104-03-5	LIQUID	OIL	ANALYSIS	Surfactant Titration
99-7107-06-4	ALUMINUM	COATING	IMMERSION	EnviroSolutions
99-7107-06-4	ALUMINUM	COATING	ULTRASONICS	EnviroSolutions
99-792-03-2	STAINLESS STEEL	OIL	IMMERSION	A.W. Chesterton
99-792-03-2	STAINLESS STEEL	OIL	IMMERSION	Calgon Corporation
99-792-03-2	STAINLESS STEEL	OIL	IMMERSION	US Polychem
99-792-04-4	CARBON STEEL	OIL	IMMERSION	A.W. Chesterton
99-792-04-4	CARBON STEEL	OIL	IMMERSION	Calgon Corporation
99-792-04-4	CARBON STEEL	OIL	IMMERSION	US Polychem
99-792-04-4	STAINLESS STEEL	OIL	IMMERSION	A.W. Chesterton
99-792-04-4	STAINLESS STEEL	OIL	IMMERSION	Calgon Corporation
99-792-004-4	STAINLESS STEEL	OIL	IMMERSION	US Polychem
99-7108-04-4C	ALUMINA	ALCOHOL	IMMERSION	Chem Tech
99-7108-040-4C	ALUMINA	ALCOHOL	IMMERSION	Oakite Products
99-7108-04-4C	ALUMINA	ALCOHOL	IMMERSION	SWR Corp
99-7108-04-4C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-7108-04-4C	ALUMINA	ALCOHOL	IMMERSION	Water
99-7108-05-4C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-7108-05-4C	ALUMINA	ALCOHOL	IMMERSION	Oakite Products
99-7108-05-4C	ALUMINA	ALCOHOL	IMMERSION	Water
99-7111-01-4	NICKEL	OIL	IMMERSION	SafeScience
99-7111-01-4	NICKEL	LUBRICANT	IMMERSION	SafeScience
99-7111-01-4	NICKEL	ADHESIVE	IMMERSION	SafeScience

SCL #	Substrate	Contaminant	Mechanism	Cleaner
99-7111-01-4	COPPER	OIL	IMMERSION	SafeScience
99-7111-01-4	COPPER	LUBRICANT	IMMERSION	SafeScience
99-7111-01-4	COPPER	ADHESIVE	IMMERSION	SafeScience
99-7111-01-4	STAINLESS STEEL	GREASE	IMMERSION	SafeScience
99-7111-01-4	STAINLESS STEEL	ADHESIVE	IMMERSION	SafeScience
99-7111-02-4	STAINLESS STEEL	ADHESIVE	IMMERSION	SafeScience
99-7111-02-4	STAINLESS STEEL	OIL	IMMERSION	SafeScience
99-7108-06-5C	LIQUID	ALCOHOL	ANALYSIS	Colorimeter
99-7108-07-4C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-7108-07-4C	ALUMINA	ALCOHOL	IMMERSION	Water
99-7103-04-4	ALUMINUM	LUBRICANT	IMMERSION	New Pig
99-7103-04-4	STAINLESS STEEL	OIL	IMMERSION	New Pig
99-7103-05-4	ALUMINUM	GREASE	IMMERSION	New Pig
99-7103-05-4	STAINLESS STEEL	OIL	IMMERSION	New Pig
99-7111-03-4	ALUMINUM	GREASE	IMMERSION	SafeScience
99-7111-03-4	CR STEEL	LUBRICANT	IMMERSION	SafeScience
99-7111-03-4	LIQUID	BUFFING	IMMERSION	SafeScience
99-7104-04-5	LIQUID	OIL	ANALYSIS	Surfactant Titration
99-7109-06-5	ALUMINUM	NONE	ANALYSIS	OSEE
99-7108-08-4C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-7108-08-4C	ALUMINA	ALCOHOL	IMMERSION	Water
99-7108-09-4C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-758-02-5	LIQUID	LUBRICANT	ANALYSIS	Colorimeter
99-758-02-5	LIQUID	GLASS	ANALYSIS	Colorimeter
99-758-02-5	LIQUID	FLUX	ANALYSIS	Colorimeter
99-758-002-5	LIQUID	GRIME	ANALYSIS	Colorimeter
99-7108-11-5C	LIQUID	ALCOHOL	ANALYSIS	Colorimeter
99-7108-12-4C	ALUMINA	ALCOHOL	ULTRASONICS	International Products
99-7108-12-4C	ALUMINA	ALCOHOL	ULTRASONICS	Water
99-7108-13-4C	ALUMINA	ALCOHOL	ULTRASONICS	International Products
99-7108-14-5C	ALUMINA	ALCOHOL	OFF SITE	International Products
99-7108-15-5C	LIQUID	ALCOHOL	ANALYSIS	Colorimeter
99-7102-04-4	STEEL	OIL	IMMERSION	US Polychem
99-7102-04-4	STEEL	OIL	IMMERSION	Calgon Corporation
99-7102-04-4	STEEL	OIL	IMMERSION	Oakite Products
99-7102-04-4	STEEL	DIRT	IMMERSION	US Polychem
99-7102-04-4	STEEL	DIRT	IMMERSION	Calgon Corporation
99-7102-04-4	STEEL	DIRT	IMMERSION	Oakite Products
99-7102-04-2	STAINLESS STEEL	OIL	IMMERSION	US Polychem
99-7102-04-4	STAINLESS STEEL	OIL	IMMERSION	Oakite Products
99-7102-04-4	STAINLESS STEEL	DIRT	IMMERSION	US Polychem
99-7102-04-4	STAINLESS STEEL	DIRT	IMMERSION	Oakite Products
99-7113-01-4	ALUMINUM	ADHESIVE	IMMERSION	Westford Chemical
99-7113-01-4	STAINLESS STEEL	LUBRICANT	IMMERSION	Westford Chemical
99-7113-01-4	STEEL	GREASE	IMMERSION	Westford Chemical
99-7113-01-4	ALUMINA	OIL	IMMERSION	Westford Chemical
99-720-02-5	ELECTRONICS	FLUX	ANALYSIS	Black Light
99-720-02-5	ELECTRONICS	SALT	ANALYSIS	Black Light
99-7108-16-4C	ALUMINA	ALCOHOL	ULTRASONICS	International Products
99-7108-17-5C	LIQUID	ALCOHOL	ANALYSIS	Colorimeter
99-7115-01-2	BRASS	FLUX	IMMERSION	Church & Dwight Co.
99-7115-02-2	BRASS	FLUX	IMMERSION	Oakite Products
99-7108-18-5C	ALUMINA	ALCOHOL	ANALYSIS	FTIR
99-7115-03-3	BRASS	FLUX	ULTRASONICS	Church & Dwight Co.
99-7115-03-3	BRASS	FLUX	ULTRASONICS	EnviroSolutions
99-7115-03-3	BRASS	FLUX	ULTRASONICS	Oakite
99-7115-03-3	BRASS	FLUX	ULTRASONICS	Emkay
98-676-05-4	ALUMINUM	NONE	ANALYSIS	Gravimetric
98-676-05-4	ALUMINUM	NONE	ANALYSIS	Visual
98-676-05-4	ALUMINUM	NONE	ANALYSIS	Wipe
99-7115-04-4	BRASS	FLUX	ULTRASONICS	Church & Dwight Co.
99-7115-04-4	BRASS	FLUX	ULTRASONICS	Oakite Products
99-7108-19-5C	LIQUID	ALCOHOL	ANALYSIS	Colorimeter
99-7108-20-5C	ALUMINA	ALCOHOL	ANALYSIS	FTIR
99-7116-01-5	STEEL	OIL	ANALYSIS	OSEE
99-7115-05-4	BRASS	FLUX	ULTRASONICS	Church & Dwight Co.
99-7115-05-4	BRASS	FLUX	ULTRASONICS	EnviroSolutions, Inc.
99-7115-05-4	BRASS	FLUX	ULTRASONICS	Emkay Chemical Co.
99-7115-07-3	BRASS	OIL	ULTRASONICS	EnviroSolutions, Inc.
99-7115-07-3	BRASS	OIL	ULTRASONICS	Church & Dwight Co.
99-7115-07-3	BRASS	OIL	ULTRASONICS	Oakite Products

SCL #	Substrate	Contaminant	Mechanism	Cleaner
99-7108-21-5C	LIQUID	ALCOHOL	ANALYSIS	Colorimeter
99-7116-02-4	HR STEEL	OIL	ULTRASONICS	Water
99-7108-22-4C	ALUMINA	ALCOHOL	IMMERSION	International Products
99-7103-06-4	ALUMINUM	OIL	IMMERSION	Ensolve Biosystems
99-7103-06-4	STAINLESS STEEL	GREASE	IMMERSION	Ensolve Biosystems
99-7103-06-4	BRASS	LUBRICANT	IMMERSION	Ensolve Biosystems
99-7103-06-4	ALUMINUM	OIL	IMMERSION	United Laboratories
99-7103-06-4	BRASS	LUBRICANT	IMMERSION	United Laboratories
99-7103-06-4	STAINLESS STEEL	GREASE	IMMERSION	United Laboratories
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	SafeScience
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	Oakite Products
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	Texo Corporation
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	U.S. Polychem Corp.
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	Valtech Corporation
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	W.R. Grace & Co.
99-7119-01-2	STAINLESS STEEL	BUFFING	IMMERSION	International Products
99-7119-02-2	STAINLESS STEEL	GREASE	IMMERSION	Oakite Products
99-7119-02-2	STAINLESS STEEL	GREASE	IMMERSION	U.S. Polychem Corp.
99-7119-02-2	STAINLESS STEEL	GREASE	IMMERSION	Valtech Corporation
99-7119-02-2	STAINLESS STEEL	GREASE	IMMERSION	W.R. Grace & Co.
99-7119-02-2	STAINLESS STEEL	GREASE	IMMERSION	International Products
99-7119-03-4	STAINLESS STEEL	GREASE	ULTRASONICS	Oakite Products
99-7119-03-4	STAINLESS STEEL	GREASE	ULTRASONICS	Texo Corporation
99-7119-03-4	STAINLESS STEEL	GREASE	ULTRASONICS	U.S. Polychem Corp.
99-7119-03-4	STAINLESS STEEL	GREASE	ULTRASONICS	Valtech Corporation
99-7119-03-4	STAINLESS STEEL	GREASE	ULTRASONICS	W.R. Grace & Co.
99-7119-03-4	STAINLESS STEEL	GREASE	ULTRASONICS	International Products
99-7119-04-2	STAINLESS STEEL	PITCH	ULTRASONICS	SafeScience
99-7119-04-2	STAINLESS STEEL	PITCH	ULTRASONICS	EnviroSolutions, Inc.
99-7119-04-2	STAINLESS STEEL	PITCH	ULTRASONICS	Oakite Products
99-7119-05-4	STEEL	PITCH	ULTRASONICS	EnviroSolutions, Inc.
99-7119-05-4	STAINLESS STEEL	BUFFING	ULTRASONICS	Oakite Products
99-7119-05-4	STAINLESS STEEL	BUFFING	ULTRASONICS	Texo Corporation
99-7119-05-4	STAINLESS STEEL	BUFFING	ULTRASONICS	W.R. Grace & Co.
99-7119-05-4	STAINLESS STEEL	BUFFING	ULTRASONICS	International Products
99-7115-06-3	BRASS	WATER	DRYING	Vacuum Oven

AL = Aluminum
CR = Cold Roll
C = Confidential
* = Especially noteworthy

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Article from the October issue <*italics added*>
The Cleanest Cleaners by JohnPaul Kusz and Mark T. Petruzzi

Green Seal's Sustainable Lodging Stakeholder Initiative

The U.S. lodging industry provides more than 3.9 million guestrooms that generate some $93.1 billion in revenue. Given the nature and size of the industry, significant opportunities to reduce environmental impacts are available—and environmentally responsible practices can be good business practices. To further understand the placement and use of environmentally friendly products in the lodging industry, Green Seal embarked on the "Sustainable Lodging Stakeholder Initiative," designed to identify the link between product users and service providers; buyers and suppliers; and products' economic and environmental benefit.

Marriott International permitted Green Seal to review the environmental practices of four properties: the Residence Inn, Gaithersburg, Maryland; the Courtyard by Marriott Fair Oaks, Fairfax, Virginia; the Fairview Park Marriott, Falls Church, Virginia; and the Renaissance Mayflower Hotel, Washington, D.C. Similarly, the Saunders Hotel Group, allowed the review of the Lenox Hotel and the Copley Square Hotel in Boston.

The six hotels were evaluated in targeted areas of daily operational practices in physical plant, laundry and dry cleaning, landscaping, pool/spa, kitchen facilities, and guestroom services departments. People, products, and processes also were reviewed.

Early on, property owners, general managers, and other staff met with suppliers to discuss specific products and hotel operations. This forum was informative, allowing insights into possible barriers to progressive change—even when all parties viewed the change as beneficial.

The selection and use of housekeeping chemicals stood out as a prime target for further exploration and improvement. Green Seal solicited the participation of several housekeeping product suppliers, including the current suppliers of housekeeping chemicals to the properties studied. While the current suppliers were reluctant to participate, Rochester Midland, of Rochester, New York, agreed to a product evaluation between its cleaning products and the products currently being used at the six properties.

To evaluate product performance in both a lab and a real-world setting, Green Seal enlisted the Toxics Use Reduction Institute's Surface Cleaning Laboratory at the University of Massachusetts, which assists businesses in the evaluation and selection of alternative cleaning products. In the hazard analysis and laboratory efficacy testing, the products in these categories submitted by Rochester Midland were clearly environmentally superior than the products currently used by the hotels. What's more, the Rochester Midland products were well designed with regard to their formulation in terms of environmental, health, and safety issues. However, evaluating products in actual use was one of the most revealing components of the study.

Even with the knowledge that the Rochester Midland products were proven better in objective analyses, our findings in the field were not as clear. By virtue of observation, data gathering, and discussion with management and staff, we learned that cultural markers influence the perception of a product's efficacy. Specifically, if a product has a strong scent, or if a product's color in dilution stayed dark, it was more likely to be perceived as a better cleaner. Meanwhile, many companies with products that contain superior environmentally friendly characteristics are trying to reduce scent and color to minimize olfactory and lung irritation and staining. This is one area where product education would be beneficial to users.

Perhaps the most important component of success when transitioning to an environmentally superior product is realizing that saving money and the environment are goals worth pursuing in tandem. Many high-performance, environmentally friendly products already exist on the market and with better awareness and training, even cost-conscious properties can avoid overuse and overconcentration of cleaning chemicals.

JohnPaul Kusz is the project manager for Green Seal's Sustainable Lodging Stakeholder Initiative. Mark T. Petruzzi is lodging program director at Green Seal, a Washington, D.C.-based organization devoted to environmentally responsible purchasing. For more information on the Sustainable Lodging Stakeholder Initiative, contact Green Seal at 202-872-6400.

Appendix I.

Full-Day Training Module
CRITICAL THINKING FOR CLEANING ALTERNATIVES
Chelmsford Radisson, October 27, 2000

9:00 AM INTRODUCTION
- Part 1. General Introduction
  - A. Statement of the Problem
  - B. Central Scientific Questions
  - C. Importance of Definitions
  - D. Structure of this Workshop
- Part 2. Solvent Background
  - A. Historical Discovery of Substances
  - B. Characterization of Chemical Types
  - C. Environmental and Health Effects
  - D. Legislative Initiatives

10:30 AM BREAK

10:45 AM CLEANING ALTERNATIVES RESEARCH
- Part 3. Return to Water-Based Cleaning
  - A. The Role of Environmental Indicators
  - B. Aqueous and Semi-Aqueous Cleaners: What's In Them and How They Work
- Part 4. Developing A Testing Protocol for Surface Cleaning
  - A. Designing A Questionnaire for Companies with Cleaning Problems
  - B. Determining the Phases of an Aqueous Cleaning Trial
  - C. Using Analytical Techniques to Measure Cleaning Efficiencies
- Part 5. Other Replacement (i.e., Non-Aqueous) Cleaners and Methods

12:00 PM LUNCH

1:00 PM CLEANING ALTERNATIVES RESEARCH (CONT.)
- Part 6. The Three Worlds of Cleaning
  - A. Precision Cleaning
  - B. Parts Cleaning
  - C. Institutional (Janitorial) Cleaning
- Part 7. How the Interactive Matrix *The Aqueous Way to Go* Was Constructed
  - A. Identifying Sources of Technical Information and Assistance: Databases, Standards, Publications and the WORLD WIDE WEB
  - B. Other Important Considerations: Natural Resource Management, Environmental Management Systems, Life Cycle Assessment, Sustainability Factors and CLEANING PERFORMANCE
  - C. Defining Costs: the Problem with Most Purchasing Programs

(Time Permitting) FOR DISCUSSION
- Part 8. The Future of Industrial Cleaning and Related Public Policy
  - A. The Precautionary Principle
  - B. Environmental Epidemiology

3:30 PM OBSERVATIONS AND RESULTS
- Part 9. Summation of Notable Findings
  - A. Examples of Some Results
  - B. Shortcomings of Present Technology
  - C. Utilizing this Workshop as a Tool for Environmental Decision-Making

4:00 PM ADJOURN

Appendix I.

CONTINUING EDUCATION ONE-DAY CONFERENCE AND INDUSTRY SPECIFIC TRAINING DAY EVALUATION FORM

Please answer the following questions and rate the following elements of today's event according to the scales provided. Under "comments" please offer specific examples and suggestions regarding strengths and weakness. Thank you for taking the time to provide your feedback.

	***Average Answers:**	
1. Overall, how would you rate the Methodology *Critical Thinking for Cleaning Alternatives*? Poor Fair Excellent 1 2 3 4 5	**1.**	**3.6 (overall)**
(a) How would you rate the delivery of instruction (i.e., presentation, visual aids)? Poor Fair Excellent 1 2 3 4 5	**(a)**	**3.7**
(b) How would you rate the instructional materials (i.e., handouts)? Poor Fair Excellent 1 2 3 4 5	**(b)**	**4**
(c) How would you rate the depth and level of detail covered? Poor Fair Excellent 1 2 3 4 5	**(c)**	**3.6**
2. Overall, how would you rate the Tool/Interactive Matrix *The Aqueous Way to Go*? Poor Fair Excellent 1 2 3 4 5	**2.**	**3.6 (overall)**
(a) How would you rate the organization of its materials? Poor Fair Excellent 1 2 3 4 5	**(a)**	**4.2**
(b) How would you rate the usefulness of its contents? Poor Fair Excellent 1 2 3 4 5	**(b)**	**3.9**
(c) How would you rate the relevance of its web sites? Poor Fair Excellent 1 2 3 4 5	**(c)**	**3.8**
3. How would you rate the length of time allotted **For Session:** Poor Fair Excellent 1 2 3 4 5 **For Questions:** Poor Fair Excellent 1 2 3 4 5	**3.**	**For Session: 3.4** **For Questions: 4**

4. Other comments and suggestions:

*Average scores are for *specific answers only*, as some respondents chose not to answer all questions.

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Curriculum Vitae

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Experience:

Over Fifteen Years in Research and Development in Medical and Environmental Sciences, Curriculum Development, Laboratory and Business Management, Technical Writing and Public Affairs

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Salutatorian, Our Lady of Nazareth Academy, Wakefield, MA
Cum Laude, B.S., Biology; B.S., Chemistry, Boston College, MA
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American Electroplaters and Surface Finishers, Local Branches (AESF)
Massachusetts Manufacturing Partnership (MMP)
New England Waste Management Officials Association (NEWMOA)
Society of Manufacturing Engineers, Local Chapters (SME)

Regional	State	National
Boards of Health	MA DEP*	EPA (Region I, NEEAT*)
Chambers of Commerce	MA OTA*	OSHA
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International: European Cleaner Production Roundtable

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Laboratory Assistant, Boston College,
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Laboratory Associate, Tufts Medical School,
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Regional Manager, Colgate-Palmolive, Inc.,
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Regional Board, Association of Official Analytical Chemists (AOAC)
Editorial Advisory Board, Witter Publishing, Flemington, NJ, USA
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Selected Publications:

The Effects of Colchicine on Protosynchronized Cultures of Tetrahymena pyriformis GL, Thesis, Boston College Cancer Institute, 1973.

In Vivo Localization of Immunoglobulins in Bullous Pemphigoid, Contributor, Journal of Investigative Dermatology (JID), 1975.

Homogenization and the Control of Particle Size in Liquids, National Conference Proceedings, American Institute of Chemical Engineers, Houston, Texas, 1988.

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Exploring Cleaning Options with an Eye on Quality Control, Precision Cleaning: The Magazine of Critical Cleaning Technology, June, 1995.

HCFCs and Cleaning, Toxics Use Reduction Institute, Surface Cleaning Series Fact No. SC-2, 1996.

Aqueous Cleaning at the Massachusetts Toxics Use Reduction Institute: Some Lessons Learned, Manufacturers' Mart: The Action Publication Serving New England Manufacturing, January, 1997.

The Toxics Use Reduction Act (TURA) of 1989: Lessons Learned, Annual Conference Proceedings, Precision Cleaning, Cincinnati, Ohio, April, 1997.

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The Environmental and Health Hazards of Halogenated and Organic Solvents, American Environmental Laboratory: An International Scientific Communications, Inc. (ISC) Publication, August 1998.

The Cost of Process Conversion, Co-Author, Annual Conference Proceedings: CleanTech, Chicago, Illinois, USA, May 1999.

Cleaning Metals: Strategies for the New Millennium, Handbook for Critical Cleaning, ed., Barbara Kanegsberg, CRC Press, 2000.

Major Affiliations:

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AFL-CIO, Local 254 (Union Steward to Professional Unit)
AIChE, American Institute of Chemical Engineers (National Presenter)
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NAFE, National Association of Female Executives
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Ph.D. Thesis Propositions

The Search for Safer and Greener Chemical Solvents in Surface Cleaning: A Proposed Tool to Support Environmental Decision-Making

1. Complete chemical disclosure of ingredients via product labeling is the best way to ensure that a cleaner's hazards, based on the latest information, are publicly transparent. Current U.S. "right-to-know" legislation (thesis sections 2.5.5 and 2.6.2), is inadequate to fully protect the environment, workers and citizens, creating a need for the tool, *The Aqueous Way to Go*, to distinguish risks.

2. Such complete disclosure should be on a global scale, to ensure fair competition among companies. This effort will require negotiation with the European community, in particular, to reach labeling consensus for chemical reporting, *similar to the approach described throughout the thesis for stakeholder participation in solvent substitution* (see also, thesis section 2.6.1 as to the Montreal Protocol).

3. Newly developed compounds, such as ionic liquids (thesis section 9.1.3) will cause substantial health damage, unless an advisory panel of technical experts is charged with diffusing information on their hazards. Panel members from government, industry and academia should *establish criteria, like those used in the notebook headings of this thesis' tool*, under which scientists must report.

4. Scientific/trade associations could act as 'watchdog' intermediates or liaisons to ensure company participation in the above precautionary framework *without retribution against reporting scientists*. Failure to recognize these organizations' roles could lead to the firm's loss of accreditation, membership or professional standing.

5. In addition to studying new chemicals, the advisory panel (of stelling three) could examine *existing* chemicals, not unlike the U.S.'s first National Report on Human Exposure to Environmental Chemicals.[1] If these assessment studies do not use hormetic principles and non-cancer (i.e., endocrine disrupter) models, then the *true* safety of the proposed substance will remain uncertain (thesis sections 9.2.1 and 9.2.2)

6. Given the chemical industry's poor record in releasing deleterious information about its products prior to extensive damage to humans or the environment,[2] these studies (of stelling five) should focus on chemical exposure and (1) reproduction, (2) brain functioning, (3) rare forms and 'cluster appearances' of cancer/disease and (4) multiple-chemical sensitivity (thesis section 9.3.2).

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[1] U.S. Center for Disease Control (CDC) and Prevention press release dated March 21, 2001 (http://www.cdc.gov/od/oc/media/pressrel/r010321.htm) in which the presence of soaps and perfumes in subjects' blood was revealed.

[2] Bill Moyers' PBS telecast, *Trade Secrets* on March 26, 2001, documenting the chemical industry's strong lobbying interests in the U.S. Congress at http://www.pbs.org/tradesecrets.

7. An automated mechanism for the communication of these developments to the thesis' training component, *Critical Thinking for Cleaning Alternatives* (i.e., notebook tab 14), must be devised. Otherwise, cleaning practitioners may not be informed of the U. S. EPA's findings that recycling organo-chlorinated solvents for reuse could result in the generation of toxic by-product(s).[3]

8. Manufacturers who change the formulation of a given product, substituting an ingredient at will without informing consumers and workers, create health risks for these stakeholders (thesis section 5.1.1). They should be held liable for the damages caused by labeling misrepresentations, and wide variations in percent concentrations of ingredients (closing statement).

9. This type of disclosure may not always reveal exposure data at the ppm, ppb or contaminant levels. But identifying the potential sources of harmful chemicals associated with a product's intended ingredients as well as its contaminants (e.g., mercury in talc) should lead to cleaner products (that is, cleaner cleaners!) and advance the science of environmental epidemiology (thesis sections 2.5.3 and 2.5.4).

10. Wherever possible, it should be the stated goal of corporate and governmental policies to develop self-cleaning or no-clean surfaces within various industrial sectors (thesis section 3.1.1). Innovative taxation methods involving financial incentives will be necessary to foster R & D in these more sustainable manufacturing methods and alternative materials.

11. Where surface cleaning *is* required, cleaners that are designed to disassociate into smaller, benign and common components such as H_2O and CO_2, may be re-used for entirely different purposes, as demonstrated in industrial ecology, or released into the natural environment without harm. The disassociation process could be chemically triggered by the removal of the last traces of contaminant(s).

12. Ph.D. candidates who do surface-cleaning research are unable to effectively and safely clean their own offices.

13. Either a Norwegian graduate (a male) returns to the next Intensive with his own car OR a Canadian graduate (a female) rents a Ford Festiva.

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[3] Peavey, D., U.S. EPA Region 1, Seminar on Polyaromatic Hydrocarbons (PAHs) and Persistent Bioaccumulative Toxins (PBTs) on February 1, 2001 in Natick, Massachusetts.

THE SEARCH FOR SAFER AND GREENER CHEMICAL SOLVENTS IN SURFACE CLEANING:
A PROPOSED TOOL TO SUPPORT ENVIRONMENTAL DECISION-MAKING

Traditional solvent-based cleaning and degreasing agents pose well-established environmental, health and safety hazards. Finding effective, environmentally-friendlier cleaning methods, however, has proven to be no easy task.

It is the mission of the Toxics Use Reduction Institute's Surface Cleaning Lab (SCL) located at the University of Massachusetts Lowell to test and evaluate the effectiveness of different chemical cleaners and cleaning equipment on a variety of substrates and surface contaminants. SCL's objective is to identify, develop and promote safer cleaning alternatives to hazardous materials such as organic and chlorinated solvents. This necessarily involves studying the supplies and practices of surface preparation, cleaning, rinsing, drying and analysis.

This thesis chronicles five years of the laboratory's research and offers a systematic approach to solvent substitution, the first of its kind to cover a wide range of manufacturing applications in such specificity. It theorizes that a test data/ material's information methodology will assist governments, companies, scientists and cleaning practitioners in their quest for more sustainable cleaning chemicals and processes. Because the proposed tool is rooted in actual performance testing and is capable of being expanded to include new technologies, this strategy may enhance the efficiency and effectivity of searching within the burgeoning field of Green Chemistry for safer cleaning solvents.

The author envisions the day when businesses will no longer be forced to use hazardous materials for surface cleaning in the production of quality goods and services. This thesis also suggests that toxic-free analytical techniques for surface inspection will be developed that are superior to those now in use. Furthermore, the drain on natural resources, such as energy and water will diminish with the use of more efficient cleaning systems.

Based on the cornerstones of pollution prevention and cleaner production, pursuit of this vision minimizes or eliminates risks associated with many of today's industrial cleaning applications. Specifically, reductions in ozone depletion, global warming and VOC emissions as well as decreases in exposures to flammable, carcinogenic and other toxic substances are sought: valuable goals for workers, consumers and communities alike.