

**DEMONSTRATION OF
ALTERNATIVE CLEANING SYSTEMS**

Dean M. Menke
Gary A. Davis
Lori E. Kincaid
Rupy Sawhney

University of Tennessee
Center for Clean Products and Clean Technologies
Knoxville, Tennessee 37996-0710

Project Officer

Diana R. Kirk
Sustainable Technology Division
National Risk Management Research Laboratory
Clean Processes and Products Branch
Cincinnati, Ohio 45268

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems ; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

TABLE OF CONTENTS

	Page
DISCLAIMER	ii
FOREWORD	iii
ABSTRACT	iv
LIST OF TABLES	viii
LIST OF FIGURES	xi
ACRONYMS	xii
ACKNOWLEDGMENT	xiv
 CHAPTER 1: INTRODUCTION	 1
33/50 PROGRAM	1
OBJECTIVES OF THIS RESEARCH	2
METHODOLOGY	5
CHAPTER 2: MATERIALS AND PARTS CLEANING	6
MATERIALS AND PARTS DEGREASING DESCRIPTION	6
Cold Cleaning	6
Vapor Degreasing	7
Conveyorized Degreasing	7
Hybrid Degreasing Systems	7
PROPERTIES OF CHLORINATED DEGREASING SOLVENTS	8
Degreasing Properties	8
Health, Safety and Environmental Properties	8
REGULATORY BACKGROUND	10
SAFE SUBSTITUTES FOR THE 33/50 DEGREASING SOLVENTS	10
Aqueous Wash Systems	10
No-Clean Technologies	12
CHAPTER 3: CALSONIC'S CHLORINATED SOLVENT SUBSTITUTES PROGRAM	 14
BACKGROUND INFORMATION ON CALSONIC	14
THE RADIATOR LINE AND AQUEOUS WASH SYSTEM	15
THE CONDENSER LINE AND NO-CLEAN TECHNOLOGY	17
THE CONVERTER LINE AND HOT WATER WASH SYSTEM	22
CHAPTER 4: TECHNICAL EVALUATIONS	25
TECHNICAL BACKGROUND	25
CMC TECHNICAL EVALUATION	26
The Evaluation of the Process Cycle Time	26
The Evaluation of Part Reject Rates	27
SUMMARY OF THE TECHNICAL EVALUATION	29
Aqueous Wash System of the Radiator Manufacturing Line	29
Evaporative Lubricant System of the Condenser Manufacturing Line	29
CHAPTER 5: ENVIRONMENTAL EVALUATION	30
ENVIRONMENTAL BACKGROUND	30

Table of Contents continued

REFERENCES 120

APPENDIX A: RAW DATA IN DATA REQUEST TABLES 126

APPENDIX B: SCREENING TEST RESULTS FOR THE AQUEOUS
WASH SYSTEM 140

APPENDIX C: STATISTICAL EVALUATIONS 144

APPENDIX D: CONVERSION TABLE 149

APPENDIX E: CALSONIC CORPORATION'S ENVIRONMENTAL PROGRAM ... 151

APPENDIX F: ANALYSIS RESULTS OF PRETREATED WASTEWATER
EFFLUENT 162

APPENDIX G: UNIQUE BILLS OF ACTIVITIES 163

List of Tables continued

TABLE 24.	COMPARISON OF HYBRID AND TRADITIONAL ANALYSES - RADIATOR MANUFACTURING LINE	64
TABLE 25.	HYBRID COST ANALYSIS OF THE PROCESS CHANGES TO THE CONDENSER MANUFACTURING LINE	65
TABLE 26.	COMPARISON OF HYBRID AND TRADITIONAL ANALYSES - CONDENSER MANUFACTURING LINE	65
TABLE 27.	SUPPLY AND DEMAND OF THE CHLORINATED DEGREASING SOLVENTS	70
TABLE 28.	TRI RELEASES AND TRANSFERS OF CHLORINATED DEGREASING SOLVENTS FROM PRODUCTION FACILITIES	71
TABLE 29.	CHLORINATED SOLVENT CONSUMPTION BY DEGREASING APPLICATIONS	73
TABLE 30.	PRODUCERS OF ETHOXYLATED ALCOHOL SURFACTANTS	76
TABLE 31.	RELEASES AND TRANSFERS FROM ETHOXYLATED ALCOHOL PRODUCTION FACILITIES	77
TABLE 32.	PRODUCERS OF ETHOXYLATED NONYLPHENOL SURFACTANTS	79
TABLE 33.	TRI RELEASES AND TRANSFERS FROM ETHOXYLATED NONYLPHENOL PRODUCTION FACILITIES	82
TABLE 34.	PRODUCERS OF DODECYLBENZENE SULFONIC ACID	85
TABLE 35.	TRI RELEASES AND TRANSFERS FROM DODECYLBENZENE SULFONIC ACID PRODUCTION FACILITIES	86
TABLE 36.	TOTAL RELEASES AND TRANSFERS FROM SURFACTANT AND SOAP/DETERGENT MANUFACTURERS	87
TABLE 37.	PRODUCERS OF TETRAPOTASSIUM PYROPHOSPHATE	88
TABLE 38.	TRI RELEASES AND TRANSFERS FROM TETRAPOTASSIUM PYROPHOSPHATE PRODUCTION FACILITIES	91
TABLE 39.	PRODUCERS OF SODIUM TRIPOLYPHOSPHATE	90
TABLE 40.	TRI RELEASES AND TRANSFERS FROM SODIUM TRIPOLYPHOSPHATE PRODUCTION FACILITIES	92
TABLE 41.	PRODUCERS OF ETHYLENEDIAMINETETRAACETIC ACID	93
TABLE 42.	TRI RELEASES AND TRANSFERS FROM ETHYLENEDIAMINETETRAACETIC ACID PRODUCTION FACILITIES	95
TABLE 43.	TRI RELEASES AND TRANSFERS FROM THE PRODUCTION OF NTA - W.R. GRACE AND COMPANY	96
TABLE 44.	TOTAL TRI RELEASES AND TRANSFERS FROM INDUSTRIAL INORGANIC CHEMICAL PRODUCERS	97
TABLE 45.	NATIONAL BASELINE AIR RELEASES	99
TABLE 46.	TRI RELEASES AND TRANSFERS OF CHLORINATED DEGREASING SOLVENTS FROM TOP INDUSTRY SECTORS	100
TABLE 47.	COMPARISON OF 1992 TRI EMISSIONS AND NESHAP BASELINE EMISSION ESTIMATIONS	102

LIST OF FIGURES

	Page
FIGURE 1. CHLORINATED ORGANIC CHEMICALS	4
FIGURE 2. CURRENT RADIATOR MANUFACTURING LINE WITH THE AQUEOUS WASH SYSTEM	16
FIGURE 3. PAST RADIATOR MANUFACTURING LINE WITH THE SOLVENT DEGREASING SYSTEM	18
FIGURE 4. CURRENT CONDENSER MANUFACTURING LINE WITH THE NO-CLEAN TECHNOLOGY	19
FIGURE 5. PAST CONDENSER MANUFACTURING LINE WITH THE SOLVENT DEGREASING SYSTEM	20
FIGURE 6. CURRENT CONVERTER MANUFACTURING LINE WITH THE HOT WATER WASH SYSTEM	23
FIGURE 7. PAST CONVERTER MANUFACTURING LINE WITH THE SOLVENT DEGREASING SYSTEM	24
FIGURE 8. PART REJECT RATES (NORMALIZED) OVER TIME FOR THE RADIATOR MANUFACTURING LINE	28
FIGURE 9. TCA RELEASES AND TRANSFERS FROM THE RADIATOR AND CONDENSER MANUFACTURING LINES - 1990 TO 1994	33
FIGURE 10. SUMMARY OF RADIATOR LINE EMISSIONS OVER TIME	45
FIGURE 11. SUMMARY OF CONDENSER LINE EMISSIONS OVER TIME	46
FIGURE 12. SIMPLIFIED MANUFACTURING SCHEME FOR 1,1,1-TRICHLOROETHANE	68
FIGURE 13. SURFACTANT MANUFACTURING	74
FIGURE 14. SIMPLIFIED MANUFACTURING SCHEME FOR NONYLPHENOL ETHOXYLATES	80
FIGURE 15. SIMPLIFIED MANUFACTURING SCHEME FOR DODECYLBENZENE SULFONIC ACID	84
FIGURE 16. SIMPLIFIED MANUFACTURING SCHEME OF TETRAPOTASSIUM PYROPHOSPHATE	89
FIGURE 17. EDTA MANUFACTURING SCHEME	94
FIGURE 18. DISTRIBUTION OF DOCUMENTED NEEDS	109
FIGURE C1. REPRESENTATION OF STATISTICALLY DIFFERENT DATA SETS	147

DISCLAIMER

The information in this document has been funded wholly by the United States Environmental Protection Agency under Cooperative Agreement CR821848 to the University of Tennessee's Center for Clean Products and Clean Technologies. It has been subject to peer and administrative review, and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Acronyms continued

Pa-sec	pascal second
Pb	lead
PCE	tetrachloroethylene or perchloroethylene
PEL	permissible exposure limit
POTW	Publicly Owned Treatment Works
ppm	parts per million
SAGE	Solvent Alternatives Guide
STPP	sodium tripolyphosphate
TCA	1,1,1-trichloroethane
TCE	trichloroethylene
TRI	Toxic Release Inventory
TSD	treatment, storage, and disposal
TURI	Toxics Use Reduction Institute
VOC	volatile organic compound

ABSTRACT

Widespread use of toxic chemicals in all segments of industry and commerce has created the need to deal with burgeoning waste streams containing toxic chemicals emitted into the air and water and buried in the soil. Two decades of pollution control regulations have not been completely effective in reducing environmental releases of toxic chemicals, nor in mitigating the human health effects from toxic chemical use. The United States Environmental Protection Agency's 33/50 Program is one example of a new generation of voluntary programs that focus directly on pollution prevention to reduce toxic chemical releases. The 33/50 Program encourages industry to enter agreements to reduce emissions of 17 toxic chemicals.

This report represents the first demonstration of cleaner technologies to support the goals of the 33/50 Program under the EPA Cooperative Agreement No. CR821848. It focuses on substitutes for solvent degreasing processes that eliminate the use of chlorinated organic chemicals in the automotive parts sector. The substitute technologies demonstrated were: 1) an aqueous wash system, 2) a no-clean technology, and 3) a hot water wash system. Technical, environmental, and economic evaluations were performed to determine the merits of the substitutes as they were implemented by the project's industry partner, Calsonic Manufacturing Corporation. A national environmental impact evaluation was also performed to estimate the potential impacts on the nation's environment if entire industrial sectors were to implement the substitutes.

The evaluations were supportive of the implementation of the alternative technologies. The aqueous wash system reduced cycle time by 50 percent and part reject rates by nearly 77 percent with improved cleaning characteristics as compared to the 1,1,1-trichloroethane (TCA) solvent degreasing system. The no-clean alternative had no effect on either cycle time or part reject rates. The environmental evaluation identified a shift in waste stream releases and transfers. The traditional processes released TCA to the air, as well as generating a TCA hazardous waste stream; the substitutes generates either a significant wastewater discharge (aqueous and hot water wash systems), or a volatile organic compound air emission (no-clean technology). The wastewater and VOC releases created by the alternatives, however, do not contain 33/50 chemicals or chemicals that can cause ozone depletion, and are relatively less toxic than the chlorinated solvents. Each alternative offered significant financial advantages when economically evaluated using activity-based cost accounting and compared to the traditional solvent degreasing systems.

The national environmental impact evaluation compared the life-cycle environmental merits of traditional solvent systems and the alternatives. Chlorinated solvents, produced from petroleum feedstocks, result in significant emissions during the manufacturing and use of the products. The aqueous wash systems utilize detergents which include surfactants, builders, and chelating agents, all of which are produced from various raw materials and generate waste streams which must be compared to traditional attributes. The nation's infrastructure for wastewater treatment was then evaluated, and the potential impact estimated.

CHAPTER 1

INTRODUCTION

The hazardous waste problem and many of the persistent air and water pollution problems are primarily toxic chemical problems. Widespread use of toxic chemicals in all segments of industry and commerce has created the need to deal with burgeoning waste streams containing toxic chemicals emitted into the air and water and buried in the soil. Two decades of pollution control regulations have not been completely effective in reducing environmental releases of toxic chemicals. Nor have regulations always protected workers from the effects of toxic chemicals used in the workplace or consumers from the effects of toxic chemicals found in consumer products. However, a new generation of programs and policies are emerging which have a greater potential to reduce toxic chemical releases. The United States Environmental Protection Agency's (EPA) 33/50 Program is one such new generation program.

33/50 PROGRAM

The 33/50 Program is a voluntary pollution prevention initiative to reduce national releases and off-site transfers to the environment of 17 toxic chemicals. The Program asks industry to voluntarily develop their own reduction goals that contribute toward national reduction goals of 33 percent by the end of 1992 and 50 percent by the end of 1995. Reductions are measured against a 1989 baseline of information reported to EPA under the Toxic Release Inventory (TRI). The 17 chemicals or chemical groups included in the 33/50 Program are as follows:

Benzene	Methyl Ethyl Ketone (MEK)
Cadmium and Cadmium Compounds	Methyl Isobutyl Ketone (MIBK)
Carbon Tetrachloride (CTC)	Nickel and Nickel Compounds
Chromium and Chromium Compounds	Tetrachloroethylene (PCE)
Chloroform (CFM)	Toluene
Cyanide and Cyanide Compounds	1,1,1-Trichloroethane (TCA)
Lead and Lead Compounds	Trichloroethylene (TCE)
Mercury and Mercury Compounds	Xylenes
Methylene Chloride (DCM)	

EPA selected these compounds for the voluntary pollution prevention initiative based on a number of factors including their high production volume, high releases and off-site transfers relative to their production, opportunities for pollution prevention, and their potential for causing health and environmental effects.¹

EPA's National Risk Management Research Laboratory (NRMRL, formerly Risk Reduction Engineering Laboratory) has funded research in support of the 33/50 Program. The goal of the NRMRL-funded research is to evaluate the performance and cost of pollution prevention options and to disseminate that information through reports, technical meetings, seminars, and other media. While this research was originally funded by NRMRL to support

Table of Contents continued

RELEASES AND TRANSFERS TO LAND (OFF-SITE TRANSFERS)	34
Radiator Manufacturing Line	35
Condenser Manufacturing Line	36
RELEASES AND TRANSFERS TO AIR	36
Radiator Manufacturing Line	37
Condenser Manufacturing Line	37
RELEASES AND TRANSFERS TO WATER	38
Radiator Manufacturing Line	38
Condenser Manufacturing Line	39
Converter Manufacturing Line	39
TOXICITY, EXPOSURE, AND RISK	39
Toxicity	40
Exposure Potential	41
Risk	42
SUMMARY OF THE ENVIRONMENTAL EVALUATION	43
CHAPTER 6: ECONOMIC EVALUATION	47
ECONOMIC BACKGROUND	47
TRADITIONAL COST EVALUATIONS	48
Traditional Cost Evaluation of the Radiator Manufacturing Line	49
Traditional Cost Evaluation of the Condenser Manufacturing Line	52
ACTIVITY-BASED COST ACCOUNTING	56
ABC Analysis of CMC	56
ABC Analysis of the Radiator Manufacturing Line	57
ABC Analysis of the Condenser Manufacturing Line	61
HYBRID ACCOUNTING SYSTEM	63
Hybrid Analysis for the Radiator Manufacturing Line	63
Hybrid Analysis for the Condenser Manufacturing Line	63
CHAPTER 7: NATIONAL ENVIRONMENTAL IMPACT EVALUATION	66
NATIONAL ENVIRONMENTAL IMPACT BACKGROUND	66
CHEMICAL PRODUCTION PROCESSES	67
Production of Chlorinated Solvents	67
Production of Detergent Ingredients	73
CHEMICAL USE AND DISPOSAL PROCESSES	98
Use and Disposal of Chlorinated Degreasing Solvents	98
Use and Disposal of Detergents in Metal and Parts Cleaning Applications	103
SUMMARY OF NATIONAL ENVIRONMENTAL IMPACT EVALUATIONS	112
CHAPTER 8: CONCLUSIONS	114
TECHNICAL EVALUATION	115
ENVIRONMENTAL EVALUATION	115
ECONOMIC EVALUATION	117
NATIONAL ENVIRONMENTAL IMPACT EVALUATION	118

TABLE 1. PRIORITY USES OF THE 33/50 CHEMICALS		
Priority Use	33/50 Chemicals	Function
batteries	Cd, Hg, Ni, Pb Hg	electrode additive
metal finishing	Cd, Cr, Ni cyanides	metal plate plating bath
plastics and resins	benzene, toluene, cyanides Cd, Cr	chemical intermediate stabilizer
paints and coatings	xylene, toluene, MEK, MIBK, Cd, Cr, Pb benzene, toluene, cyanides	solvent pigment intermediates of paint resins
degreasing	TCE, TCA, PCE (CFCs), DCM	solvent
dry cleaning	PCE, TCA	solvent
paint stripping	DCM	solvent

Key: DCM - methylene chloride
PCE - perchloroethylene
TCE - trichloroethylene
Cd - cadmium
Ni - nickel
Cr - chromium
MEK - methyl ethyl ketone
MIBK - methyl isobutyl ketone
TCA - 1,1,1-trichloroethane
CFC - chlorofluorocarbon
Hg - mercury
Pb - lead

Source: "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," EPA, 1994.

Priority uses are defined as those products and/or processes that consume a significant portion (weight fraction) of the 33/50 chemicals. "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," used chemical use trees as the analytical tool to evaluate the priority uses of the four classes of 33/50 chemicals. The process of metals and parts degreasing uses four of the six chlorinated organic chemicals (DCM, PCE, TCA, TCE), and was selected as a priority use of these chemicals as illustrated by the Chlorinated Organic Chemicals chemical use tree, Figure 1.³

In this study the Center worked directly with an industry partner to demonstrate substitute feasibility and to gain actual industrial information for the technical, environmental, and economic evaluations. Calsonic Manufacturing Corporation (hereafter referred to as CMC) is aggressively pursuing less polluting alternatives to solvent degreasing and agreed to participate as the Center's industrial partner to demonstrate solvent degreasing alternatives.

LIST OF TABLES

		Page
TABLE 1.	PRIORITY USES OF THE 33/50 CHEMICALS	3
TABLE 2.	SELECTED PROPERTIES OF THE CHLORINATED DEGREASING SOLVENTS	9
TABLE 3.	CHRONOLOGY OF CHANGES AT CMC	15
TABLE 4.	COMPARISON OF LUBRICANT PROPERTIES	21
TABLE 5.	GOALS OF WASTE MANAGEMENT PLAN BY WASTE STREAM ...	31
TABLE 6.	1,1,1,-TRICHLOROETHANE TRI RELEASES AND TRANSFERS REPORTED BY CMC	32
TABLE 7.	CMC TRI OFF-SITE TRANSFERS OF TCA	35
TABLE 8.	SUMMARY OF INFORMATION USED TO CALCULATE CMC AIR EMISSIONS OF TCA	36
TABLE 9.	POTENTIAL EXPOSURE TO WASTE STREAMS AND ASSOCIATED RISK	43
TABLE 10.	EPA'S EXPANDED COST INVENTORY	48
TABLE 11.	TRADITIONAL COST ANALYSIS OF THE RADIATOR MANUFACTURING LINE	50
TABLE 12.	RETURN ON INVESTMENT AND COMPARISON OF NET PRESENT VALUES - RADIATOR	52
TABLE 13.	COMPARISON OF CAPITAL COSTS FOR THE SOLVENT DEGREASING AND EVAPORATIVE LUBRICANT SYSTEMS	53
TABLE 14.	TRADITIONAL COST ANALYSIS OF THE CONDENSER MANUFACTURING LINE	54
TABLE 15.	RETURN ON INVESTMENT AND COMPARISON OF NET PRESENT VALUES - CONDENSER	55
TABLE 16.	COST DRIVERS FOR THE PRIMARY ACTIVITIES	57
TABLE 17.	PRIMARY ACTIVITIES UNIQUE TO THE SOLVENT DEGREASING AND AQUEOUS WASH SYSTEMS OF THE RADIATOR LINE	58
TABLE 18.	DETAILED EXAMPLE OF THE SUPPORTING ACTIVITIES FOR THE ASSEMBLY AND CLEANING OF RADIATOR CORES	59
TABLE 19.	SUMMARY OF ABC RESULTS FOR THE RADIATOR MANUFACTURING LINE	60
TABLE 20.	PRIMARY ACTIVITIES UNIQUE TO THE SOLVENT DEGREASING AND EVAPORATIVE LUBE SYSTEMS OF THE CONDENSER LINE	61
TABLE 21.	SUMMARY OF ABC RESULTS FOR THE CONDENSER MANUFACTURING LINE	62
TABLE 22.	COMPARISON OF OPERATING AND MAINTENANCE COSTS - CMC ESTIMATES VERSUS ABC RESULTS	63
TABLE 23.	HYBRID COST ANALYSIS OF THE PROCESS CHANGES TO THE RADIATOR MANUFACTURING LINE	64

METHODOLOGY

The goals of this research were to technically, environmentally, and economically evaluate the changes in materials and parts degreasing which CMC has employed. If entire industrial sectors were to implement similar changes, the national environmental impacts of these changes were estimated from the knowledge of CMC's process changes, and other literature sources.

Data required to perform the technical, environmental, and economic evaluations were collected through data request tables, site visits, and interviews with CMC employees. Data request tables, completed by CMC and during site visits, collected process information including capital costs, operating and maintenance costs, utilities consumption, and production data. Similar data were requested for both the solvent degreasing systems (historic data) and alternative systems (current data). Questions concerning generation rates and disposal costs of waste (hazardous and non-hazardous) and wastewater accompanied the data request tables, as well as questions concerning permitting requirements and costs. These questions were also directed at operations both before and after the process changes. Appendix A presents the completed data request tables and questions for the radiator and condenser lines.

Site visits and interviews served two purposes for the project's evaluations. First, they allowed Center staff to become familiar with the operations of CMC, ask specific questions to complete and clarify the data request tables, and maintain a working contact with CMC. An extended site visit near the completion of this project was conducted to observe the day-to-day operations of the process lines under investigation. These observations were used to extend a traditional economic evaluation by using activity-based cost accounting.

The national impact evaluation utilized the knowledge of CMC's process changes to identify and evaluate potential changes on a national scale if entire industrial sectors were to implement solvent degreasing alternatives similar to CMC's. TRI data and information from various literature sources were used to develop a life-cycle perspective for chlorinated solvent degreasing and its alternatives.

Chapter 2 discusses materials and parts cleaning processes. Chapter 3 introduces CMC, the industry partner for the project, and their solvent substitution program. Chapters 4, 5, and 6 present the technical, environmental, and economic evaluations of this research, respectively, and Chapter 7 presents the national impact evaluation.

List of Tables continued

TABLE 48.	TOTAL TRI RELEASES AND TRANSFERS OF CHLORINATED DEGREASING SOLVENTS FROM OTHER INDUSTRY SECTORS . .	104
TABLE 49.	CAPACITY OF NATION'S TREATMENT FACILITIES	106
TABLE 50.	LEVEL OF TREATMENT FOR THE NATION'S TREATMENT FACILITIES	107
TABLE 51.	SUMMARY OF DOCUMENTED NEEDS FOR YEARS 1988, 1990 AND 1992	108
TABLE 52.	SUMMARY OF THE TECHNICAL EVALUATION RESULTS	115
TABLE 53.	SUMMARY OF ENVIRONMENTAL EVALUATION RESULTS	116
TABLE 54.	SUMMARY OF ECONOMIC ANALYSES RESULTS - RADIATOR MANUFACTURING LINE	117
TABLE 55.	SUMMARY OF ECONOMIC ANALYSES RESULTS - CONDENSER MANUFACTURING LINE	118
TABLE A1.	COMPLETED DATA REQUEST TABLES - RADIATOR MANUFACTURING LINE	126
TABLE A2.	COMPLETED DATA REQUEST TABLES - CONDENSER MANUFACTURING LINE	130
TABLE B1.	AQUEOUS WASH TRIALS BLACK LIGHT CONTAMINATION CHECK	141
TABLE B2.	AQUEOUS WASH TRIALS BRAZED CORE CHECK	142
TABLE C1.	SAMPLE DATA	145
TABLE C2.	RESULTS OF CHI SQUARE ANALYSES	145
TABLE C3.	PARAMETER FOR DATA SETS AND ANALYSES	146
TABLE C4.	RESULTS OF STUDENT T ANALYSES	146
TABLE C5.	RESULTS OF PRODUCTION RATE STATISTICAL ANALYSES	148
TABLE D1.	CONVERSION FACTORS	149
TABLE F1.	ANALYSIS RESULTS OF WASTEWATER DISCHARGES TO POTW	162
TABLE G1.	RADIATOR MANUFACTURING LINE - OLD, TCA DEGREASING SYSTEM'S BOA	163
TABLE G2.	RADIATOR MANUFACTURING LINE - NEW, AQUEOUS DETERGENT SYSTEM'S BOA	167
TABLE G3.	CONDENSER MANUFACTURING LINE - OLD, TCA DEGREASING SYSTEM'S BOA	171
TABLE G4.	CONDENSER MANUFACTURING LINE - NEW, EVAPORATIVE LUBRICANT SYSTEM'S BOA	174

Vapor Degreasing

The vapor degreasing process uses the vapor of the cleaning solvent to remove contaminants from materials or parts. The vapors, generated by boiling the solvent, condense on the relatively cold parts, dissolving and displacing the contaminants and soils, thus cleaning the surface. Cleaning ceases when the parts and vapor temperatures are at equilibrium.

The open-top vapor degreaser is a large tank with three distinct zones: the solvent reservoir, vapor zone, and freeboard. The solvent reservoir, which contains the cleaning solvent, is equipped with electric or steam heater coils to create the vapor zone by boiling the solvent. The vapor zone, directly above the solvent reservoir, is the zone into which the relatively cold parts are lowered causing vapor condensation and thus parts cleaning. The vapor zone height is controlled by cooling coils located near the top and on the inside perimeter of the tank. The coils condense the solvent vapors and return them as liquid to the reservoir.^{8, 9} The density of the solvent vapors also assists in maintaining a vapor zone and containing the vapors within the tank. The freeboard is the vacant space above the vapor zone which minimizes solvent drag-out when the parts are removed from the vapor zone after cleaning. The freeboard space allows condensed solvent vapors to drip from the cleaned parts, as well as offering drying time for the parts. Much of the solvent vapors and liquid in this zone fall back to the vapor zone and reservoir.^{10, 11}

Vapor degreasing is frequently more advantageous than cold cleaning because the cold solvent bath becomes increasingly more contaminated during the cleaning process. As the cold bath becomes more and more contaminated, the relative cleanliness of the parts may decrease because the parts are in direct contact with the contaminated liquid solvent. In vapor degreasing, although the boiling liquid solvent in the reservoir contains the contaminants from previously cleaned parts, the solvent usually boils at lower temperatures than the contaminants, resulting in the formation of essentially pure solvent vapors. In addition, the high temperature of vapor cleaning aids in wax and heavy grease removal and significantly reduces the time it takes for cleaned parts to dry.

Conveyorized Degreasing

Conveyorized, or in-line, degreasers have automated, enclosed conveying systems for continuous cleaning of parts. Conveyorized degreasers clean by either the cold solvent process or the vaporized solvent process. While these units tend to be the largest degreasers, they actually produce less emissions per part cleaned than other types of degreasers. This is due primarily to the enclosed design of the conveyor systems.

Hybrid Degreasing Systems

Combinations of immersion and vapor degreasing systems can be employed to aid in the cleaning of problematic soils (e.g., waxes), or highly soiled parts. These hybrid units can utilize agitated solvent baths, spray units and/or ultrasonics in conjunction with vapor degreasing processes. Ultrasonics apply energy to a cleaning solution to induce cavitation, or the collapse of millions of tiny bubbles produced in the solution by the applied energy. It is the collapse of these bubbles that create a scrubbing effect to clean the immersed parts.¹²

ACRONYMS

J	Joules
ABC	activity-based costing
ABS	alkylbenzene sulfonate
ASTM	American Society of Testing and Materials
atm	atmosphere
BOA	bill of activities
BOD	biological oxygen demand
BTU	British thermal unit
Cd	cadmium
CFC	chlorofluorocarbon
CFM	chloroform
CMC	Calsonic Manufacturing Corporation
CNS	central nervous system
Cr	chromium
CTC	carbon tetrachloride
DCM	methylene chloride or dichloromethane
DOE	Department of Energy
EDTA	ethylenediaminetetraacetic acid
FOG	fats, oils, and greases
g	grams
g/L	grams per liter
gpd	gallons/day
Hg	mercury
HSDB	Hazardous Substances Data Bank
K ₂ HPO ₄	dipotassium hydrogen phosphate
L	liter
LAB	linear alkylbenzene
LAS	linear alkylbenzene sulfonate
m	meter
MACT	maximum achievable control technology
MEK	methyl ethyl ketone
mgd	million gallons per day
MIBK	methyl isobutyl ketone
MSDS	Material Safety Data Sheet
NESHAP	National Emissions Standards for Hazardous Air Pollutants
Ni	nickel
NPDES	National Pollutant Discharge Elimination System
NPV	net present value
NRMRL	National Risk Management Research Laboratory
NTA	nitrilotriacetic acid
ORNL	Oak Ridge National Laboratory
P	poise
Pa	pascal

TABLE 2. SELECTED PROPERTIES OF THE CHLORINATED DEGREASING SOLVENTS				
Property	DCM	PCE	TCA	TCE
Chemical Formula	CH ₂ Cl ₂	C ₂ Cl ₄	C ₂ H ₃ Cl ₃	C ₂ HCl ₃
CAS No.	75-09-2	127-18-4	71-55-6	79-01-6
Molecular Weight	84.92	165.83	133.05	131.39
Boiling Point, at 101.3 kPa, °C	39.8	121.20	74.00	86.7
Freezing Point, °C	-96.7	-22.7	-33.00	-87.1
Specific Gravity, at 20°C	1.320	1.62260	1.325	1.465
Density, at 20°C, kg/m ³	1,315.7	1,622.4	1,324.9	1,460.0
Viscosity, at 20°C, cP	0.43	0.870	0.858	0.58
Heat of Vaporization, at 20°C, kJ/kg	329.23	209.2 ^a	248.11	240 ^a
Heat Capacity, at 25°C, kJ/kg K	0.6369	0.85	1.004	0.94
Heat of Combustion, MJ/kg	1.1175	5.051598 ^b	6.69	7.325
Vapor Pressure, at 25°C, kPa	53.3 ^c	2.5	16.5	7.7 ^d
Solubility in Water, at 20°C, g/kg	13.2	1.40	0.95	1.07
Flash Point (ASTM), °C	none	none	none	none
Critical Temperature, °C	245.0	347.1	311.5	271.0
Critical Pressure, °C	6.171	9.74	4.48	5.02
Critical Density, kg/m ³	472	--	--	--
log K _{ow}	no data	3.40	2.49	2.29

- a latent heat of vaporization at the boiling point
b heat of combustion, liquid at constant volume, 18.7°C
c vapor pressure at 24.1°C
d vapor pressure at 20°C

Sources: Kirk-Othmer Encyclopedia of Chemical Technology, 1978
Hazardous Chemical Desk Reference, 1987
Hazardous Substance Data Bank

ACKNOWLEDGMENT

The authors of this report would like to acknowledge the following individuals who contributed their time, expertise, and information to the completion of this report. Without their involvement this report and its contents could not have been possible.

- Michael McWilliams - Environmental Engineer, Calsonic Manufacturing Corporation: Mike's daily involvement and patience offered the basic information for the report.
- Special thanks is extended to the project's industry partner, Calsonic Manufacturing Corporation of Shelbyville, Tennessee. As a leading industry in the application of cleaner technologies and processes, Calsonic's role in the project was immeasurable. Information and expertise were shared openly. The involvement and support of engineers, supervisors, and management offered the information and expertise required for this project to succeed.
- Jack Geibig - Research Associate, and Andrew Core - Student Research Assistant, Center for Clean Products and Clean Technologies: Their assistance with data collection and analysis was greatly appreciated.

Types of Aqueous Wash Systems. Aqueous cleaning systems can include alkaline solutions and detergents to enhance their soil removal capabilities, or consist of solely hot water washes. These systems are often used with pressurized sprays, agitation, ultrasonics, filtration, heat, or some other physical process to further provide effective cleaning in many industrial cleaning applications. Water-based cleaners have little or no volatile components, which means that cleaning cannot take place in the vapor phase. Therefore, immersion tanks are most commonly used for these applications in conjunction with heat and agitation. Agitation can be accomplished with ultrasonics or by mechanically rotating the parts and/or circulating the solution.

Because they apply immersion rather than a vapor phase process for cleaning, aqueous cleaning systems are not usually drop-in replacements for chlorinated degreasing solvents. However, some vapor degreasers and other solvent cleaning processes can be modified to accommodate water-based cleaners. Large vapor degreasing units can be converted to multiple tanks, and modified to incorporate spray rinsing, immersion, ultrasonics, mechanical agitation, filtration, or other methods. Immersion tanks that have a means for adequate skimming of floating oils are the most useful aqueous method of cleaning blind holes and complex geometries. Aqueous cleaning alternatives usually require the addition of rinsing and drying steps after cleaning to accomplish comparable solvent degreasing results.

Aqueous Cleaning Ingredients. Some additives of aqueous cleaning systems include synthetic detergents and organic surfactants, saponifiers, acids and alkalies, and corrosion inhibitors. The combination of additives selected alter the foaming, wetting, and soil removal properties of the solution.¹⁷ Detergents and surfactants are surface-active agents that emulsify insoluble solids into solution. Saponifiers change water-insoluble fats and fatty acids into water-soluble soaps. Oxidants may be added to loosen rust and stains for easy removal. Other additives are used to penetrate the soils and wet the surface of the materials to be cleaned, to precipitate or float the soils, and to neutralize the material. Depending on the requirements of subsequent operations, rinsing may be required to remove residual films left by these additives in the cleaning process.¹⁸ Large suppliers will typically formulate cleaners designed for the particular soils to be cleaned and the subsequent production process.

Aqueous cleaners must be carefully evaluated for their compatibility with the materials being cleaned and the cleaning equipment. Acid and alkaline cleaners may attack some metal substrates. Caustics or strong alkalies will aggressively attack aluminum and zinc. Strong acids will attack steel. Strong oxidizing acids like nitric acid and chromic acid will attack copper. The application of ultrasonics in an aqueous system can also increase the corrosiveness of the solution.¹⁹ In addition, alkaline cleaning systems sometimes have problems with surface oil recontamination of the parts, rapid fluid depletion, long cleaning time, and high maintenance.

An alternative approach to aqueous cleaning is the elimination of the detergent additives and the application of only hot water to clean the soiled parts. Cutting oils, cooling fluids, and other soils can be effectively removed by a hot water spray, and the issue of additive compatibility is eliminated. Ease of operation can also be an added benefit of a hot water spray system; the oils and greases separate more quickly from the water phase (float to the water's surface) than would be observed with detergents that emulsify the oils. This allows for skimming of the oils and grease and easy water recirculation minimizing or eliminating the need for pretreatment. Eliminating the need for monitoring and adjusting the

the 33/50 Program, the technologies that will be evaluated have a broad range of applications within industry. This should offer pollution prevention benefits beyond the reduction of national pollution releases and off-site transfers of the 33/50 chemicals.

OBJECTIVES OF THIS RESEARCH

The "Cleaner Technology Demonstrations for the 33/50 Chemicals" project is a cooperative agreement between EPA and the Center for Clean Products and Clean Technologies funded by NRMRL in support of the 33/50 Program. The overall objective of this project is to demonstrate substitutes for the 33/50 chemicals in order to encourage reductions in their use and release. For the substitutes that will be evaluated, this study has objectives in the areas of technical, environmental, economic and national impact evaluations. The following are the specific objectives in each area:

1. technical evaluation
 - ▣ evaluate the effect of a substitute on process and product performance as compared to the 33/50 chemicals
2. environmental evaluation
 - ▣ evaluate the potential for reduction in releases and off-site transfers of the 33/50 chemicals in the production process or product stage in which the 33/50 chemicals are used and released
 - ▣ compare the overall life-cycle environmental attributes of the 33/50 chemicals and the substitute for the same use
3. economic evaluation
 - ▣ evaluate the total cost of the substitute as compared to the 33/50 chemicals
4. national environmental impact evaluation
 - ▣ evaluate the environmental impact of replacing the 33/50 chemicals with the substitute on a national scale

This report represents the first such demonstration project to be completed under the EPA NRMRL project. It focuses on substitutes for solvent degreasing processes that eliminate the use of chlorinated organic chemicals. This subject was selected from seven priority uses of the 33/50 chemicals identified in "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," a report by the Center for Clean Products and Clean Technologies (hereafter referred to as Center).² These seven priority uses are shown in Table 1.

cases, cleaning may not be required at all. Furthermore, the manufacturing processes can sometimes be rearranged to require fewer cleaning steps.

Developing alternative methods that do not require cleaning means reevaluating the steps in the manufacturing process which introduce materials that must be cleaned. For example, the printed circuit board industry has developed no-clean flux technologies that eliminate the need to clean flux from some printed circuit boards. Unfortunately, use of new technologies is often stymied by their lack of working history. Industries that are required to comply with government specifications may have difficulty introducing no-clean technologies that require process modifications or product redesign. Specifications for manufacturing parts for the military often dictate the type of cleaning solvent and the cleaning process to be used. Unfortunately, changing government specifications is a long and arduous process that may slow progress in the use of safe substitutes.

No-clean processes require innovative, optimized manufacturing to eliminate cleaning. They save time and chemicals and reduce the regulatory burden and potential liability that results from using hazardous chemicals. The disadvantages of no-clean technologies are that they may require process modifications and even product redesign.

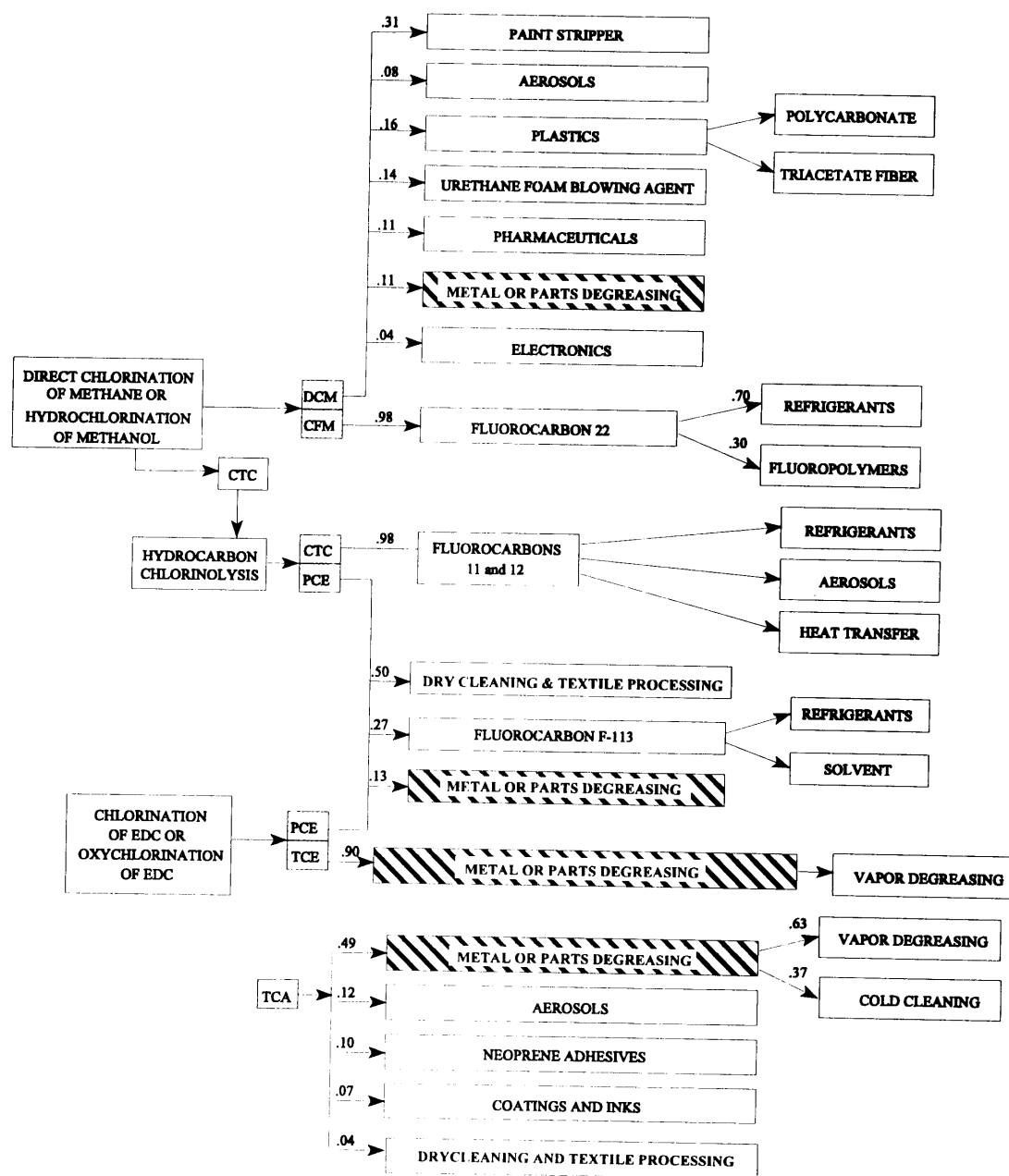


FIGURE 1. CHLORINATED ORGANIC CHEMICALS

Key: DCM = methylene chloride, CFM = chloroform, CTC = carbon tetrachloride, PCE = perchloroethylene, TCE = trichloroethylene, TCA = 1,1,1-trichloroethane

- Notes: 1. Reliable data were not available to estimate weight fractions along some branches of the chemical-use tree.
2. The numbers along each branch are weight fractions of the usage of the chemical or product in the first box to produce the chemical or product in the second box. Where there is a box that is divided, the chemicals or products are co-products.

TABLE 3. CHRONOLOGY OF CHANGES AT CMC			
Year	Radiator	Condenser	Converter
1991	installation of aqueous wash system eliminating five vapor degreasers (October, 1991)	no pertinent changes	no pertinent changes
1992	installation of in-house tube manufacturing mill (August, 1992)	no pertinent changes	no pertinent changes
1993	no pertinent changes	installation of no-clean fin corrugation system eliminating two vapor degreasers (June, 1993)	installation of hot water wash; elimination of one vapor degreaser (December, 1993)
1994	no pertinent changes	no pertinent changes	no pertinent changes

THE RADIATOR LINE AND AQUEOUS WASH SYSTEM

Radiators are designed to hold a large volume of water and antifreeze in proximity to a large volume of air to allow efficient heat transfer from the fluid to the air. The radiator core consists of two parts, one for the passage of liquid and the other for the passage of air. CMC manufactures the tube-and-fin type of radiator core, consisting of a series of long tubes extending between a top tank and bottom tank of the radiator. In this type of configuration, fins are placed between the tubes; air passes between the fins and around the outside of the tubes, absorbing heat from the fluid in the tubes.

Figure 2 is a process flow diagram of CMC's radiator line. Rolls of aluminum are lubricated with a forming (naphthenic) oil, placed through fin corrugators, and cut to length. Once formed and cut, the fins are sent to assembly. There are five fin corrugators in the radiator line. Aluminum is rolled into tubes at a rolling station, cut to length and sent to assembly. Excess coolant used in the rolling process is manually rinsed from the completed tubes with a small amount of water. Endplates are supplied by another company.

The fins, tubes and endplates are assembled in a jig to complete the radiator core. After assembly, a conveyORIZED aqueous wash is used to remove forming oils, cutting oils, and the remaining coolant from rolling the tubes. The conveyORIZED aqueous wash process begins with a water wash, intended to remove the majority of the contaminants, followed by a heated detergent bath, and completed by a hot water rinse. Effluent from the aqueous wash process is sent to a wastewater treatment plant at the facility for pretreatment prior to discharge to the local sewer system. After the aqueous wash, flux is applied, followed by drying, brazing, assembly of the radiator core with the nylon fluid tanks (also manufactured at CMC), and leak testing.

CHAPTER 2

MATERIALS AND PARTS CLEANING

Within several industrial sectors, solvents and solvent blends of halogenated and nonhalogenated organic chemicals are employed as solvents to clean organic materials, water-insoluble soils, inorganic salts, and foreign particles from manufactured materials or parts. Methylene chloride, perchloroethylene, trichloroethylene, and 1,1,1-trichloroethane (hereafter referred to as the chlorinated degreasing solvents) have been the traditional chlorinated solvents used in degreasing processes due to their physical and chemical properties. In recent years, however, increased awareness of the health, safety, and environmental issues surrounding their use has stimulated research into substitutes for the chlorinated degreasing solvents. This chapter reviews the processes of materials and parts degreasing, briefly discusses the regulations concerning the solvent degreasing chemicals and processes, and then identifies and discusses safe substitutes for chlorinated solvent degreasing.

MATERIALS AND PARTS DEGREASING DESCRIPTION

Materials and parts degreasing is an integral part of many industrial processes, including the manufacturing of automobiles, electronics, furniture, appliances, jewelry, and plumbing fixtures. Degreasing is also frequently used in the textiles, paper, plastics, and glass manufacturing industries. It is most often employed as a surface-preparation process to remove contaminants and prepare raw materials and parts for subsequent operations like machining, painting, electroplating, inspection, and packaging. In 1991, it was estimated that 24,500 chlorinated solvent degreasers were operational within the United States.⁴ The variety of solvent degreasing equipment falls within three basic configurations: cold cleaners, open-top vapor degreasers, and conveyorized degreasers.^{5,6} These systems, and a hybrid of them, are briefly discussed below.

Cold Cleaning

Cold cleaners are usually the simplest and least expensive of the three types of degreasing equipment. Parts are cleaned by being immersed and soaked, sprayed, or wiped with solvent. A typical cold cleaner consists of a tank filled with solvent and a cover for periods of nonuse. More sophisticated cold cleaners are equipped with solvent sumps, spray nozzles, drains, and automatic controls.

In the basic cold cleaning process, soiled objects are dipped into the solvent bath to dissolve the contaminants from their surface. This cleaning process can be enhanced by agitating the solvent, or by brushing or spraying the solvent onto the soiled objects. Cold cleaning is usually conducted at room temperature and ambient pressure, although in some cases the solvent may be heated, but not above its boiling point. When the parts are removed from the immersion bath, solvents are allowed to drain and evaporate from the parts.⁷

In 1991, CMC converted the cleaning step in the radiator line from a vapor degreasing process to the current aqueous wash system. Previously, five batch vapor degreasers were used to clean the assembled radiator core, one located at each fin corrugation and assembly station. Under this process scheme the radiator core was an assembly of corrugated fins (process above) and prefabricated tubes and endplates supplied by another company. These assemblies were then cleaned in one of the five vapor degreasers. CMC used TCA as the degreasing solvent. The use of TCA resulted in releases of TCA to the air from the process, releases to water (wastewater) from solvent carryover on parts to subsequent process units, and a hazardous waste stream of spent TCA. CMC sent this hazardous waste stream to an off-site recycling facility. Figure 3 shows the location of the vapor degreasing step and potential sources of TCA releases in the previous radiator process. CMC switched from prefabricated tubes to in-house formation after the aqueous wash system became operational. No other changes have been made in the radiator manufacturing process or operating conditions since that time.

Radiators are leak-tested using a Freon-based (R-22) pressure-decay system. In this system each completed radiator is pressurized using a mix of R-22 and nitrogen. To pass the test procedure, the pressure must be maintained for a dwell-time specified in the Radiator Process Control Plan.

THE CONDENSER LINE AND NO-CLEAN TECHNOLOGY

CMC manufactures condensers for use in automobile air conditioning systems. The condenser consists of a serpentine tube on which fins have been mounted. Compressed vapor passes through the tube; air passing around the fins and between the tubes removes heat from the compressed vapors. The cooled vapor condenses and runs into a receiver-dryer.

Figure 4 is a process flow diagram of CMC's condenser line. In 1993, Calsonic converted its fin manufacturing process from a conveyORIZED solvent degreasing process using TCA (Figure 5) lubricant to remove a petroleum-based lubricant to a no-clean process using an "evaporative lubricant" (also called vanishing oils). In this no-clean system, rolls of aluminum are lubricated with a low-boiling-point oil and placed through a fin corrugator. The fin then passes through fin driers to evaporate the oils, resulting in a no-clean process for fin manufacturing. CMC operates four fin corrugator stations in the condenser line. In the current system, the corrugated fin is still conveyed through the now empty vapor degreasing chambers, then cut to length and sent to assembly. A comparison of the petroleum-based lubricant and the evaporative lubricant is presented in Table 4.

PROPERTIES OF CHLORINATED DEGREASING SOLVENTS

A good degreasing solvent should have excellent solvency for a broad range of organic materials, particularly oils and greases. The solvent should preferably be nonflammable, especially in vapor degreasing applications, and be noncorrosive to the metals or parts being cleaned and the degreasing equipment. A good degreasing solvent should also have low toxicity. Additional properties desired in a degreasing solvent include a low heat of vaporization, a high vapor pressure that allows evaporative drying of cleaned parts, and chemical stability.

Degreasing Properties

The chlorinated degreasing solvents have been extensively used in industrial applications of cleaning, primarily because of their excellent solvency, nonflammability, and high vapor pressures. Additionally, their vapors are heavier than air and thus can be somewhat contained within the degreasing equipment. Only recently have health, safety, and environmental issues concerning their use and disposal contributed to a decrease in their use as degreasing solvents and to a search for substitutes.

DCM, PCE, TCA, and TCE share several common physical features. They are volatile, colorless, nonflammable liquids characterized by a sweet or ether-like odor. Their high chlorine content gives their liquids and vapors relatively high density and also reduces their ability to support combustion. They are subject to decomposition by hydrolysis with water and by high temperatures, oxygen, and sunlight. They are only slightly soluble in water and are miscible with most organic liquids. Table 2 shows selected physical properties and the chemical formulae of these compounds.

Health, Safety, and Environmental Properties

Just as the chlorinated degreasing solvents have similar physical properties, they also have similar health, safety, and environmental issues associated with their production and use. Low level and short duration exposure to these chemicals causes irritation and inflammation of the nose, throat, eyes, and respiratory tract. All but TCA are classified as possible or probable human carcinogens by EPA. All four compounds are central nervous system (CNS) and respiratory depressants. Exposure to DCM, PCE, and TCE is associated with liver and kidney problems.¹³ TCA is an ozone depleting chemical.

The major routes of exposure to these compounds are through inhalation or ingestion, although dermal exposure may occur from absorption through the skin. Air emissions account for the largest environmental releases of these compounds, due to their high volatility. Land disposal of these chemicals is prohibited under the Hazardous and Solid Waste Amendments of 1984. The chlorinated degreasing solvents are also highly mobile in soil and groundwater and are common groundwater contaminants.¹⁴

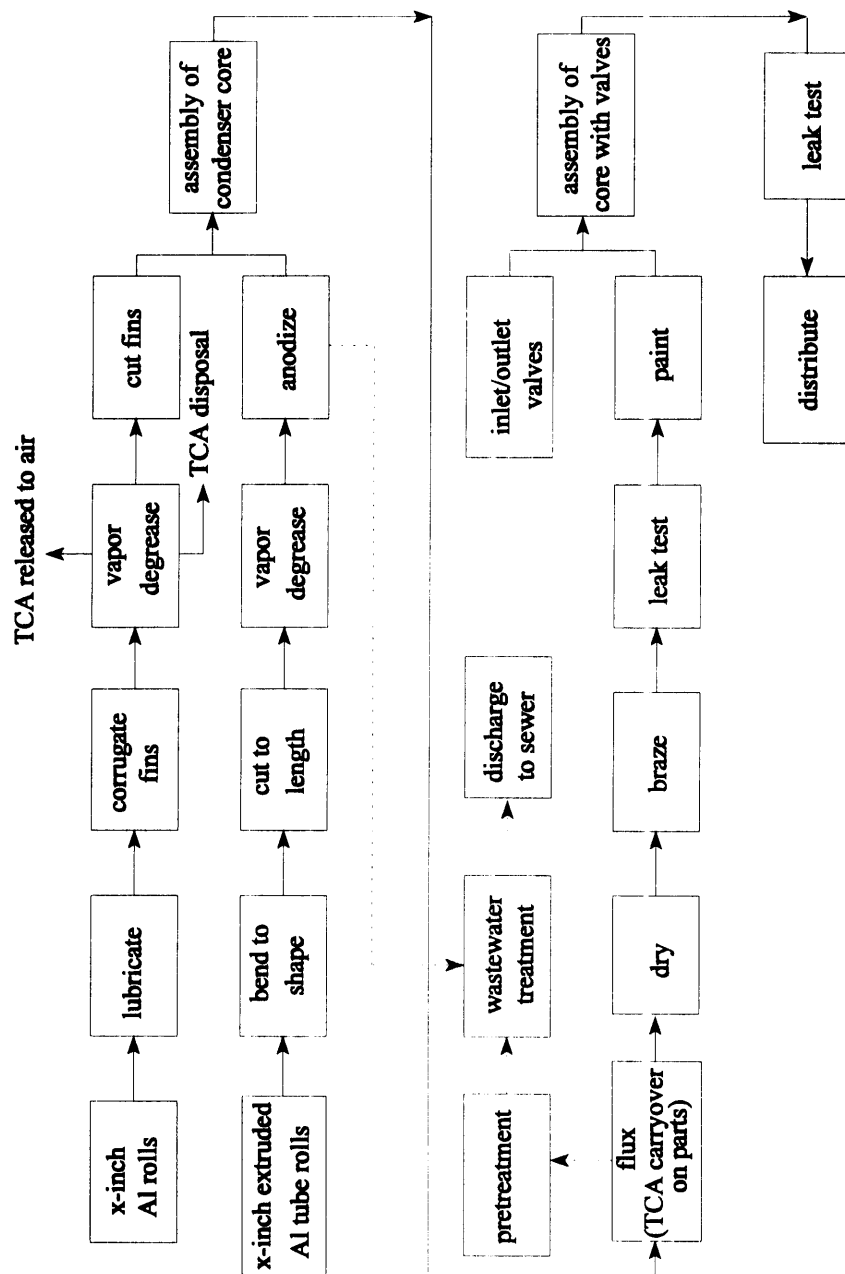


FIGURE 4. CURRENT CONDENSER MANUFACTURING LINE WITH THE NO-CLEAN TECHNOLOGY

REGULATORY BACKGROUND

Regulations, recently enacted and expected, for the chlorinated degreasing solvents and the degreasing process could promote the application of alternative cleaners and cleaning systems for degreasing. Among the most recent regulations for chlorinated degreasing solvents is National Emissions Standards for Hazardous Air Pollutants (NESHAP) promulgated under the Clean Air Act.

The NESHAP, finalized by EPA in November 1994, sets maximum achievable control technology (MACT) standards for owners and operators of halogenated solvent cleaning machines. The MACT standards cover batch vapor solvent cleaning machines and in-line solvent cleaning machines, and are designed to regulate the emissions of methylene chloride, perchloroethylene, trichloroethylene, carbon tetrachloride, and chloroform. Publication of these standards occurred on December 2, 1994 in the Federal Register. NESHAP enforcement is expected by mid-1995.¹⁵

Furthermore, as a result of the Montreal Protocol and the subsequent Presidential edict by President Bush, the manufacture of TCA and carbon tetrachloride (two Class I ozone depleters) must cease by the end of 1995 within the U.S.¹⁶

SAFE SUBSTITUTES FOR THE 33/50 DEGREASING SOLVENTS

Several viable alternatives for the chlorinated degreasing solvents and the degreasing process exist. Substantial pollution prevention progress is being made in metal and parts cleaning by using these alternatives. Safe substitute approaches to reducing the use of chlorinated organic chemicals in the degreasing process include the following:

- using no-clean manufacturing methods;
- substituting safe, aqueous, or semi-aqueous degreasing solvents for the chlorinated organic solvents;
- substituting safe, non-aqueous degreasing solvents for the chlorinated organic solvents; and
- substituting non-liquid cleaning technologies for the degreasing process.

Many of these approaches are already seeing widespread use because of pending or potential regulations affecting the chlorinated solvents and their potential to contribute to photochemical smog or ozone depletion. This demonstration project will focus on two of the above process alternatives which have been implemented by CMC: an aqueous degreasing process and a no-clean manufacturing option. These alternatives to solvent degreasing are discussed below.

Aqueous Wash Systems

Aqueous cleaning systems, or parts washing, have been used for years to remove salts, rust, scale, and other inorganic soils from ferrous metals. In recent years, the metal parts and metal finishing industries, such as CMC, have identified and applied aqueous cleaners and cleaning systems as substitutes for solvent vapor degreasers.

TABLE 4. COMPARISON OF LUBRICANT PROPERTIES		
Property	Petroleum-based Lubricant	Evaporative Lubricant
Hazard Composition	"not considered hazardous"	"none"
Boiling Point (°F)	520	323.6 (IBP)
Vapor Pressure (mmHg)	< 0.01	< 10
Vapor Density (air = 1)	> 5	> 1.0
Specific Gravity (water = 1)	0.88	0.764
Melting Point	not applicable	--
Evaporation Rate (butyl acetate = 1)	< 0.01	negligible
Solubility in Water	negligible	negligible
Flash Point (°F)	320	127.4 (PM)
LEL	1%	--
UEL	6%	--

Source: Material Safety Data Sheets of each product

To make the serpentine tube, rolls of purchased extruded aluminum are placed in a bender, bent to shape, and then cut to length. CMC operates two bending stations in the condenser line, with three aluminum rolls per bender. Tubes are sent to a conveyORIZED vapor degreaser to remove cutting and hydraulic oils from the bending operations. Following this step the tubes are coated with zinc oxide to inhibit corrosion and improve the paintability of the aluminum substrate, and assembled with the fins to form the condenser core. After assembly of the condenser core, flux is applied, followed by brazing and leak testing with helium. After leak testing, the core is painted, followed by final assembly of the condenser core with the receiver-dryer, and final leak testing using R-22.

The helium leak testing procedure is also a pressure-decay type method but is complicated by the small size of the helium molecule which makes it easier to leak. As with the radiator line, leak testing is accomplished by pressurizing each part with helium and then measuring the rate of pressure decay. Acceptable parts must maintain pressure for a specified dwell time outlined in the Condenser Process Control Plan. Prior to helium leak testing, CMC used R-22 and nitrogen for both leak testing steps for the condenser line. The procedure follows that outlined in the radiator line.

concentration of additives in the aqueous solution can also free operator time for other activities. These simplified management and waste disposal issues, discussed below, can be advantages of the hot water systems.

Effects on Wastewater Treatment Capacity. Significant changes in the characteristics of wastewater and wastewater flow rate are also issues that must be considered when changing to aqueous cleaning systems. The treatment and disposal of the aqueous cleaning solutions is an important consideration when changing to an aqueous system. Some additives create new health and safety or treatment and disposal issues. Detergents and surfactants may not be readily biodegradable; the solution's pH may be unacceptable for direct discharge; cleaning solutions containing saponifiers tend to have high biochemical oxygen demands (BODs) which may exceed limits in National Pollutant Discharge Elimination System (NPDES) permits and Publicly Owned Treatment Works (POTW, or municipal wastewater treatment plants) pretreatment permits. As a result, pretreatment prior to discharge to the sewer system may be required to meet local, state, or federal requirements.

As a response to these disposal issues, "closed-loop" aqueous cleaning systems have been developed which minimize the process water that must be treated, and concentrate the oils and other contaminants for disposal. These closed-loop systems can include filtration (micro or ultra), gravity separation, adsorption, and chemical treatment units which recirculate the water back to the cleaning system and concentrate the contaminants.²⁰ The hot water wash system may increase the application of closed loop systems. The elimination of additives for the aqueous wash may simplify oils and soils separation from the water. Furthermore, the filtrations and adsorption systems will not be fouled by the present of detergent products.

No-Clean Technologies

The most fundamental technique for eliminating the use of degreasing solvents is to design processes and/or use materials that do not require cleaning. This is most readily achieved when designing new products or new manufacturing processes. Still, existing facilities, such as CMC, may realize cost savings and dramatically decreased potential environmental liabilities by reconsidering their existing processes and developing alternative methods that do not require cleaning.

Reconsidering an existing process means evaluating the present cleaning operation, as well as the process line, both up-stream and down-stream of the cleaning step. Up-stream of the cleaning step, processes that introduce the soils (oils, greases, etc.) that must later be removed should be evaluated to determine whether alternative materials can be substituted that do not require cleaning, or whether the soil material can be eliminated completely. An example of a no-clean technology is the replacement of lubricating oils with a mineral spirit-based vanishing oil. Due to its relatively high vapor pressure, the mineral spirit-based oil can be removed using flash-drying or other technologies such that the substitute does not require cleaning prior to subsequent operations. This process still results in an air emission, but one of the objectives of this study was to evaluate the relative amount and toxicity of the air releases from the TCA vapor degreaser as compared to the evaporative lubricant system.

Considering process requirements down-stream, the current degree of cleanliness specified may not be required to satisfactorily perform the next manufacturing step. In some

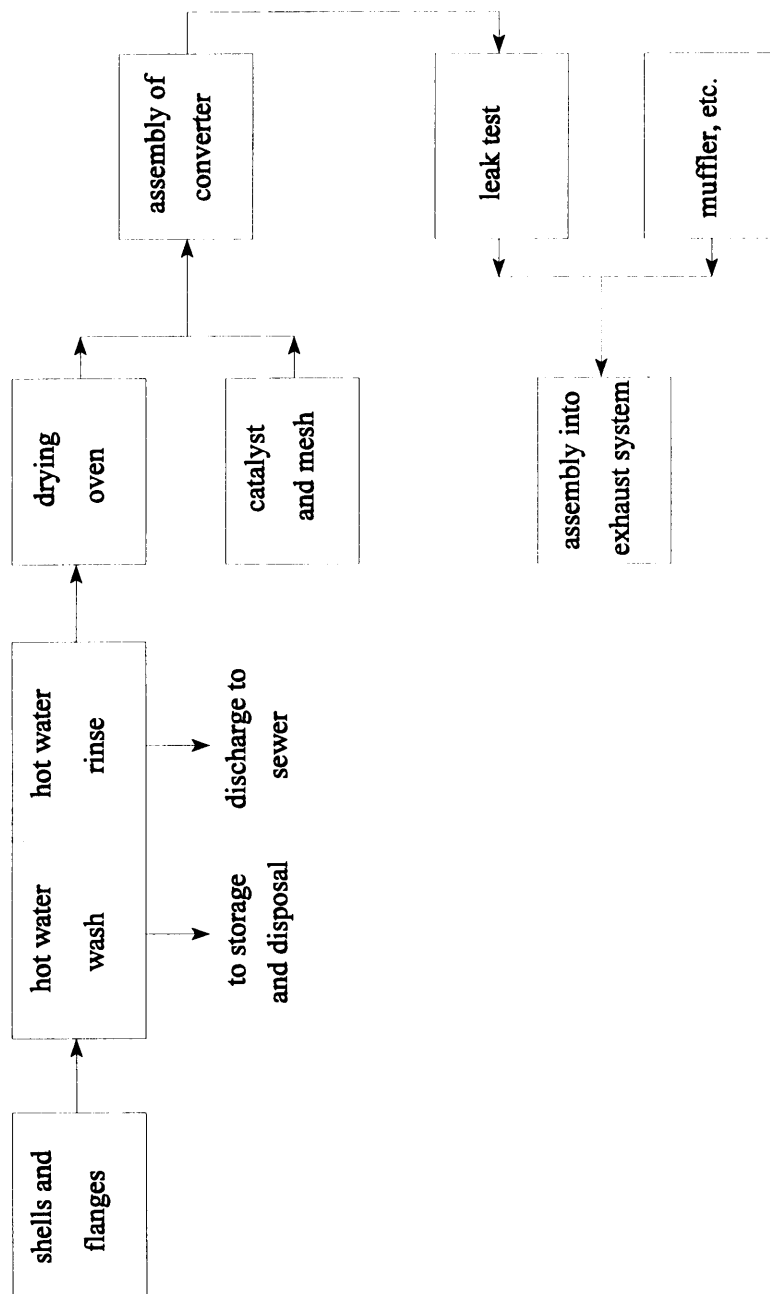


FIGURE 6. CURRENT CONVERTER MANUFACTURING LINE WITH THE HOT WATER WASH SYSTEM

CHAPTER 3

CALSONIC'S CHLORINATED SOLVENT SUBSTITUTES PROGRAM

The Center for Clean Products and Clean Technologies worked with an industry partner to evaluate the technical, environmental, and economic merits of alternative cleaners and systems for the chlorinated degreasing solvents. This industry partner, Calsonic Manufacturing Corporation (CMC), had initiated a number of changes to eliminate TCA from their manufacturing process. The background of CMC and a brief overview of the process changes pertinent to this project are presented in this chapter.

BACKGROUND INFORMATION ON CALSONIC

CMC is a Japanese-owned, American-managed company located in Shelbyville, Tennessee, with several sister companies throughout the U.S. and the world. In Shelbyville CMC employs approximately 800 persons and has more than 430,000 ft² of manufacturing area divided between two sites and three buildings. CMC manufactures automotive parts, including heaters, blowers, cooling units, motor fans, radiators, auxiliary oil coolers and exhaust systems.

The automotive parts manufactured by CMC are composed of a variety of materials including nylons, polypropylenes, aluminum, and stainless steel. Part configurations range from complex extruded metal parts and serpentine parts to flat-surfaced injection-molded plastic parts. Part cleanliness requirements vary and are dependent on subsequent process steps.

Over the past four years, CMC has begun to evaluate and implement a number of environmental improvements in its manufacturing processes. An internal schedule set by CMC to eliminate all TCA cleaning operations by the end of 1994 was met in November of that year. This phase-out was accomplished through the application of aqueous cleaning and no-clean technologies. This research focuses on three CMC process lines which utilize substitutes for solvent degreasing: 1) the aqueous wash system in the radiator line; 2) the no-clean technology in the condenser line; and 3) the hot water wash of the converter line. A chronology of these changes is presented in Table 3. The following sections describe the manufacturing lines which employ these processes.

CHAPTER 4

TECHNICAL EVALUATIONS

The technical evaluation of CMC's process alternatives to solvent degreasing revealed positive merits of their implementation. The aqueous wash system cleaned parts 80 percent faster than the solvent system, and improved parts' cleanliness resulting in a 76.8 percent decrease in part reject rates. The no-clean system had no effect on cycle time or part reject rates as compared to the solvent systems. The management, supervisors, and line personnel believe both alternatives create a more efficient production process.

TECHNICAL BACKGROUND

Several basic questions must be asked of any industry/business to simplify the switch from a solvent degreasing system to a safe and effective alternative. These basic questions include subjects such as cleanliness desired and required (desired levels may not be required for subsequent processing), substrate characteristics, soils (source and characteristics), and process/facility specifications. Research Triangle Institute has developed the Solvent Alternatives Guide (known by the acronym of SAGE) to answer many of these questions. By entering information about the current solvent cleaning process and cleaning requirements, SAGE recommends a variety of solvent alternatives. SAGE is an electronic handbook designed to work on a PC-AT (or better) computer system, and is distributed by the EPA. In addition to this computer program, there are also a number of literature sources which address similar issues; "It's Time to Panic," by Robert B. Aronson²¹ and "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," by the Center for Emissions Control are only two specific examples.²²

A significant number of studies are also being conducted, or have been completed, which evaluate the effectiveness of cleaning alternatives. Some studies evaluate the effectiveness of various alternative solvents and cleaning solutions for removing specific soils. Such studies are being conducted by the Department of Energy, Oak Ridge National Laboratory (ORNL), in Oak Ridge, Tennessee, and the Toxics Use Reduction Institute (TURI) at the University of Massachusetts, Lowell, Massachusetts. In the ORNL study, a variety of pure solvents are evaluated for their ability to remove specific standard soils (e.g., lubricating oils, fingerprints, etc.) from metal substrates; the cleanliness of each tested part is determined at a molecular-layer level. TURI operates the Surface Cleaning Laboratory designed to assist companies in the transition away from solvent-based technologies by providing objective information and testing services. This study differs from other research because it brings information on the technical, economic, and environmental impacts of alternatives together, using a life-cycle perspective and actual industrial experiences.

The procedure taken by CMC to determine which alternatives to employ included extensive vendor consultation, initial performance screenings, and pilot testing of the promising alternatives. Identifying and contacting vendors of available alternatives were the responsibilities of the line engineers for each process. These vendor contacts were used to identify applicable alternative cleaning systems and to perform initial screening tests to determine the alternatives' effectiveness. Vendor contacts and screening tests for the radiator



FIGURE 2. CURRENT RADIATOR MANUFACTURING LINE WITH THE AQUEOUS WASH SYSTEM

reliability of the aqueous wash system allows CMC to focus attentions to other units, further optimizing the entire process.

Condenser Manufacturing Line. Similar production rate data were not available for the condenser manufacturing line. However, interviews with line and quality control personnel indicated that the implementation of the evaporative lubricant system to replace the solvent degreasers did not affect the cycle time for fin production.

The Evaluation of Part Reject Rates

The second parameter used to evaluate the technical feasibility of the alternatives was the core reject rate. For CMC, cores are either recorded as production or scrap based on the results of leak tests performed on each and every unit manufactured. The cleanliness of the assembled core before fluxing and brazing directly affects the quality of the braze. Brazing of the radiator or condenser cores not only protects the product from corrosion, but also seals all tube-to-tank joints to create a leak-proof product. When the core is not adequately cleaned, the aqueous solution of flux cannot properly penetrate all areas of the core. This, in turn, results in a poor braze and potential leaks.

Radiator Manufacturing Line. The current radiator line, using a petroleum-based lubricant in processes prior to cleaning, accomplishes the required level of cleanliness by detergent cleaning within the aqueous wash system. The lubricant, if not sufficiently removed from all areas of the radiator core, will repel the aqueous flux and result in a poor braze and possibly a rejected core due to leaks. Cleaning was previously accomplished by the five solvent degreasers.

Identical data sets as those used for the analysis of the production rate were used here for the analysis of the part reject rate. Specifically, a data set prior to October 1991, and a data set between October 1991 and August 1992 were analyzed to capture the potential effects of the cleaning process. Statistical analyses of this part reject rate data indicate that the aqueous wash system improved the level of cleanliness when compared to the solvent degreasing system. Comparing the mean of each data set shows that the radiator core reject rate decreased 76.8 percent after the aqueous wash system was implemented. This decrease is apparent in Figure 8 which presents normalized radiator reject rate data for the time periods statistically analyzed. Historic data are not presented in this report in raw form, however. Analyses summaries and normalized values are given to ensure confidentiality. The methods and results of the statistical evaluations performed ("chi square" and "student T") are presented in Appendix C.

The availability of these data were due to an on-going "Radiator Task Force" established by CMC to reduce the reject rates for the radiator line. Established in early 1991, this Radiator Task Force analyzed the factors that resulted in rejected cores and improved process parameters to minimize reject rates. Through the efforts of this Task Force, and its support of the aqueous wash system, the reject rate of the radiator line was decreased 76.8 percent after the aqueous wash system was implemented.

Condenser Manufacturing Line. The condenser line, by using an evaporative lubricant, eliminated the need for additional cleaning to achieve adequate flux penetration and a high-

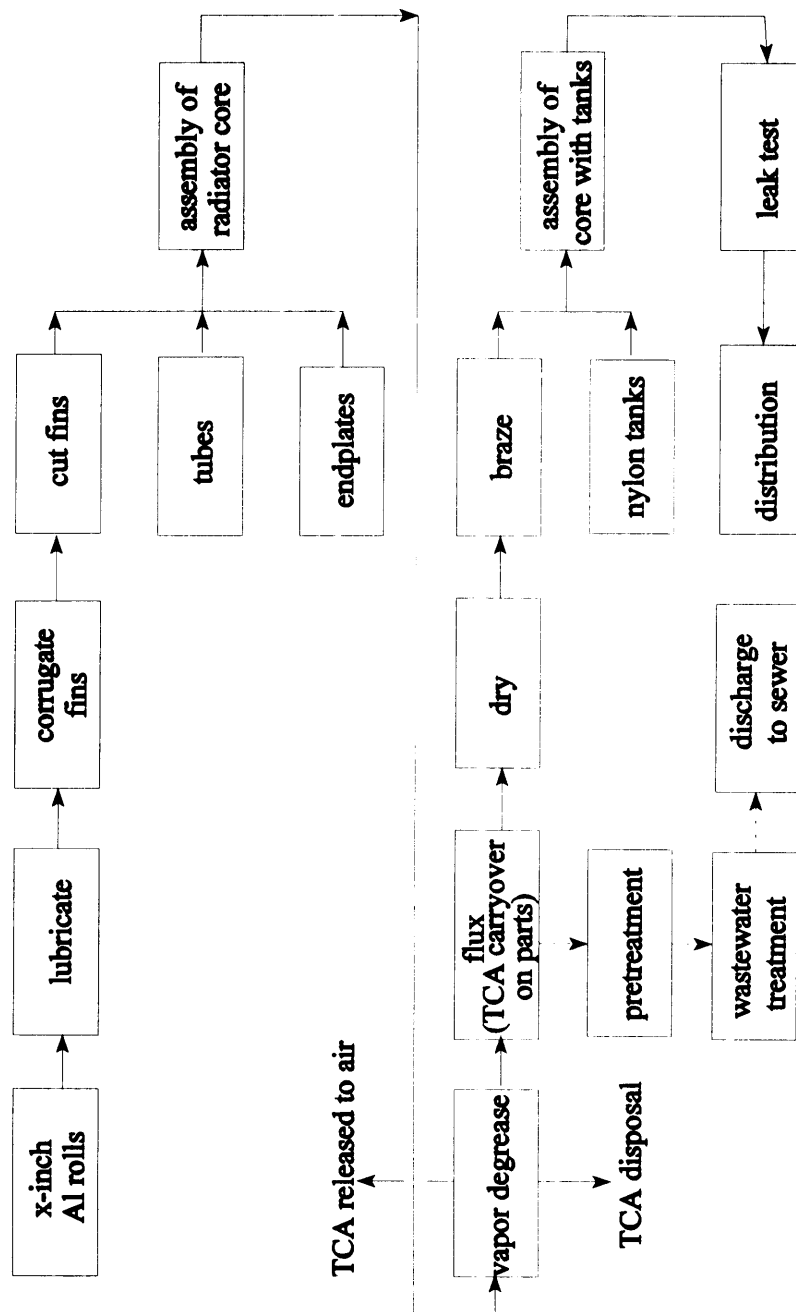


FIGURE 3. PAST RADIATOR MANUFACTURING LINE WITH THE SOLVENT DEGREASING SYSTEM

SUMMARY OF THE TECHNICAL EVALUATION

The elimination of the solvent degreasing units from the radiator and condenser manufacturing lines was accomplished by the implementation of the aqueous wash system and application of the evaporative lubricant. The technical merits of these alternatives were determined by evaluating the cycle time and product reject rate for each manufacturing line. Based on these parameters, the technical merits of the alternatives were either neutral (no discernable effects), or positive (processing improvements).

Due to the historic dates of the process changes, portions of the part reject rate data were not available. To accommodate for these data, interviews with process-line employees, line supervisors, and management were used. Discussions with line supervisors regarding process control plans for each manufacturing line supplied cycle time data. Radiator reject rate data were available for periods prior to and after the process change to the aqueous wash system. Statistical analyses of these data were performed. Reject rate data for the condenser line were gathered through interviews with CMC employees; line personnel, supervisors, and quality control personnel. Using the available information and employee interviews, the following conclusions can be made.

Aqueous Wash System of the Radiator Manufacturing Line

The cycle time per manufactured part was decreased by 50 percent with the implementation of the aqueous wash system. Two characteristics of the aqueous wash system contribute to this decrease in cycle time. First, the aqueous wash system is a continuous process, as compared to the batch system of the solvent degreasers. Second, the aqueous system is a more reliable system requiring less down time and maintenance when compared to the solvent systems.

The aqueous wash system also reduce the part reject rate, significantly. When compared to the previous degreasing operation, a reduction of over 76 percent in the rate of part rejects was observed after the aqueous wash system replaced the five vapor degreasers previously used to clean the radiator cores prior to subsequent processing.

Evaporative Lubricant System of the Condenser Manufacturing Line

The evaporative lubricant, which replaced a petroleum-based lubricant in the fin corrugation process of the condenser line, showed no impact on either the rate of production or part reject rate of this manufacturing line.

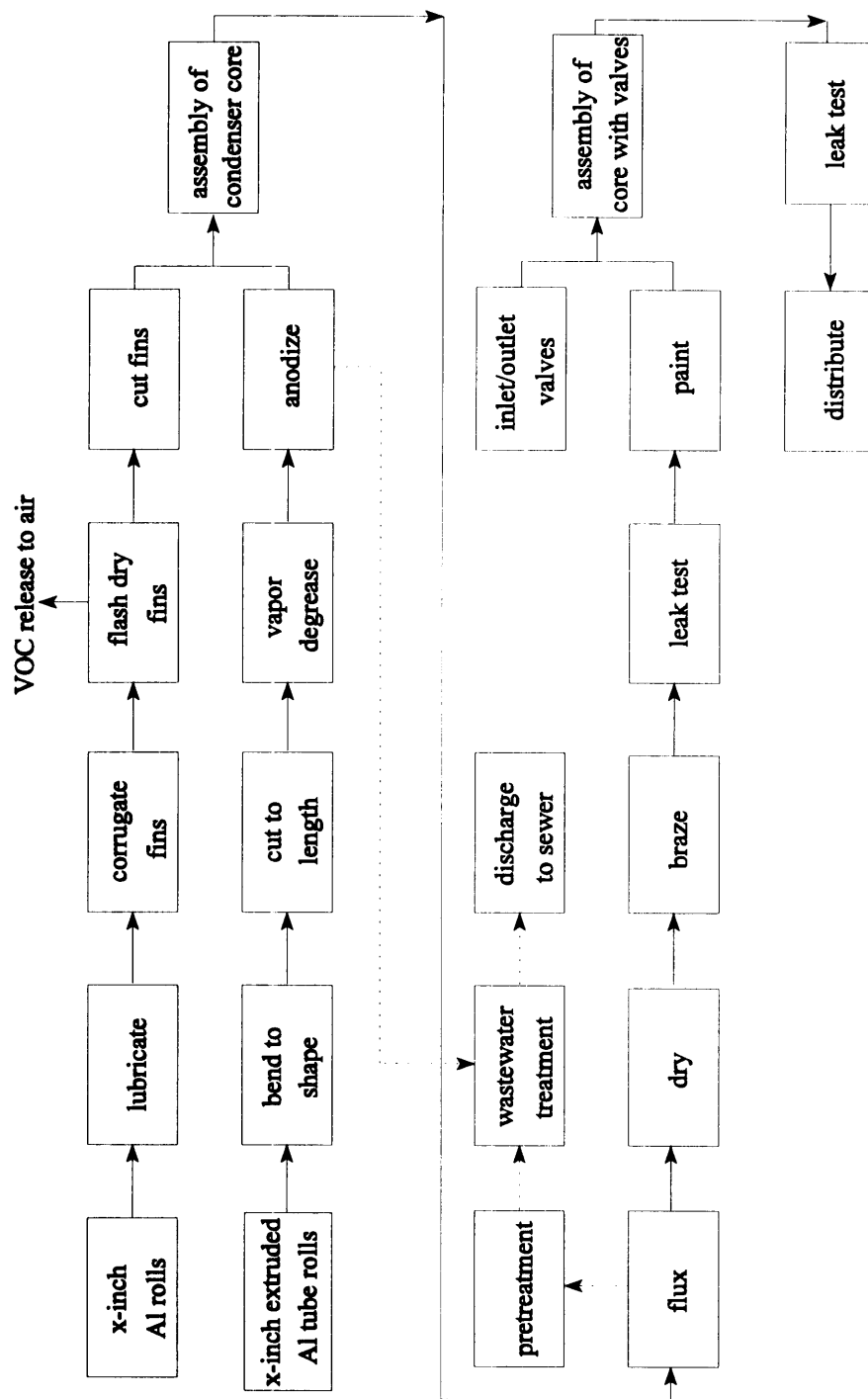


FIGURE 5. PAST CONDENSER MANUFACTURING LINE WITH THE SOLVENT DEGREASING SYSTEM

- 1993 condenser line vapor degreasers and the utilization of petroleum-based lubricants operational for five (5) months, evaporative oils utilized the remaining seven (7) months (i.e., elimination of vapor degreasers); and
- 1994 first full year evaporative lube system was operational.

TABLE 5. GOALS OF WASTE MANAGEMENT PLAN BY WASTE STREAM		
Waste Stream	Waste Generation, 1989 (lb/yr)	Goal
1,1,1-trichloroethane ^a	168,000	90% reduction by 1995
flammable liquid	9,480	80% reduction by 1995
CFCs	36,755	no numeric goal set
methylene chloride	8,338	100% reduction by 1992
chromic acid	7,815	100% reduction by 1995
sodium hydroxide	13,327	100% reduction by 1994 (condenser line only)
flammable solid	2,981	60% reduction by 1995
petroleum naphtha	1,224	100% reduction by 1995
hazardous waste solid	66,549	no numeric goal set

a 1,1,1-trichloroethane is the chemical associated with the cleaning processes and the focus of this evaluation.

Source: CMC's Waste Management Plan

Table 6 presents CMC's TCA release and transfer data from the TRI database for the five years of interest. CMC maintains manifest records and reports TRI emissions on a facility-wide basis, not line-by-line. Therefore, a variety of information to supplement Table 6 is given to estimate the impacts of each process change. TCA consumption, hazardous waste generation, and air release estimates for the radiator and condenser manufacturing lines are presented in Figure 9.

THE CONVERTER LINE AND HOT WATER WASH SYSTEM

CMC installed a hot water wash system to replace a third application of solvent degreasers. The process flow diagram of CMC's current catalytic converter assembly line which utilizes this hot water wash system is pictured in Figure 6. The catalytic converter shell and flanges, the ceramic substrate and wire mesh separator are supplied by other manufacturers. After receipt, the catalytic converter shell and flanges are cleaned in a conveyORIZED hot water wash system to remove cutting and lubricating oils left by the manufacturer. The wash system consists of a hot water spray zone, followed by a second hot water spray (rinse) zone and a drying oven. After cleaning, the ceramic substrate and wire mesh separator are inserted in the two shell halves, which are then welded together with the flanges. Each catalytic converter is leak-tested using an air-based pressure-decay system. The converters then continue along the process train to be incorporated into the exhaust system.

Until December 1993, Calsonic used a conveyORIZED vapor degreaser with TCA as the degreasing solvent (Figure 7). The current equipment used in the hot water wash system was converted by CMC from an obsolete muffler washing system and a defunct paint spray booth and curing oven. Although in operation, this system is still in the development stage; CMC has not yet completed equipment conversions. For this reason, this process is not quantitatively evaluated in this study.

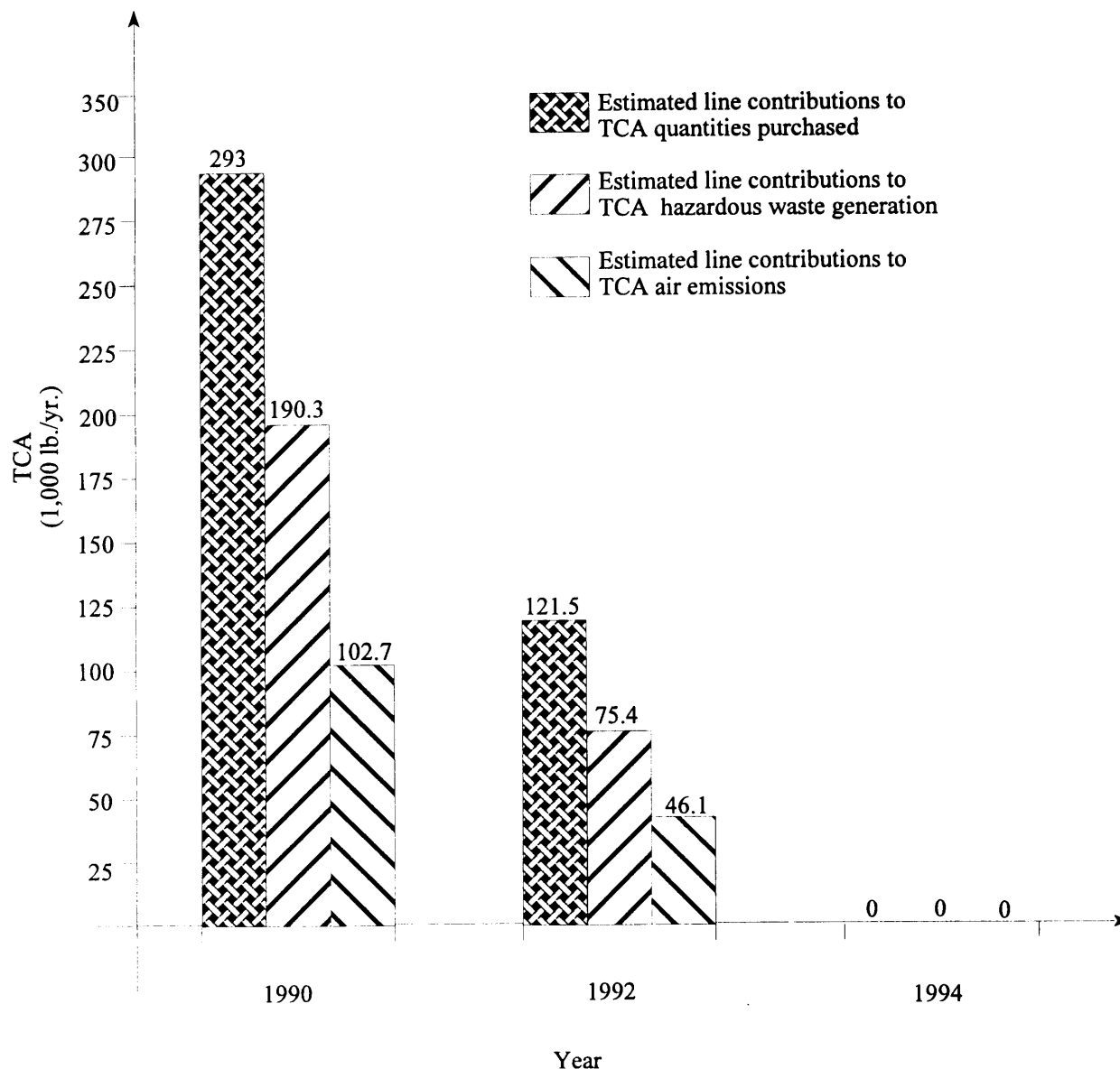


FIGURE 9. TCA RELEASES AND TRANSFERS FROM THE RADIATOR AND CONDENSER MANUFACTURING LINES - 1990 TO 1994

- a 1990 chemical purchase and emission quantities represent estimates from the radiator and condenser manufacturing lines. Air releases were determined by subtracting TCA hazardous waste generation estimates from TCA consumption quantities.
- b 1992 chemical purchase and emission quantities represent estimates from the condenser manufacturing line. Air releases were determined by subtracting TCA hazardous waste generation estimates from TCA consumption quantities.

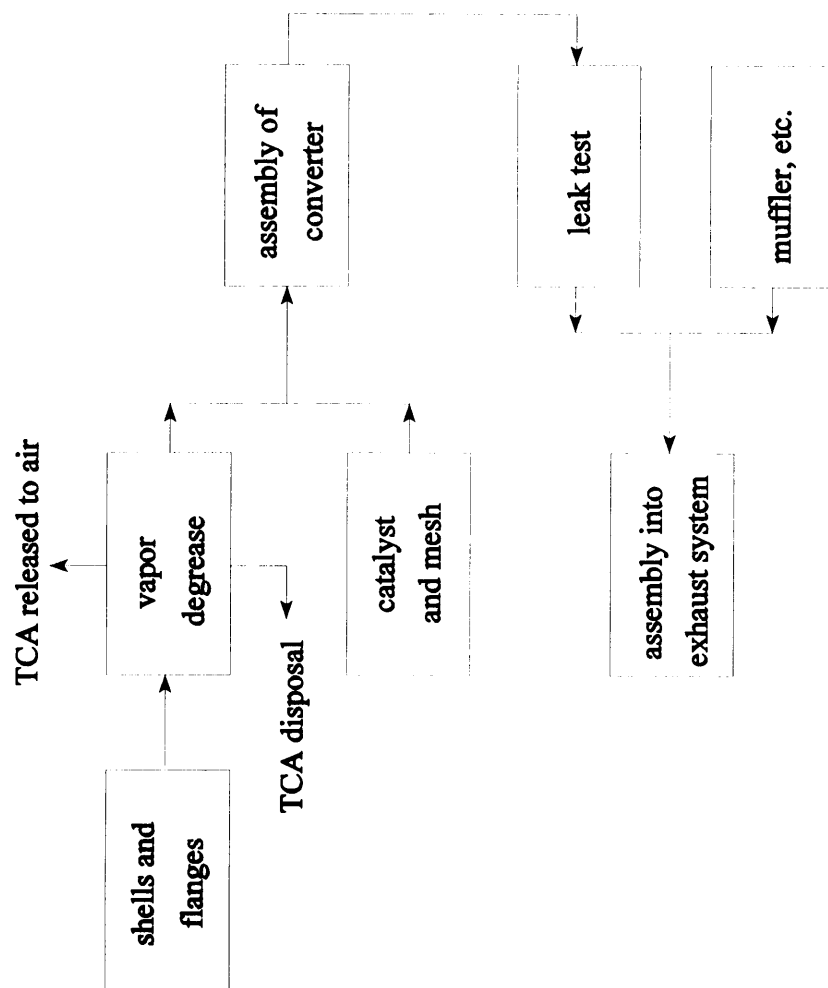


FIGURE 7. PAST CONVERTER MANUFACTURING LINE WITH THE SOLVENT DEGREASING SYSTEM

TABLE 7. CMC TRI OFF-SITE TRANSFERS OF TCA		
Year	Off-Site Transfers (lb/yr)	Percent Change
1990	233,530	-
1991	338,525	45.0%
1992	206,345	-39.0%
1993	194,975	-5.5%
1994	109,000 ^a	-44.1%

a Extrapolated for 1994 based on 11 months of TCA purchase and hazardous waste manifest records.

Source: TRI, 1992

Radiator Manufacturing Line

While the aqueous wash system of the radiator line eliminated the use of TCA and thus the waste streams generated from that use, additional land-disposed waste streams are created by this alternative process. The first such waste stream is a non-hazardous, oily waste generated in the first rinse tank of the aqueous wash system. Designed to remove the majority of oils and soils to reduce the burden on the detergent wash step, this first rinse tank accumulates oils and solids. The oils float to the top of the water reservoir, and are skimmed off and periodically (once every two or three weeks) collected in a 55 gallon drum. The solids, which settle to the bottom of the water reservoir, are collected weekly when the tanks are drained and cleaned. These solids, the volume of which is minimal, are also collected in the 55 gallon drum. The quantity of non-hazardous, oily waste generated yearly is approximately 1,320 gal (or 11,000 lb at 8.2 lb/gal) and is processed for fuel at an off-site fuel blending facility. This oily waste stream, segregated by the aqueous wash system, does not represent a new waste stream. These oils and greases were dissolved by the TCA of the solvent degreasing systems and disposed of off-site in the spent solvent.

The second additional land-disposed waste stream generated from the aqueous wash system is the solids generated at the industrial wastewater pretreatment facility operated on-site by CMC. The manufacturing processes of CMC, including the aqueous wash system, generate nearly 25,000 gal/d of wastewater which CMC pretreats prior to sewer discharge. This pretreatment process, discussed in more detail in the "Releases and Transfers of Water," generates a non-hazardous, solids waste stream. The rate of solids generation for the entire facility was approximately 26,400 gal/yr. The average wastewater flow rate from the aqueous wash system (explained below) represents approximately 30 percent of the total wastewater flow treated by CMC. If it is assumed that sludge generation is directly proportional to the wastewater flow rate, approximately 30 percent of the solids generated during wastewater pretreatment, or 7,900 gal/yr (or 64,700 lb/yr at 8.2 lb/gal), may be attributed to the aqueous wash system of the radiator line. This assumption may not reflect the true influence of the

line lasted eight months; the aqueous wash system was considered the most effective and feasible alternative after that time. Approximately one month was required for condenser line alternatives' screenings; the evaporative lube alternative was previously documented in the screening tests for the radiator line. Initial performance screenings included black light tests of cleaned parts, as well as leak tests and braze-bond efficiencies; example test results are included in Appendix B. Finally, full-scale trial runs were conducted to test alternative process performance with the rest of the manufacturing process. Both the aqueous wash system (radiator) and the evaporative lubricant (condenser) were implemented at CMC following these procedures.

CMC TECHNICAL EVALUATION

The objective of the technical evaluation was to determine the effects the substitutes had on process and product performance compared to the 33/50 chemicals. For this study, process and product performance were used as the two parameters to evaluate the technical merits of the alternative cleaning systems. As part of a continuous manufacturing line, the cleaning process (or no-clean alternative) has the potential to influence both of these parameters. Process performance of the alternative processes was defined as the cycle time required to clean a single unit. As a potential bottle-neck in the process, the cleaning step can limit the quantity of parts manufactured. Cycle times were established from available process data, equipment capacity and employee interviews. Product performance was based on part reject rates per unit of production; the degree of cleanliness a part has prior to flux application and brazing greatly effects the quality of the braze, thus the quality of the final product. Part reject rates were established using the results of leak testing described in Chapter 3. The production and part reject rates when the solvent degreasing processes were on-line were used as the baseline for comparisons with the alternative processes.

The Evaluation of the Process Cycle Time

Radiator Manufacturing Line. Process control plans specifying equipment capacities and employee interviews identified significant differences in the cycle times between the solvent degreasers and aqueous wash system. The chlorinated solvent degreasers, when on-line, represented the bottle-neck of the radiator manufacturing process, according to the supervisors and line personnel interviewed. Standard operating procedures for these units involves assembling a core, placing it into the degreasing unit, and assembling a second core while the first was automatically cleaned. This cleaning step, a batch process, was the single limiting factor of the radiator production rate. Furthermore, maintenance and down-time of these units caused normal manufacturing hours to be consumed by non-productive down-time, resulting in work schedules beyond normal operating hours to fulfill production quotas.

The aqueous wash system, on the other hand, has a cycle time capable of processing/cleaning cores at a rate 50 percent faster than the degreasing processes, thus changing the process line bottle-neck away from the cleaning operation. Within the two years of operation, the aqueous wash system, a continuous conveyor system, has required one maintenance repair which was remedied during a shift switch. Down-time due to mechanical failure or operating difficulties has not been experienced with this unit. The efficiency and

Radiator Manufacturing Line

The elimination of the chlorinated solvent degreasers from the radiator manufacturing line eliminated all reportable air releases associated with the cleaning of the radiator cores. In 1988 air releases represented over 66 percent of CMC's total TCA releases and transfers; by 1992 this percentage had decreased to 46 percent. From discussions with CMC employees, reasons for this percentage decrease include elimination of the least efficient solvent degreasers which contributed the greatest amount of air releases, and better operating/control procedures on remaining degreasers. The five solvent degreasers of the radiator line were examples of low-efficiency cleaning systems. The reduction of 54.3 percent in air releases between 1990 and 1991 in part reflects the elimination and replacement of these inefficient degreasers by the aqueous wash system.

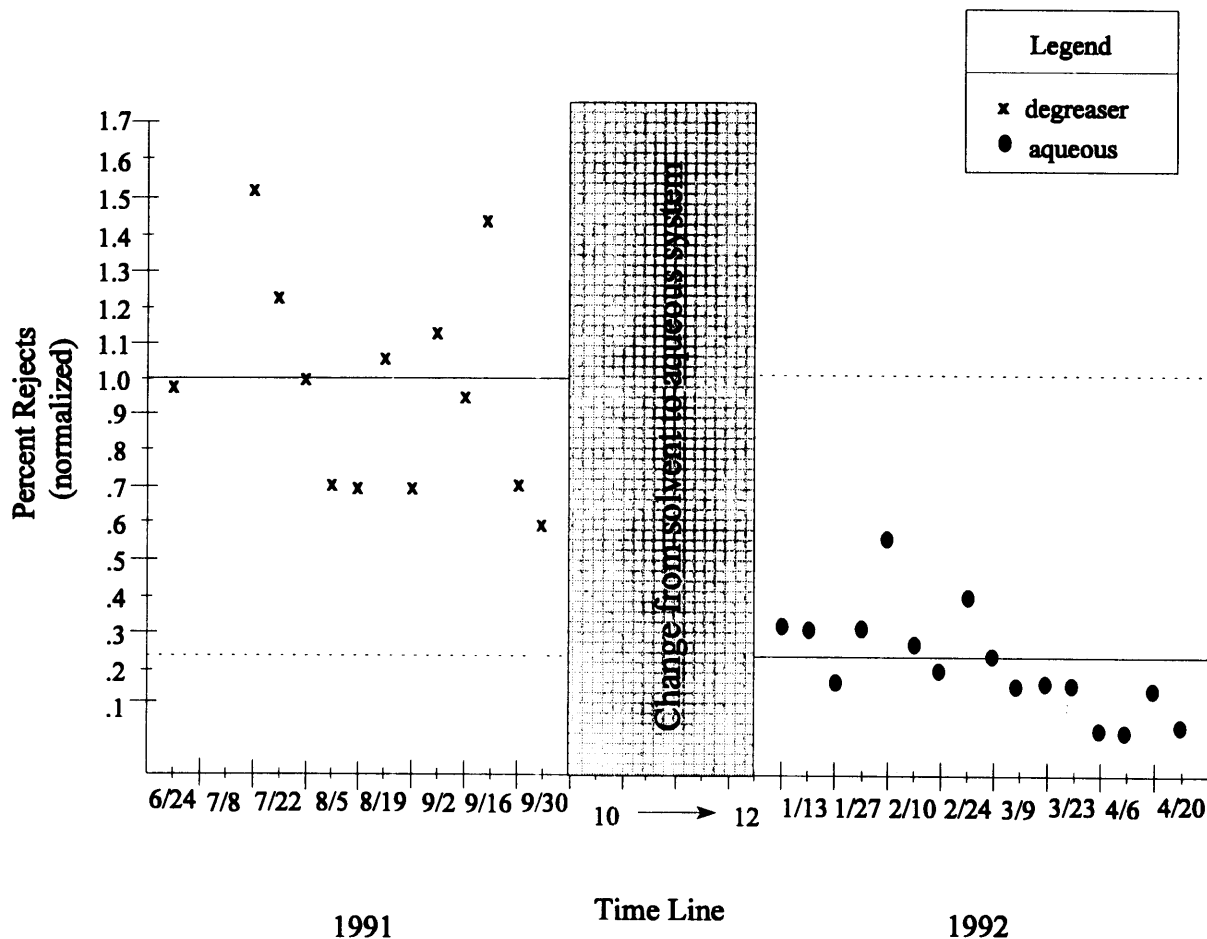
Condenser Manufacturing Line

The elimination of the chlorinated solvent degreasers from the condenser manufacturing line also eliminated TCA air releases associated with the cleaning of the condenser corrugated fins. The significant percent decrease in air releases of TCA observed between 1992 and 1993 corresponds to the elimination of the condenser's solvent degreasing processes.

However, the evaporative lubricant utilized in the new condenser processing line generates an air emission not present when the solvent degreasers were operational. The evaporative lubricant is a volatile organic compound (VOC) that is vaporized by flash driers prior to subsequent processing. Consumption of the lubricant was recorded as 2 gal/d per corrugation unit. With this, and assuming that 100 percent of the lubricant evaporates within the flash driers, air emissions of VOC were estimated to be nearly 12,200 lb/yr (specific gravity is 0.764). Interviews with the line supervisors and engineers, however, indicate that only a fraction of the lubricant is actually evaporated by the flash driers, and that some of the lubricant remains on the corrugated fins as they are assembled with the tubes and enter the flux and braze processes. Therefore, the estimate of 12,200 lb/yr sets the upper boundary of air releases from the alternative process of the condenser line.

Though not required under TRI to be reported, this VOC release of lubricant is regulated by the Tennessee Department of Environment and Conservation Division of Air Pollution Control. Under the requirements of this Division, VOC emissions must be permitted, and release quantities over one ton must be reported yearly. This reporting requirement, and concerns about potential employee exposure to the VOCs, prompted CMC to look for alternatives. During the six-month course of this research project, CMC began testing alternative synthetic, water-based lubricants to replace the evaporative lube. Because of the water-based nature of the new alternatives, removal of the lubricant before subsequent processing (i.e., fluxing and brazing) would not be required, thus eliminating the need for the flash driers. Trial tests are still underway at CMC to determine the applicability of these alternative lubricants. Pilot studies for testing the lubricity and effects on subsequent processes have shown positive results, and full implementation of a synthetic, water-based lubricant is expected by early 1995. CMC management and line supervisors see this synthetic, water-based lubricant as the ultimate solution to eliminate solvent degreasing, even over aqueous wash alternatives.

quality braze. Residuals from the flash drying of the lubricant do not interfere with flux application. The original processes of these lines employed solvent degreasing to achieve the required level of cleanliness. Interviews with CMC quality control employees indicated that there was no change in core reject rates after the evaporative lubrication system was operational when compared to the reject rates of the degreasing process.



the aqueous wash system and discharged to the on-site treatment facility. The other process changes which offset the additional aqueous wash wastewater consisted of inert aqueous flux solutions and electroplating rise baths, neither of which contribute to the wastewaters BOD load. The treatment scheme, as discussed above, is not intended to biologically remove these contaminants. A limited amount of oil can be removed during flocculation due to entrainment and adsorption of the oils on the solid particles. The majority of the oil and soil contaminants, however, pass through the pretreatment facility essentially unchanged. The potential impact this waste stream has on the POTW is presented in the national environmental impact evaluation of Chapter 7.

Condenser Manufacturing Line

The implementation of the evaporative lubricant alternative to the condenser manufacturing line, while eliminating the TCA water contamination due to carry over, does not generate wastewater. Therefore, the condenser line does not directly affect the releases and transfers to water. However, the subsequent processes of the condenser manufacturing line include the application of an aqueous flux to the condenser core. Lubricant residual remaining on the corrugated fins of the condenser core could contaminate the aqueous flux solution, which in turn could contaminate the pretreated wastewater discharge to the POTW when the flux solution is treated by CMC's on-site treatment facility. This potential contamination is considered insignificant for this CMC-specific evaluation due to the small quantities of lubricant used, and its evaporative characteristics. However, this issue is addressed in the national environmental impact evaluation of Chapter 7 where impacts on POTWs and synthetic lubricants are developed.

Converter Manufacturing Line

The hot water wash system of the converter line generates wastewater while eliminating the use and hazardous waste disposal of TCA (approximately 27,100 lb/yr hazardous waste and unknown air releases). Due to the details of their POTW discharge permit at this site, and other managerial considerations, CMC has chosen to drum this wastewater and dispose of it as an oil-contaminated, non-hazardous waste. Twelve drums every three months are filled with the contaminated water and disposed of off-site. The longevity of the hot water wash reservoir, when compared to the radiator detergent reservoir, is due to the elimination of the detergent and the ability to periodically remove oily residues from the reservoir surface. The advantages of this reservoir longevity and the elimination of a detergent from aqueous cleaning are more fully explained in Chapter 7, National Environmental Impact Evaluation.

TOXICITY, EXPOSURE, AND RISK

Accompanying the shifts in environmental emissions presented above are changes in the toxicity and potential risk to human health and the environment from chemical exposure. An assessment of toxicity and exposure potential associated with the waste shifts is presented

CHAPTER 5

ENVIRONMENTAL EVALUATION

The objectives of this evaluation were to analyze the releases and transfers of the chlorinated degreasing solvents from CMC's manufacturing facilities, and to compare these to the chemical releases and transfers associated with the alternative cleaning or no-clean processes. Though the chlorinated degreasing solvents and their emissions were eliminated by the implementation of the alternative processes, releases and transfers of other chemicals now exist. Therefore, a multimedia approach, evaluating releases and transfers to land (off-site transfer), air, and water, were used to capture the full benefits and costs of the changes to the alternative processes. Both hazardous and nonhazardous wastes were also included in the analysis. Data obtained from CMC and TRI were maintained in English units. Conversion tables to metric units are supplied in Appendix D.

The replacement of the solvent degreasing systems of the radiator and condenser manufacturing lines with the alternative technologies eliminated approximately 293,000 lb/yr of TCA releases and transfers to the air and soil. The aqueous wash system, while eliminating the emissions of TCA, created an additional wastewater stream equalling over two million gal/yr, and a nonhazardous oily waste stream totalling 1,320 gal/yr. The pretreatment of the wastewater stream also generates an estimated 7,900 gal/yr of nonhazardous solid waste. The no-clean alternative technology implemented on the condenser line generated volatile organic compound air emissions totalling about 12,200 lb/yr while eliminating all TCA emissions. These results of the environmental evaluation are presented in detail in the following sections.

ENVIRONMENTAL BACKGROUND

Calsonic Corporation, in 1991, established an Environmental Program "to properly manage and reduce usage and emissions of pollutants and hazardous materials . . ." This Program (Appendix E) states that each Calsonic operation must designate a person to be responsible for environmental compliance. The responsibilities of this environmental designee are then listed in twelve additional statements. In response to this corporate program, CMC established a "Waste Management Plan" in 1992. In this Plan, also presented in Appendix E, hazardous waste reduction goals were specifically defined, goals that were to be achieved by 1995. These goals, outlined in Table 5, below, have been aggressively pursued by CMC. The application of alternative processes to eliminate TCA and solvent degreasing has been one step towards achieving these goals.

Based on the information of Table 3 of Chapter 2, the years of interest for data interpretation are as follows:

- 1990 last full year radiator vapor degreasers were operational;
- 1991 radiator vapor degreasers operational for nine (9) months of the year, aqueous wash system installed and running the remaining three (3) months;
- 1992 first full year aqueous wash system was operational, and the last full year in which petroleum-based lubricants were utilized on the condenser line (i.e., the last full year condenser line vapor degreasers were operational);

two such detergent builders. Ingestion of excess quantities of these phosphate salts are toxic. Effects include upset mineral balance in the body and prevention of mineral nutrient utilization. LD₅₀ values for STPP include 3.02 g/kg in mice, and 5.19 g/kg in rats.²⁹

The primary industrial chelators are essentially environmentally benign and nontoxic under normal handling and use conditions.³⁰ Bioconcentration values suggest EDTA will not bioaccumulate in aquatic organisms. However, the strong chelating characteristics of EDTA mobilize heavy metals, including lead and cadmium, in wastewater streams, sewer sludge, and soils. This mobilization of metals causes treatment problems for POTWs (discussed further in Chapter 7), and has the potential to create situations in which aquatic organisms are exposed to a toxic environment. LD₅₀ values for EDTA for fish is 159 mg/L in a 96 hour test; no adverse effect level is 100 mg/L. EDTA is not metabolized by the human body and is readily excreted in the urine. The FAO/WHO Acceptable Daily Intake for EDTA in humans is 0 to 2.5 mg/kg body weight.³¹

Nitrilotriacetic acid (NTA) is another chelating agent commonly used in detergent formulation. Laboratory findings in the later 1960s suggested that NTA was a potential teratogenicide, and in 1970, the U.S. Surgeon General requested the withdrawal of NTA from the market. However, since that time, further studies supporting its safety have encouraged the EPA to drop its opposition to NTA. Currently, NTA is beginning to reappear in some nonphosphate consumer laundry detergents.³²

Exposure Potential

To evaluate the exposure potential for the various waste streams, potential exposure pathways must be identified. Exposure pathways are the physical courses chemicals take from the source to the organism exposed. An example of an exposure pathway might be worker inhalation of volatile organic compounds that have evaporated from a solvent to the air; the inhalation of solvent in air is the exposure pathway. Potential exposure pathways for each of the waste streams generated by the solvent degreasing and alternative processes, exposure pathways and routes will be assessed.

1,1,1-Trichloroethane. Chlorinated alkanes (e.g., TCA) readily vaporize, and consequently distribute primarily to air. TCA releases from point sources such as vapor degreasers disperse into the environment and contribute to the concentrations of the chemical in the ambient environment. Therefore, the primary exposure pathway of TCA as a degreasing solvent is expected to be inhalation of TCA in air.

However, a hazardous waste stream of spent TCA was also generated by the solvent degreasers. This waste stream was drummed by CMC employees and transferred off-site to a recycling facility. Dermal contact with liquid TCA and inhalation of TCA vapors are possible during drumming activities, although appropriate standard operating procedures can minimize their potential. Additional air releases could occur at the recycling facility as well as hazardous waste generation of residues contaminated with TCA.

Wastewater. The containment, pretreatment, and POTW treatment of wastewaters from the aqueous wash system minimizes the potential pathways and routes of exposure to detergent constituents. The primary pathway is via water, and dermal contact with or ingestion of contaminated water would be the potential routes.

TABLE 6. 1,1,1-TRICHLOROETHANE TRI RELEASES AND TRANSFERS REPORTED BY CMC								
Year	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
1988	241,000	0	0	0	241,000	0	100,000	100,000
1989	370,000	0	0	0	370,000	0	168,000	168,000
1990	425,756	0	0	0	425,756	0	233,530	233,530
1991	194,622	0	0	0	194,622	0	338,525	338,525
1992	176,239	0	0	0	176,239	0	206,345	206,345
1993 ^a	89,446	0	0	0	89,446	0	194,975	194,975
1994 ^b	66,800	0	0	0	66,800	0	109,000	109,000

^a Release and transfer information obtained directly from CMC.

^b Extrapolated for 1994 from 11 months of TCA purchase and hazardous waste manifest records from CMC.

Source: TRI

TABLE 9. POTENTIAL EXPOSURE TO WASTE STREAMS AND ASSOCIATED RISK		
Waste Stream	Primary Exposure Pathway	Potential Risk
TCA	Air and Inhalation	Uncontrolled point source creating the highest potential for exposure and risk
Wastewater (Detergent)	Water and Ingestion or Dermal Contact	Contained and treated point source reducing potential for exposure and risk
VOC (Evaporative Lube)	Air and Inhalation	Uncontrolled point source (small volume) creating high potential for exposure and risk

SUMMARY OF THE ENVIRONMENTAL EVALUATION

A quantitative evaluation of the impacts the alternatives have on releases and transfers was performed based on available data, such as limited TCA consumption data and CMC employee estimates. The implementation of the alternative processes to solvent degreasing within the radiator and condenser manufacturing lines significantly affected the releases and transfers from CMC's facility, both in chemical composition and quantity. The TCA air and hazardous waste streams associated with the operation of solvent degreasers were eliminated from both the radiator and condenser manufacturing lines. The alternative processes, however, introduced additional waste streams unique to their application.

The aqueous wash system of the radiator line introduced three additional waste streams, all of which are classified as non-hazardous. The wastewater generated by the aqueous system contributed more than two million gal/yr of wastewater to CMC's on-site pretreatment facility. This pretreatment facility, in turn, generates nearly 26,400 gal/yr of wastewater treatment solids, 7,900 gal of which may be attributed to the aqueous wash system. An additional non-hazardous, oily waste stream is also generated by the aqueous wash system. These emissions, compared to the TCA emissions are presented in Figure 10.

The application of the evaporative lubricant to the fin corrugation process of the condenser line, while eliminating all TCA waste streams, generated one additional waste stream. The VOC emissions of the lubricant, resulting from the flash driers of the fin corrugation units, is a regulated air release. Based on lubricant consumption data, 12,200 lb of VOC are emitted to the atmosphere each year from this process. This represents the only direct release or transfer from this alternative process. Figure 11 compares the emissions from the old and new condenser processes.

These shifts in waste stream composition and media must be coupled with a consideration of toxicity and potential risk to human health and the environment. For the aqueous wash of the radiator line, releases of the toxic, ozone-depleting chemical TCA were eliminated, but a larger volume, low toxicity wastewater stream was generated. Although hazardous waste reporting requirements have been eliminated for this line, pretreatment requirements must still be met. For the condenser line, hazardous waste and TCA were once

Based on TCA chemical use logs of each manufacturing line, the yearly consumption of TCA was estimated; 171,500 lb of TCA were consumed in 1990 by the degreasers of the radiator line, and 121,500 lb of TCA were consumed in 1992 by the degreasers of the condenser line. The hazardous waste disposal values identified in Figure 9 are estimates from line personnel; air releases represent the difference between consumption and hazardous waste disposal estimates. By 1992 TCA use by the radiator manufacturing line was eliminated, and therefore the hazardous waste stream associated with the TCA use. Similarly, by 1994 the use and hazardous waste disposal of TCA by the condenser fin corrugation process were eliminated. The changes in releases and transfers to land (off-site transfer), air, and water are evaluated for each process line. Included in this multimedia analysis is the consideration of hazardous, toxic, nonhazardous, and nontoxic releases and transfers.

RELEASES AND TRANSFERS TO LAND (OFF-SITE TRANSFERS)

The use of TCA for solvent degreasing resulted in a hazardous waste stream of spent solvent. Periodically, to maintain optimal cleaning potential, the reservoirs of the solvent degreasers would be drained of TCA, which was contaminated with moisture and soils removed from the parts. The reservoir would be filled again with fresh solvent, and the collected TCA would be disposed of off-site in 55 gallon drums as hazardous waste. Calsonic chose off-site solvent recovery/recycling as the most desirable method to manage this hazardous waste stream. The alternative processes which replaced the solvent degreasers of the radiator, condenser, and converter manufacturing lines eliminated this TCA waste stream from these lines.

Disposal quantities of hazardous waste containing TCA, retrieved from the TRI for the years 1990 through 1992, are presented in Table 7. Within TRI, this waste stream was reported under "Other Off-Site Transfers" which can include treatment and licensed land disposal. This TCA hazardous waste stream was completely eliminated from the radiator and condenser manufacturing lines by the aqueous wash and no-clean alternatives. Table 7 also presents the percent change of the total TCA hazardous waste stream from year to year. The increase in hazardous waste from 1990 to 1991 was due to the addition of a new product line manufactured by CMC. This new product manufacturing line introduced two new TCA vapor degreasing processes. The hazardous waste streams from the new degreasers mask the elimination of TCA waste from the radiator line. The 44 percent reduction in these hazardous waste transfers from 1993 to 1994, however, can be predominantly attributed to the full implementation of the evaporative lubrication system and the elimination of the vapor degreasers of the condenser manufacturing line.

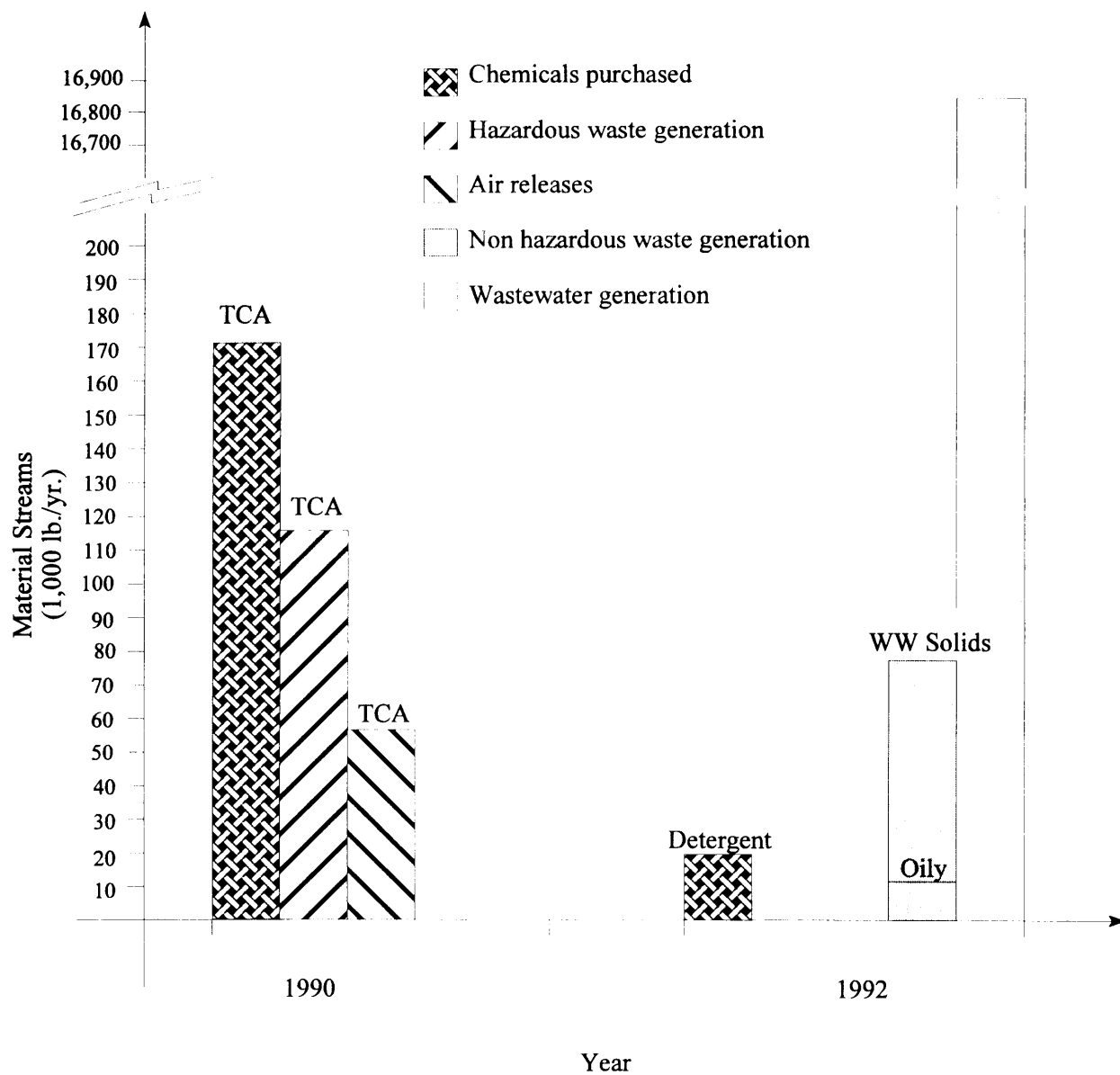


FIGURE 10. SUMMARY OF RADIATOR LINE EMISSIONS OVER TIME

aqueous wash system on wastewater treatment solids generation, but the information to establish a direct relationship was not available.

Condenser Manufacturing Line

The elimination of the chlorinated solvent degreasers from the condenser line eliminated all off-site transfers of either hazardous or non-hazardous waste associated with fin corrugation and the cleaning process. The evaporative lubricant now utilized is removed by flash driers after fin corrugation; the waste stream is thus in a vapor phase and is discussed in the following section, Releases and Transfers to Air.

RELEASES AND TRANSFERS TO AIR

Releases to air from the radiator and condenser process lines also changed significantly due to the application of alternative systems for solvent degreasing. Standard operating procedures of the solvent degreasers can result in solvent vapor losses; drag-out on cleaned parts, air drafts through the units, and poorly maintained operating conditions are only some of the possible reasons for solvent losses. On-site emissions to air, reported each year in the TRI database, were estimated by CMC using TCA purchase records and TCA hazardous waste disposal data from manifest records. Table 8 summarizes the information used for these calculations. Also presented in Table 8 is the percent change of air releases from year to year.

TABLE 8. SUMMARY OF INFORMATION USED TO CALCULATE CMC AIR EMISSIONS OF TCA				
Year	Total TCA Purchased (lb/yr)	TCA Disposed (Manifest) (lb/yr)	TCA Air Releases^a (lb/yr)	Percent Change
1990	659,286	233,530	425,756	-
1991	533,147	338,525	194,622	-54.3%
1992	382,584	206,345	176,239	-9.4%
1993	284,421	194,975	89,446	-49.8%
1994 ^b	175,800	109,000	66,800	-25.3%

a Reported in the TRI.

b Extrapolated for 1994 based on 11 months of TCA purchase and hazardous waste manifest records.

CHAPTER 6

ECONOMIC EVALUATION

The final results of the economic analyses of CMC's manufacturing lines supported the implementation of the pollution prevention alternatives. Though traditional analyses identified returns on investment within ten years, a typical time horizon for pollution prevention investments, activity-based cost accounting methods more accurately identified the savings associated with the alternative processes, and resulted in return on investments within five years, a typical time horizon for all investments by industry. Hybrid analyses, which combined traditional and activity-based costing methods, offered return on investments in as short as three months, therefore fully supporting the implementation of the alternative processes.

The radiator line, with the aqueous wash system, resulted in a return on investment of 11.6 years using traditional cost evaluation methods. Typical industrial practices require a return on investment of five years; if cost was the only metric considered, the aqueous wash system would not be supported using traditional accounting methods. Activity-based cost accounting methods more accurately evaluated the benefits of the aqueous wash system and resulted in a 2.4 year return on investment, therefore supporting the implementation of the aqueous system even when a typical 5-year time horizon is used. The 5-year net present value calculation resulted in a positive net flow of \$1,069,890 when compared to the solvent degreasing system. A four percent interest rate (typical of a low risk investment) was used to calculate the time value of money.

The no-clean technology of the converter line identified even greater savings due to the elimination of the solvent degreasers and limited added costs. A 0.45 year return on investment and 0.27 year return on investment were calculated using traditional and activity-based cost accounting methods, respectively. A 5-year net present value for the evaporative lube system was calculated to be \$869,890 when compared to the solvent degreasing system.

ECONOMIC BACKGROUND

The objective of the economic evaluation was to analyze the total cost of the substitutes as compared to the chlorinated solvent degreasers. This analysis of total cost was accomplished in two steps. The first step was a traditional analysis evaluating direct costs. Direct costs are traditionally used in the analyses of most financial statements, and are therefore part of the accounting systems of most companies. As noted in recent literature, however, direct costs may not capture all the benefits of a pollution prevention project. These benefits fall into the categories of indirect costs (overhead), potential liabilities, and less-tangible costs. Therefore, the second step taken to economically evaluate the benefits and costs of the alternative systems, when compared to the solvent degreasing systems, was to more accurately capture these additional costs. Activity-based costing (hereafter referred to as ABC) was the analytical tool applied to perform this second cost analysis step.

The four categories of cost identified above (direct costs, indirect costs, potential liabilities, and less-tangible costs) are the four tiers of data the EPA calls the 'expanded cost inventory'.³³ These tiers, designated "Tier 0" through "Tier 3" are presented in Table 10. The more accurately the costs within each of these tiers are accounted for and quantified, the more

RELEASES AND TRANSFERS TO WATER

CMC reported no releases to water of TCA, whether under an NPDES permit (on-site) or off-site to a POTW, when the solvent degreasers of either process were on line. Air releases and hazardous waste transfers of TCA were the only reported waste stream by CMC, as shown in Table 8. Water releases of TCA that were possible under these degreasing operations may have resulted from solvent carry-over on the cleaned cores into the aqueous flux application system. This flux solution is periodically drained and treated by CMC's on-site wastewater pretreatment facility, which is discharged to the sewer (i.e., POTW) after treatment. It was assumed by CMC that any TCA reaching the flux solution by carry-over is volatilized either during the flux application process, or in the aerated equalization basin of the pretreatment facility. This volatilization contributes to the TCA air releases and is already accounted for by CMC's method used to calculate this waste stream. Sampling and analysis of the pretreated wastewater entering the sewer system, required under CMC's discharge permit, support this assumption. Even at the highest concentration of TCA detected (0.41 mg/L on December 28, 1992) in sample analyses, only 0.068 lb/d, or 16.4 lb/yr, of TCA would have been discharged to the POTW (data presented in Appendix F).

Radiator Manufacturing Line

The aqueous wash alternative of the radiator line introduces an additional water waste stream not associated with the original solvent degreasing system. The operation of this aqueous wash system generates an average of 8,400 gal/d (over two million gal/yr) of wastewater which must be treated by CMC's existing pretreatment facility. This discharge to the pretreatment facility includes a continuous discharge from the first rinse tank, and a batch discharge from all three tanks which occur weekly. Pretreatment of this waste stream includes separately shocking the detergent bath wastewater by extreme pH variations to minimize foaming in subsequent treatment steps, and treatment of the continuous wastewater stream, along with other wastewaters from CMC, with varying pH, polymer addition, flocculation and settling, solids dewatering, and final sand/coal filtration of the water prior to discharge to the sewer. Reporting of this wastewater stream is not required under TRI. However, the discharge to sewer requires periodic sampling and analysis.

The existing wastewater pretreatment facility of CMC treats wastewaters from all manufacturing operations. The treatment scheme of this wastewater pretreatment operation is primarily designed to remove metals and suspended solids from the wastewater; biological treatment of organics is not possible by the current system. Other changes in CMC manufacturing processes off-set the additional 8,400 gal/d of wastewater generated by the radiator aqueous wash system; the average flow rate of the pretreatment facility actually decreased even with the addition of the aqueous system.

Although the flow rate has not increased due to the implementation of the aqueous wash system, pretreated effluent analysis results indicate a significant increase in the wastewater's biological oxygen demand (BOD). CMC is required by their industrial discharge permit to quarterly analyze the pretreated wastewater effluent to the sewer system. The results, presented in Appendix F and statistically analyzed in Appendix C, indicate the average BOD has increased over 700 percent (from 3.8 to 27.8 mg/L) after the implementation of the aqueous wash system. This increase can largely be attributed to the oils and soils removed by

degreasers for zero salvage value. Both assumptions result in a conservative estimate in favor of the solvent degreasing systems. The capital investment for each of the alternative processes was supplied by CMC in the data request tables of Appendix A.

Also included in the traditional cost analyses are the raw materials, waste disposal, and energy costs for both the old and new manufacturing processes. The Environmental Evaluation of Chapter 5 offers the chemical use rates for each process, old and new, as well as the waste generation rates. Combining this information with chemical purchase costs, waste disposal fees, and energy consumption/costs completes the data required for the traditional cost analysis. These costs for each manufacturing line are presented below. Using these values for direct cost, return on investment, and net present values, typical economic parameters employed by industry, were calculated and are also included in the following discussion.

Additional operation and maintenance costs which would include maintenance labor and materials, as well as supervision, are not included in the traditional analyses. This is due to the fact that the implementation of the aqueous wash and evaporative lube systems did not effect the direct labor hours of the radiator and condenser manufacturing lines. The same number of employees currently work on the lines as did for the vapor degreasing systems; therefore, direct labor costs have not changed. The labor differences that do significantly change are those of supporting activities (maintenance and supervision). The costs associated with these activities, not traditionally included in direct cost analyses, will be accounted for in the ABC analysis which follows.

Traditional Cost Evaluation of the Radiator Manufacturing Line

The implementation of the aqueous wash system removed five solvent degreasers, one from each assembly station, and centrally located the cleaning process for the radiator line. As established in Chapter 4, the rate of production was not changed significantly due to the implementation of the alternative cleaning process. Therefore, the only raw material costs included in the analysis are those associated with the cleaning process; specifically the cost of TCA for the solvent systems, and the costs of detergent and water for the aqueous system. These costs are presented in Table 11, below. The waste disposal and energy costs of each of these processes are also presented in the table.

in this section. From this information, conclusions about the relative risks these wastes have on the environment and human health are drawn.

Toxicity

The term toxicity describes the various adverse human health and environmental effects possible as a result of chemical exposure. These effects can be described as toxic (e.g., acute, chronic, or subchronic), neurotoxic, carcinogenic, mutagenic, or teratogenic.²³ An assessment of toxicity is the characterization of the toxicological properties and effects of a chemical with specific emphasis on the identification of a dose-response relationship. Some of the various toxicological characteristics of each waste stream and their constituents are presented below.

1,1,1-Trichloroethane. TCA is readily absorbed through the lungs and the gastrointestinal tract. It is considered to be poorly absorbed through the skin. Metabolic conversion of TCA within the body is nearly non-existent; most of the dose is expired, predominately by exhalation, unchanged regardless of the route of administration. TCA does not accumulate in the tissues. Under EPA's weight-of-evidence classification, TCA has been placed in Group D, unclassified as to human carcinogenicity.²⁴ TCA is a CNS and respiratory depressant; exposure to concentrations greater than 5,000 to 10,000 parts per million (ppm) can be lethal due to cardiac arrest or respiratory failure.²⁵ Recommended maximum workplace concentrations of solvents have tended to decrease with time, consistent with available information identifying potential adverse effects from exposure to these chemicals, and with technological improvements for their use. The occupational permissible exposure limit (PEL) to TCA established by Occupational Safety and Health Association is 350 ppm. TCA readily vaporizes into the air, thus the potential for adverse effects on the aquatic environment would not be a primary concern. Though not a direct toxic effect, TCA has a half-life of six months to 25 years in the atmosphere and therefore can travel long distances. Furthermore, TCA is listed as an ozone depleting chemical.²⁶

Surfactants. Commonly used surfactants are relatively non-toxic to humans; some cause skin, mucous membrane, and eye irritation. Acute oral toxicity is low, typically in the range of several hundred to several thousand mg/kg of bodyweight. The LD₅₀ in rats for linear alkylbenzene sulfonate (LAS), for instance, is 650-2,480 mg/kg. LD₅₀ is the lethal dose of a chemical taken by mouth, absorbed by the skin, or injected that causes death in 50 percent of the test animals. Experiments studying the carcinogenicity of surfactants provided no indication of increased risk of cancer after oral ingestion.²⁷

Surfactants, however, do exhibit toxic effects toward aquatic organisms. Acute toxicity tests of LAS show that LC₅₀ values for aquatic organisms range from 3-10 mg/L for fish and 8-20 mg/L for daphnia. LC₅₀ is the concentration of a chemical in air or water which is expected to cause death in 50 percent of the test animals exposed to that air or water. The no-observable-effect-concentration for algae was determined to be 30-300 mg/L.²⁸

Builders and Chelators. Some of the commonly used builders can be particularly irritating to skin, eyes, mucous membranes, and the lungs. Tetrapotassium pyrophosphate, the primary ingredient in CMC's detergent formulation, and sodium tripolyphosphate (STPP) represent

The direct costs associated with the solvent degreasers include TCA consumption costs, energy costs, and the disposal of TCA hazardous waste. As presented in Table 11, TCA consumption costs equalled \$76,000; this cost is based on the 1990 TCA consumption estimate of 15,820 gal at a 1990 TCA cost of \$4.62/gal, which has been adjusted to 1991 equivalent dollars for comparison with the aqueous wash system. Also in 1990, an estimated 10,600 gal of TCA hazardous waste were disposed of off-site at a cost of \$1.84/gal, or a 1991 equivalent cost of \$20,300. Energy requirements for each of the five vapor degreasers includes four reservoir heaters and a motor which moves the soiled part into and out of the cleaning zone. The total energy requirement for these electrical units was estimated to be 156 kW-hr/hr (599,404 kW-hr/yr), or \$20,970 equivalent 1991 dollars. These figures represent a yearly direct cost for the radiator solvent degreasers of \$117,270.

The aqueous wash system, though eliminating the use and hazardous waste disposal of TCA, has associated with it other direct costs. These include the consumption costs of detergent, water, and energy. Detergent consumption in 1992 was approximately 11 gal/d (2,640 gal/yr) at a cost of \$7.70/gal, or \$20,330. Water consumption by the aqueous wash system is approximately 8,400 gal/d (2,016,000 gal/yr) at an annual cost of \$2,700 (a \$0.00134/gal surcharge is levied by Shelbyville for water use and disposal to the city's POTW). Energy requirements of the aqueous wash system include three pumps and a natural gas heater. The pumps agitate the water and detergent reservoirs, as well as spray the radiator cores passing through the unit; the natural gas heater heats the detergent reservoir. These direct costs total \$62,400.

Though the wastewater treatment costs would traditionally represent an overhead cost and thus be excluded from this analysis, it is included here to compare waste disposal costs for each process scenario. The treatment of the aqueous wash waste stream required the use of treatment chemicals and process units which consume energy. The treatment chemicals include acid and lime to shock the detergent bath, and sulfuric acid, sodium hydroxide, and polymer to treat the full waste stream. The cost of an acid or base solution is approximately \$1.35/gal, and the cost of lime is approximately \$0.09/lb. Process units which consume energy within the wastewater pretreatment train include acid, base, and polymer addition pumps, circulation pumps within each treatment basin, and the sludge plate-and-frame press. The total energy requirement for these units was determined to be insignificant. The flow rate of 8,400 gal/d from the radiator line's aqueous system represents approximately one-third of the wastewater flow of CMC's treatment facility. Therefore, for the purposes of this analysis, one-third of the costs accrued by treating this waste stream are associated with this alternative process. Adjusting these costs to represent the fraction of the waste stream represented by the aqueous wash wastewater establishes a yearly chemical cost of \$10,800.

In addition to the raw materials costs associated with the aqueous wash system, the disposal of the nonhazardous, oily waste stream and the wastewater solids waste stream represent other costs associated with the alternative system. The generation rate of the oily waste stream was approximately 1,320 gal/yr. Disposal costs for this material to an off-site nonhazardous fuel-blending facility is approximately \$840.00/yr (\$0.64/gal). Wastewater treatment solids generation is approximately 11,880 gal/yr (adjusted to represent 30 percent), creating a \$3,220/yr disposal costs (\$0.27/gal). As previously stated, the assumption that the aqueous wash wastewater contributes one-third of the wastewater solids may not reflect the true influence of the system on wastewater treatment solids generation, but the information to establish a direct relationship was not available.

The detergent used by CMC is 20 percent builder (tetrapotassium pyrophosphate), and less than 5 percent each of ethoxylated alcohol surfactant and chelator. In addition, the detergent is diluted during use to a ratio of 1 part detergent to 54 parts water. The addition of detergent to the cleaning bath could involve possible dermal exposure, but standard operating procedures would minimize this potential. Pretreatment at CMC of aqueous wastewaters further dilutes detergent constituents to nearly 1 part detergent to 830 parts water. Furthermore, pretreatment and biological treatment at Shelbyville's POTW have the capabilities to destroy most of the detergents constituents prior to release to surface waters (the treatability of detergent constituents are discussed further in the National Environmental Impact Evaluation of Chapter 7). Potential direct releases of untreated wastewaters are possible if the POTW's design and/or treatment capacities are exceeded. Once discharged to surface waters, exposure would primarily be limited to dermal contact and incidental ingestion of contaminated waters.

Volatile Organic Compounds. VOC emissions from the flash drying of the evaporative lubricant represent the only environmental release or transfer from the condenser manufacturing line (concerning parts cleaning). Therefore, the primary pathway for exposure is inhalation of VOCs in air.

Risk

Risk is defined as the probability of injury, disease, or death under specific circumstances. In the context of this report, risk is a qualitative expression of the likelihood of adverse health or environmental effects considering both toxicity and potential exposure. Definitive conclusions of risk require experience in human health and environmental risk assessment. Furthermore, peer-review of the completed risk characterization is recommended. The discussion below only presents the most basic conclusions.

Air releases of TCA and VOC from the solvent degreaser and evaporative lubricants, respectively, represent the most significant direct exposure to workers and the environment. All other releases, if properly managed, are contained prior to treatment and disposal. TCA recycling and fuel blending of waste oils minimize the potential for contamination of soils and groundwater; pretreatment and municipal wastewater treatment of effluent waters from the aqueous wash system greatly minimizes the potential for aquatic organism exposure and contamination. The solids from the wastewater pretreatment facility are relatively inert, and when disposed of in a properly designed and maintained landfill, the potential for environmental and human exposure is low. These comparisons are summarized in Table 9.

TABLE 13. COMPARISON OF CAPITAL COSTS FOR THE SOLVENT DEGREASING AND EVAPORATIVE LUBRICANT SYSTEMS		
Cost	Solvent Degreasing Units (1993 ^b \$)	Evaporative Lube System (1993 \$)
Equipment/Materials	\$64,900	\$22,000
Installation ^a	\$5,400	\$880
Instrumentation ^a	\$27,000	\$17,600
Plant Engineering ^a	\$10,800	\$3,520
TOTAL	\$108,100	\$44,000

a Costs were provided by CMC as a percentage of equipment cost and converted into dollars in this table.

b 1984 capital investment dollars were converted to equivalent 1993 dollars used the following equation:
 $(\text{future value}) = (\text{present value}) \times (1 + i)^n$, with i = inflation rate = four percent, and n = years = (1993 - 1984).

The analysis used to compare the direct costs of these systems will again consider only the capital costs of the flash driers. It is assumed that the cost of the solvent degreasers were fully depreciated by 1992, and the salvage value of the units is insignificant. This analysis will include costs of raw materials, waste disposal, and energy for both systems. This information is summarized in Table 14, and discussed below.

The direct costs associated with the condenser line include raw materials costs (TCA and lubricant), energy costs, and the costs of waste management (hazardous waste disposal and VOC emission permit fees). Within the Environmental Evaluation of Chapter 5, the 1992 rates of TCA consumption and disposal for the condenser line were estimated to be 11,200 gal (121,500 lb), and 7,000 gal (75,400 lb), respectively. The cost of virgin TCA in 1992 increased from the 1990 value of \$4.62/gal to \$6.60/gal. The cost of TCA hazardous waste disposal did not change from the 1990 figure of \$1.84/gal.

again eliminated. Air releases decreased substantially, suggesting less potential employee exposure. Complete data on the toxicity of the VOCs emitted by the flash drying of the evaporative lube, however, are not available. This is one reason given by CMC for their interest in a water-based synthetic lubricant which can remain on the fin for subsequent processing (fluxing and brazing).

Energy costs are the final operating and maintenance costs included in the traditional analysis of the condenser manufacturing line. As with the radiator line, labor and supervisory costs will be omitted; there are no differences in direct labor requirements between the old and new processes and the activity-based accounting method will account for those costs. The unique energy requirements for the solvent degreasers are the heaters for each reservoir. The flash driers of the evaporative lube system are the unique units for the alternative system which require energy. These rates of energy consumption and costs are presented in Table 14.

Finally, as stated in the Environmental Evaluation of Chapter 5, the evaporative lubricant system generates a VOC air emission. Yearly emissions reporting and fees are a result of this air release. Yearly emission fees, based on quantities emitted, were \$4.00/ton emitted for 1994. Therefore, the use of evaporative oil on the condenser line resulted in a fee of approximately \$24.00 in 1994. Calsonic's total VOC emissions fee for 1994 was approximately \$140. Until 1994, CMC was considered a large quantity hazardous waste generator by the EPA. As such, CMC paid a \$900 fee each year. The elimination of the solvent degreasers from the condenser manufacturing process, in conjunction with the accomplishments of the radiator and other manufacturing lines, changed CMC's status from a large quantity to a small quantity hazardous waste generator, and therefore eliminated this yearly fee.

The return on investment and net present values of these direct costs are presented in Table 15. Both economic analyses strongly support the investment into the evaporative lubricant system. The return on investment would be experienced within the first year of evaporative lubricant operation. This conclusion is consistent with the 0.3 year return of investment reported by CMC for the implementation of this alternative system. For comparison, the 5-year NPV is also presented in Table 15. The cost to continue the operation of the solvent degreasing system, based solely on direct costs, is substantially greater than the costs accrued by the operation of the evaporative lubricant system.

TABLE 15. RETURN ON INVESTMENT AND COMPARISON OF NET PRESENT VALUES - CONDENSER		
Analysis	Solvent System	Evaporative Lubricant System
Payback		0.45 years
NPV (5-year)	\$619,750	\$99,930

- Notes:
1. i = interest rate per interest period = four percent.
 2. the capital investment of the aqueous wash system was depreciated (straight-line) over seven years.
 3. assumptions: inflation rate of zero and equal costs per year.
 4. dollar values represent costs.

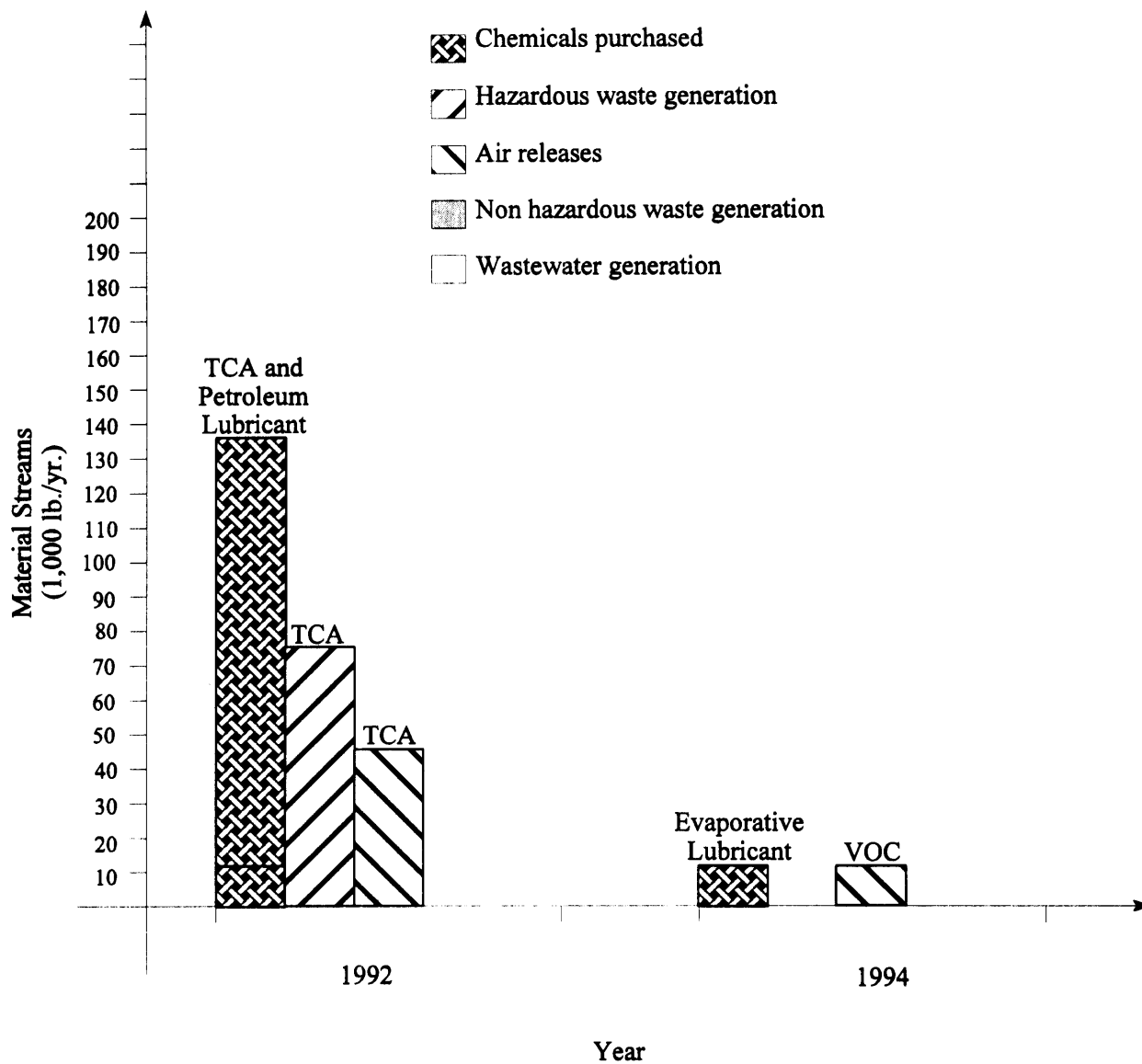


FIGURE 11. SUMMARY OF CONDENSER LINE EMISSIONS OVER TIME

BOAs were developed from a knowledge of CMC's process lines, and revised during a two-day site visit. During this site visit, three researchers observed the various steps of each process; one process line was observed per day. Observations included standard core assembly procedures, maintaining the supply of materials, product testing procedures, and some basic support activities. Activities were recorded for every step of the manufacturing process, with particular detail given the cleaning (or lack thereof) step. To record activities which may not have been observed (e.g., those that occur intermittently), line personnel and supervisors were extensively interviewed during the observation period, and at the end of each day. Interviews were also used to develop BOAs for the nonexistent solvent degreasing processes.

The analysis of this information began by comparing the old, solvent degreasing activities with those of the new, alternative processes. Differences between the old and new activities were drawn from each BOA and recorded for further analysis. Examples of differing activities would be activities that were eliminated by the implementation of the alternative processes, or additional activities that were a result of the new processes. Frequencies and durations, also identified during the site visit, as well as the cost drivers for each activity, were then added to each BOA. Table 16, below, summarizes the cost drivers used in the analysis and explains the costs included in each. ABC analysis of each manufacturing line was accomplished following these procedures. The BOAs, cost drivers, and results of the analyses are presented in the sections that follow.

TABLE 16. COST DRIVERS FOR THE PRIMARY ACTIVITIES	
Cost Driver	Explanation of Included Costs
\$/labor hr	labor costs to perform a task
\$/machine hr	operating costs of a process unit, including utilities
\$/receipt	labor costs to perform a task, and the cost of equipment utilized
\$/order	costs include person hours to follow and fulfill paperwork requirements (purchasing, accounting, manufacturing, inventory, supervisory, management)
\$/core	labor costs to perform a task, and the cost of the equipment utilized

ABC Analysis of the Radiator Manufacturing Line

Table 17 presents the primary activities which differ between the old, solvent degreasing units and the new, aqueous wash system for the radiator line. Also presented in this table are the cost drivers used to evaluate activity-based costs. A list of supporting activities for each of these primary activities are presented in Appendix G. The frequency and duration of these activities are not given in these tables, or in the appendices, to maintain confidentiality of CMC proprietary information.

accurate are the final analyses. As a result, the conclusions and decisions which are made from the final analyses are more accurate.

TABLE 10. EPA'S EXPANDED COST INVENTORY	
Tier	Included Costs
Tier 0	direct costs including raw materials, waste disposal, operating and maintenance
Tier 1	hidden costs such as monitoring expenses, reporting, records keeping, and permit requirements
Tier 2	future liability costs
Tier 3	less tangible cost such as consumer response, employee relations, and corporate image

Many industry accounting practices focus primarily on the direct costs to evaluate capital budgeting projects. These data, included in the analysis of most financial statements, are readily available, and interpretation is simplified due to familiarity. Unfortunately, this practice may not accurately assess the costs and benefits of pollution prevention projects. When applied in a cash flow analysis (e.g., net present value, internal rate of return, etc.), the inaccuracies of these cost assessments are compounded, and the benefits of pollution prevention projects are lost. As a result, many pollution prevention projects are not funded. ABC attempts to solve this limitation of traditional analysis by identifying and evaluating additional costs and benefits (Tier 1). The results of both analyses are presented in this chapter. The results of the traditional cost analyses, below, will be followed by a discussion of ABC, the results of the ABC analyses, and final analyses that combines the two accounting methods into a hybrid system.

TRADITIONAL COST EVALUATIONS

Cost analyses performed by businesses for capital budgeting purposes traditionally include those costs identified in Tier 0 of Table 10: capital expenditures, operation and maintenance costs, and expenses or revenues from raw materials, waste disposal, energy, and recovered materials.³⁴ Therefore, for the analyses of CMC's processes, the following data were used.

It was assumed that the capital costs of the original solvent degreasing units were completely depreciated at the time of replacement. Therefore, the only capital costs included in the analyses are those for the alternative processes. Considering the age of the radiator line degreasers (installed in 1983) and condenser line degreasers (installed in 1984), this assumption is valid; depreciation is typically based on a 7-year schedule for industrial equipment. The salvage value of these units were also omitted from the traditional cost analysis; this is consistent with the experience of CMC, who scrapped the obsolete solvent

TABLE 18. DETAILED EXAMPLE OF THE SUPPORTING ACTIVITIES FOR THE ASSEMBLY AND CLEANING OF RADIATOR CORES	
Old, Solvent Degreasing Process	New, Aqueous Wash Process
assemble core	assemble core
turn and place core in solvent degreaser	place core on wheeled cart
close degreaser door	repeat activities above
push button to begin degreasing process	wheel full cart (40 cores) to cleaning, fluxing, and brazing conveyORIZED line
turn and begin assembling a second core	remove cores, one by one, and place on conveyor for cleaning, fluxing, and brazing
open degreaser door	
remove cleaned core and place on wheeled cart	
place newly assembled core into degreaser	
repeat activities above	
wheel full cart (40 cores) to flux and brazing conveyORIZED line	
remove cores, one by one, and place on conveyor for fluxing and brazing	

The number of steps required for the assembly and cleaning of a radiator core under the process scenario of the solvent degreasing system, as presented in this table, are greater than the number of steps needed to accomplish the same goal under the aqueous wash scenario. The inclusion of the aqueous cleaning system into the conveyORIZED line of fluxing and brazing, not only simplified the responsibilities of the assembly personnel, but also eliminated a core transfer step (from assembly to degreaser, and from degreaser to wheeled cart). This simplification also shortened the time required to assemble and clean a radiator core. As presented in the Technical Evaluation of Chapter 4, core cleaning time has been reduced by 50 percent by the implementation of the aqueous wash system. These activity and time variations are essential to the results of ABC, and will be discussed for each primary activity within the ABC economic evaluation.

ABC analysis is completed when the bill of differing activities are combined with the appropriate cost drivers to calculate a cost of activities. The ABC analyses for the solvent degreasing and aqueous wash processes are presented in Table 19. As can be seen in this summary of results, the changes in activities due to the implementation of the aqueous wash system result in significant activity-based cost savings. The frequency at which activities

TABLE 11. TRADITIONAL COST ANALYSIS OF THE RADIATOR MANUFACTURING LINE				
Cost Category			Solvent Degreasers	Aqueous Wash
Capital Investment			0	\$463,594 (1991)
Annual Costs	quantity/yr	\$/quantity	\$/yr (1991 ^b)	\$/yr (1991)
Depreciation of Capital				\$66,230 ^a
Raw Materials				
TCA	15,820 gal	\$4.62/gal	\$76,000	0
Detergent	2,640 gal	\$7.70/gal	0	\$20,330
Water	2,000,000 gal	\$0.00134/gal	0	\$2,700
Wastewater Chemicals	See footnote c		0	\$10,800
Energy Requirements				
Electricity		\$0.035/kW-hr	\$20,970	\$11,290
Natural Gas	7,800,000 SCF	\$3.60/SCF	0	\$28,080
Waste Management				
TCA Disposal	10,600 gal	\$1.84/gal	\$20,300	0
Wastewater Treatment				
Solids Disposal ^d	11,880 gal	\$0.27/gal	0	\$3,220
Oily Waste Disposal	1,320 gal	\$0.64/gal	0	\$840
TOTAL (\$/yr)			\$117,270	\$143,490

a The capital investment of the aqueous wash system is depreciated over seven (7) years using a straight-line method. The yearly depreciation cost of the aqueous wash system is therefore; \$463,594/7 years = \$66,230.

b Values from 1990 were brought to equivalent dollars (1991) using a 4 percent interest rate.

c The cost of wastewater chemicals includes 30 percent of the sulfuric acid, sodium hydroxide, and polymer used to treat the full water waste stream, as well as 100 percent of the costs for the acid and lime required for detergent bath shocking.

d Wastewater solids disposal costs represent 30 percent of the total generation rate of wastewater solids.

on-line. Other employees included in these maintenance activities include two or three line personnel. The aqueous wash system, for the past two years of operation, has had zero down time due to maintenance problems. Scheduled yearly maintenance of the degreasers was also more time consuming and labor intensive when compared to the new, aqueous wash system. Therefore, an additional savings of \$84,500 can be attributed to the aqueous wash system due to reduced maintenance.

The activities associated with aqueous wash wastewater treatment were the only significant additional activities resulting from the implementation of the alternative cleaning method. The treatment of this wastewater resulted in activity-based costs of \$23,600. This is an additional cost that must be attributed to the new system.

ABC Analysis of the Condenser Manufacturing Line

Tables 20 presents the primary activities which differ between the old, solvent degreasing systems and the new, evaporative lubricant alternative for the condenser line. The activity of these processes are quite different and unique. The implementation of the alternative system eliminated a number of activities associated solely with the degreasing process. Also presented in Table 20 are the costs drivers used to evaluate the costs of each activity.

The ABC economic evaluation of the condenser line activities are presented in Table 21. A savings of \$62,150/yr was calculated based on activity-based costing due to the implementation of the evaporative lubricant system. The contributions to this savings by the primary activities are discussed below

TABLE 20. PRIMARY ACTIVITIES UNIQUE TO THE SOLVENT DEGREASING AND EVAPORATIVE LUBE SYSTEMS OF THE CONDENSER LINE			
Solvent Degreasing System		Evaporative Lube System	
Primary Activities	Cost Drivers	Primary Activities	Cost Drivers
paperwork for ordering and receiving TCA	\$/order	maintaining flash driers	\$/labor hr
receipt of TCA	\$/receipt	permitting and monitoring of VOC emissions	\$/labor hr and fees
maintaining solvent degreasing units - daily	\$/labor hr		
maintaining solvent degreasing units - yearly	\$/labor hr		
permitting and monitoring of hazardous waste generation facility	\$/labor hr and fees		

The direct cost analysis, as presented in Table 12, does not support the investment into the aqueous wash system to replace the solvent degreasing system using typical industrial time horizons and if cost is the only factor influencing the decision. Though the raw materials and waste disposal costs of the alternative system are significantly less than comparable costs for the solvent degreasing system, the \$463,594 capital investment costs, depreciated over seven years, overshadow these benefits. The return on investment was determined to be 11.6 years. The use of a 5-year time horizon, typical of most industrial capital investment analyses, supports the continued operation of the solvent system. As shown in Table 12, the solvent degreasing system has a 5-year net present value (hereafter referred to as NPV) which is \$147,700 better in relation to the NPV of the aqueous wash system. Only when the full cost of the aqueous wash capital investment is depreciated are the benefits of the alternative financially observed. This is also shown in Table 12 where the aqueous wash system is \$294,160 better in relation to the solvent system when a 15-year NPV calculation is used.

TABLE 12. RETURN ON INVESTMENT AND COMPARISON OF NET PRESENT VALUES - RADIATOR		
Analysis	Solvent System	Aqueous Wash System
Payback		11.6 years
NPV (5-year)	\$660,580	\$808,280
NPV (10-year)	\$1,464,270	\$1,508,720
NPV (15-year)	\$2,442,090	\$2,147,930

- Notes:
1. i = interest rate per interest period = four percent.
 2. the capital investment of the aqueous wash system was depreciated (straight-line) over seven years.
 3. assumptions: inflation rate of zero and equal costs per year.
 4. dollar values represent costs.

Traditional Cost Evaluation of the Condenser Manufacturing Line

The two solvent degreasers of the condenser manufacturing line were made obsolete with the implementation of the evaporative lubricant system. The installation of the flash driers represents the capital expenditure required to eliminate the solvent units and implement the alternative system. Capital costs for both the solvent degreasing units and the evaporative lubricant flash driers were available. As a point of comparison, these costs are presented in Table 13; the cost for the solvent system is presented in 1993 equivalent-year dollars, the year the flash driers were installed. As shown by these values, solvent degreasing systems require a significantly greater capital expenditure (more than twice as much for this particular example) than do the flash driers utilized in evaporative lubricant system.

**TABLE 22. COMPARISON OF OPERATING AND MAINTENANCE COSTS -
CMC ESTIMATES VERSUS ABC RESULTS**

Process	CMC Estimate ^a (\$/yr)	ABC Results (\$/yr)
Solvent Degreasers	\$5,620	\$37,400
Evaporative Lubricant	\$660	\$1,250

a Estimates base on multiplication factors of capital investment costs.

HYBRID ACCOUNTING SYSTEM

Combining the traditional, direct cost economic analyses with the expanded cost analyses of ABC will more accurately represent the costs and benefits of the alternative processes implemented by CMC. As previously stated, the analysis of direct costs, as performed in traditional cost analyses, does not capture the benefits and costs hidden in overhead expenses. The application of ABC was the analytical tool used to allocate unique overhead costs to the appropriate processes and products. A hybrid of these analysis methods will more fully capture the costs and savings of pollution prevention projects. The hybrid analyses for the radiator and condenser manufacturing lines are presented in the following sections.

Hybrid Analysis for the Radiator Manufacturing Line

The traditional economic analysis for the process changes of the radiator manufacturing line did not support CMC's investment into the aqueous wash system if cost is the only factor considered. Over a five-year time horizon the solvent system would have been less expensive to operate. However, by accounting for the overhead costs through ABC, the economic incentives of the aqueous wash system are revealed. The traditional cost system did not account for the administrative cost savings due to less raw materials being received, less operating and maintenance costs, and simplified permitting and reporting requirements associated with the aqueous wash system when compared to the solvent degreasing system. The hybrid analysis is presented in Table 23. The payback and NPV calculations utilizing the values of Table 23 are presented in Table 24. Also included in this table, for comparison, are similar results from the traditional analysis.

Hybrid Analysis for the Condenser Manufacturing Line

The investment into the flash driers required for the evaporative lubricant system was supported by the traditional analysis. The \$44,000 capital investment, and the increased cost of the evaporative lubricant, were off-set by the savings attributed to the elimination of TCA purchase and disposal costs. The application of ABC to this system, however, further accentuates the benefits of the alternative system by allocating unique overhead costs to the

**TABLE 14. TRADITIONAL COST ANALYSIS OF THE CONDENSER
MANUFACTURING LINE**

Cost Category			Solvent Degreasers	Evap. Lube
Capital Investment			0	\$44,000 (1993)
Annual Costs	quantity/yr	\$/quantity	\$/yr (1994 ^b)	\$/yr (1994)
Depreciation of Capital				\$6,286 ^a
Raw Materials				
TCA	11,200 gal	\$6.60/gal	\$80,040	0
Petro. Lubricant	480 gal	\$5.20/gal	\$2,700	0
Evap. Lubricant	480 gal	\$9.84/gal	0	\$4,720
Energy Requirements				
Electricity		\$0.035/kW-hr	\$12,580	\$6,710
Waste Management				
TCA Disposal	7,000 gal	\$1.84/gal	\$13,800	0
Permits and Fees			\$900	
VOC Emissions	12,200 lb	\$4.00/ton	0	\$24
TOTAL (\$/yr)			\$110,020	\$17,740

a The capital investment of the evaporative lubricant system (flash driers) is depreciated over seven (7) years using a straight-line method. The yearly depreciation costs of the flash driers is therefore; \$44,000/7 years = \$6,286.

b Values from 1992 were brought to equivalent 1994 dollars using a four percent inflation rate.

The rates of lubricant consumption for the old, petroleum-based lubricant and the new, evaporative lubricant are identical, 480 gal/yr. However, the rate of consumption and cost of each lubricant are included in Table 14 due to the difference in lubricant costs. The petroleum-based lubricant, at a cost of \$5.20/gal, generates a consumption cost of \$2,500/yr; the evaporative lubricant, at a cost of \$9.84/gal, creates a consumption cost of \$4,720/yr. This cost difference must be accounted for in this direct cost analysis.

TABLE 25. HYBRID COST ANALYSIS OF THE PROCESS CHANGES TO THE CONDENSER MANUFACTURING LINE		
Cost Categories	Solvent Degreasing System (\$/yr)	Evaporative Lubricant System (\$/yr)
Annualized Capital Investment	0	\$6,290 ^a
Raw Materials	\$82,740	\$4,720
Energy Requirements	\$12,580	\$6,710
Waste Management	\$14,700	\$24
ABC Costs	\$83,400	\$21,250
TOTAL	\$193,420/yr	\$38,994/yr

a The annualized capital cost is based on a 7-year, straight-line depreciation schedule.

TABLE 26. COMPARISON OF HYBRID AND TRADITIONAL ANALYSES - CONDENSER MANUFACTURING LINE				
Analysis	Hybrid Analysis		Traditional, Direct Cost Analysis	
	Solvent System	Evaporative Oil System	Solvent System	Evaporative Oil System
Payback		0.27 years		0.45 years
NPV (5-year)	\$1,089,550	\$219,660	\$619,750	\$99,930

- Notes:
1. i = interest rate per interest period = four percent.
 2. the capital investment of the aqueous wash system was depreciated (straight-line) over seven years.
 3. assumptions: inflation rate of zero and equal costs per year.
 4. dollar values represent costs

Traditional economic evaluations such as that presented above utilize categories of cost that are fairly easy to identify and which are readily available from most financial accounting systems. These cost categories include capital investments, direct materials, direct labor, and waste disposal costs. Overhead costs, which can represent a significant portion of an industry's costs, are typically ignored, or allocated to processes or products using an arbitrary and easily measured parameters such as labor hours or machine hours. This approach for economic analyses has limitations when evaluating pollution prevention projects. Many of the economic benefits of pollution prevention projects occur in reduced overhead expenses, and arbitrarily distributing these costs may not reflect the true benefits of a pollution prevention project. Even though each of the analyses above seem to support the implementation of the alternatives, the full benefits of the new systems were not identified and accounted for. If the traditional cost analysis of the old and new processes were much closer, the additional benefits/costs associated with a pollution prevention project could have been the pivotal set of data to support the investment in the alternatives. For this reason, the basic economic evaluation presented above is supplemented by an activity-based cost analysis. A definition of ABC, a description of the approach taken for this project, and the results of the analysis are presented below.

ACTIVITY-BASED COST ACCOUNTING

The analysis of direct costs, presented above, is traditionally used by industry to evaluate capital budgeting projects. As previously stated, however, this analysis of direct costs may not capture all the benefits of a project, specifically pollution prevention projects such as the alternatives implemented by CMC. A system to define and allocate the costs and benefits of Tiers 1, 2 and 3 of Table 10, would more accurately represent the costs and benefits of such pollution prevention projects. ABC was the tool applied in this second economic analysis to allocate costs and benefits beyond Tier 0.

Simply stated, ABC allocates overhead costs to products or processes based on the activities which result from the production of the product or the operation of the process. Overhead costs (denoted indirect costs in Tier 1) include administrative costs, regulatory compliance costs, quality control costs, training, and workman's compensation. Associated with each overhead cost are indirect activities which support the production process. These activities can include supervision, materials handling, records keeping, permitting, monitoring, and product testing. The allocation of each indirect activity to the product or process which creates it, will more accurately represent the costs and benefits of the alternative systems. Once allocated, the frequency, duration, and cost driver of each activity is determined. Cost drivers, the key to ABC, are systematic linkages between activities and costs. These procedures, as they apply to this project, are presented below.

ABC Analysis of CMC

The approach taken in this project for ABC began with a clear understanding of the various steps associated with the process lines of interest. To develop this clear understanding of all the steps in the manufacturing process of a radiator or condenser, a bill of activities (BOA) for each process line (radiator and condenser, old and new) was developed. The

CHEMICAL PRODUCTION PROCESSES

The chemical production process is the first stage of the life-cycle evaluated for this research. The production processes for the chlorinated degreasing solvents and components of industrial detergents result in chemical emissions to the environment. Portions of these emissions must be attributed to the industrial processes which utilize the chemical products (i.e. solvent degreasers or detergents) when life-cycle principals are applied. Therefore, the following sections evaluate the environmental releases and transfers from the chemical production processes of degreasing solvents and detergent components. The fraction of these emissions which may be attributed to their use in parts cleaning, or alternatives to parts cleaning, is also assessed.

Production of Chlorinated Solvents

There are a variety of processes utilized to produce the chlorinated degreasing solvents. Many of these chemicals are co-produced with other 33/50 chlorinated organics. The chemical processes include the following:

1. DCM is predominantly produced through the hydrochlorination of methanol (co-produced with chloroform and carbon tetrachloride). Raw materials include hydrogen chloride and methanol.³⁷
2. PCE is produced either by the hydrocarbon chlorinolysis (60 percent) or oxychlorination of ethylene dichloride (40 percent) processes. Feed stocks for the chlorinolysis process include propane, propylene, acetylene, naphthalene, ethylene dichloride, crude chloroform, and chlorine gas. Oxychlorination feeds include ethylene dichloride, chlorine gas, and oxygen. TCE is a co-product of the oxychlorination process.³⁸
3. The production of TCE (co-produced with PCE) is accomplished using the chlorination of ethylene dichloride. Ethylene is the primary feed with chlorine gas, which reacts through the chlorination process to form ethylene dichloride. Ethylene dichloride is further chlorinated to produce TCE.³⁹
4. The most widely used process for producing TCA involves the dehydrochlorination of ethylene dichloride to vinyl chloride, which is then hydrochlorinated to 1,1-dichloroethane. The 1,1-dichloroethane is thermally or photochemically chlorinated to produce TCA. In another important process, hydrogen chloride is added to 1,1-dichloroethylene in the presence of an iron chloride catalyst to produce TCA.⁴⁰ Figure 12 shows the life-cycle flow diagram for TCA which traces the process for manufacturing TCA back to raw materials.⁴¹

TABLE 17. PRIMARY ACTIVITIES UNIQUE TO THE SOLVENT DEGREASING AND AQUEOUS WASH SYSTEMS OF THE RADIATOR LINE			
Solvent Degreasing System		Aqueous Wash System	
Primary Activities	Cost Drivers	Primary Activities	Cost Drivers
paperwork for ordering and receiving TCA	\$/order	paperwork for ordering and receiving detergent	\$/order
receipt of TCA	\$/receipt	receipt of detergent	\$/receipt
assembly and cleaning of radiator cores	\$/core	assembly and cleaning of radiator cores	\$/core
maintaining solvent degreasing units - daily	\$/labor hr	maintaining aqueous wash system - daily	\$/labor hr
maintaining solvent degreasing units - yearly	\$/labor hr	maintaining aqueous wash system - yearly	\$/labor hr
leak testing	\$/core	leak testing	\$/core
permitting and monitoring of hazardous waste generation facility	\$/labor hr and fees	wastewater treatment activities	\$/labor hr
		permitting and monitoring of wastewater treatment facility	\$/labor hr and fees

As can be seen in this table, there are similar activities between the solvent degreasing and aqueous wash processes. These similarities include ordering and receiving raw materials, assembling and cleaning radiator cores, and leak testing of the completed cores. Though the definition of these primary activities are identical, the supporting activities, frequency, and time required for each activity vary. An example of such variations is presented in Table 18, in which a portion of the full BOA for the assembly and cleaning steps is presented for the old and new processes of the radiator line. An explanation of the differences follows the table.

Emissions of the chlorinated solvents from production processes can originate from the intermittent or continuous purging of inert gases from reactor vessels, drying beds, finishing columns, and other process vessels. Fugitive air emissions can result when process fluids leak from plant equipment such as pumps, compressors, and process valves. Air emissions from storage and handling operations also occur at production facilities. Other sources of environmental releases or transfers include the following:

- wastewater discharges directly from the plant into rivers, streams or other bodies of water, or transfers to a POTW;
- on-site release to landfills, surface impoundments, land treatment, or other modes of land disposal;
- disposal of wastes by deep well injection; and
- transfers of wastes to off-site facilities for treatment, storage or disposal.

In 1992 there were four major companies at six locations within the U.S. that produced the chlorinated degreasing solvents. Table 27 lists these producers, their products, and their annual production capacity. The environmental releases and transfers of the chlorinated degreasing solvents from these producers were retrieved from the 1992 TRI. These data are presented in Table 28. Many of the facilities reported multiple SIC codes under TRI, indicating the data may include releases and transfers from internal use of the chemicals after production.

The six chlorinated solvent production facilities released or transferred nearly 1.3 million pounds of chlorinated solvents in 1992. On-site air releases represent the vast majority of these production releases and transfers, nearly 94 percent. Off-site transfers, mainly to facilities other than POTWs, represent only 2.2 percent of all production emissions.

Not only are releases and transfers a result of the production of the degreasing solvents, but also of their distribution. Almost all of the DCM and TCE sold, and approximately 70 to 75 percent of the PCE sold, are distributed through distribution facilities.⁴² No information was available on the amount of TCA distributed through these facilities or the amount of TCA emissions from distribution facilities. Distribution facilities are not required to report their emissions in TRI. However, using the concepts of life-cycle assessment, some of the halogenated organic emissions from distribution facilities should be associated with their distribution to degreasing facilities.

In 1992, solvent degreasers consumed approximately 36 percent of chlorinated degreasing solvents produced in the U.S. The rate of consumption for each solvent in degreasing applications is presented in Table 29. These values are based on the demand figures of Table 27 and the chemical use tree diagram, Figure 1 of Chapter 1. When considering environmental impacts from a life-cycle perspective, some fraction of the production releases and transfers presented above must be associated with their use in solvent degreasing. Designating which emissions from the production facilities were a result of manufacturing a specific solvent is not possible from the data of Table 28. However, direct application of the average solvent consumption fraction for degreasing (36 percent), to the total TRI production releases establishes that over 460,000 lb/yr of the chlorinated degreasing solvents emitted by their production may be attributed to solvent degreasing.

occurred, as well as the elimination of very costly activities (i.e., machine and labor intensive activities), contribute to these savings. The alternative cleaning system eliminated many activities and added very few. An ABC-savings of \$215,770/yr was calculated due to the implementation of the aqueous wash system. The contributions from each group of activities is discussed below.

TABLE 19. SUMMARY OF ABC RESULTS FOR THE RADIATOR MANUFACTURING LINE		
Primary Activities	Costs (\$/yr) of Solvent Degreasing Process	Costs (\$/yr) of Aqueous Wash Process
paperwork for ordering and receiving	\$5,000	\$2,500
receipt of materials	\$7,000	\$3,500
assembly and cleaning	\$175,300	\$58,430
maintenance - daily	\$87,500	\$5,400
maintenance - yearly	\$32,300	\$29,900
wastewater treatment	0	\$23,600
permitting and fees (labor)	\$34,000	\$2,000
TOTAL	\$341,100	\$125,330
SAVINGS	-	\$215,770

The number of materials received for each process remained the same; the elimination of TCA resulted in the need for a detergent product. However, the frequency of receipt and the quantity of chemicals required to maintain the aqueous wash system decreased significantly when compared to the solvent degreasing system. Thus, a \$6,000 savings was attributed to the aqueous wash system based solely on the activities (direct and supporting) to maintain the materials inventory (including paperwork and receipt).

As stated in the Technical Evaluation of Chapter 4, the solvent degreasing process represented the bottle-neck of the radiator manufacturing line. Time requirements to clean each core have been reduced by the aqueous wash system by 50 percent. The activities associated with the cleaning process, however, have been reduced by two-thirds and represents a cost savings based on employee time and equipment operation. Accounting for these costs result in a \$116,870 activity-based cost saving for the aqueous system (or cost to the solvent system). Also stated in the technical evaluation, and identified in Table 19, are the considerable differences of process maintenance. The solvent degreasers were down due to maintenance problems nearly five percent of the time. During these down times, the line supervisor, lead, and technician spent their entire time trying to get the degreasers back

**TABLE 28. TRI RELEASES AND TRANSFERS OF CHLORINATED DEGRASING SOLVENTS
FROM PRODUCTION FACILITIES**

Producer	Releases and Transfers (lb/yr)						
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Total Off-Site Transfers
Dow Chemical, Freeport, TX							
PCE	40,000	0	0	0	40,000	0	15,623
DCM	230,000	0	100	0	230,100	0	170
TCE	39,000	0	0	0	39,000	0	No Data
TCA	186,000	0	14	0	186,014	0	No Data
Dow Chemical, Plaquemine, LA							
TCE	609	11	0	0	620	0	No Data
DCM	29,000	24	0	0	29,024	0	No Data
TCA	12,300	4	0	0	12,304	0	No Data
PCE	20,950	400	126	0	21,476	0	No Data
Occidental Petroleum, Belle, WV							
PCE	0	0	0	0	0	0	0
TCE	0	0	0	0	0	0	0
TCA	0	0	0	0	0	0	0
DCM	68,680	517	0	0	69,197	1	521

(continued)

TABLE 21. SUMMARY OF ABC RESULTS FOR THE CONDENSER MANUFACTURING LINE		
Primary Activities	Costs (\$/yr) of Solvent Degreasing System	Costs (\$/yr) of Evaporative Lubricant System
paperwork for ordering and receiving	\$5,000	0
receipt of materials	\$7,000	0
maintenance - daily	\$31,800	\$750
maintenance - yearly	\$5,600	\$500
permitting and fees (labor)	\$34,000	\$20,000
TOTAL	\$83,400	\$21,250
SAVINGS	-	\$62,150

As presented above, the areas of activity change for the condenser line include materials receipt and maintenance. The elimination of the solvent degreasers eliminated the need to receive TCA on a regular basis. The substitution of one lubricant for another, with identical rates of use, does not change the materials receipt activities. Therefore, a savings of \$12,000 attributed to the new system due to the decreased materials receipt was identified. Standard maintenance of solvent degreasers added additional activities to the solvent degreasing systems that are not present in the new alternative system. The flash driers, added to the process to evaporate the new lubricant, require little to no maintenance. Therefore, the maintenance differences resulted in a \$36,150 savings for the new system.

The data table for the condenser manufacturing lines presented in Appendix A also include estimates for operating and maintenance costs for the parts cleaning units. These estimates are multiplication factors used by CMC based on the capital cost of the equipment. Table 22 presents these estimates and compares them with the results of Table 21. Maintenance labor for the solvent and evaporative oil systems were reported by CMC as a percentage of the capital costs of each unit: three percent for the solvent system and 0.5 percent for the evaporative oil system. Maintenance materials were also estimated by CMC as an estimate of capital costs: two percent for the solvent systems and one percent for the evaporative oil systems. A 1992 equivalent value for the solvent degreasing units was used to determine these costs. From the results presented in Table 22, it is apparent that standard accounting practices for determining maintenance costs based on capital expenses or other parameters do not accurately represent the true costs of a system. Estimates of the maintenance costs of the solvent degreasers were 6.7 times lower than the costs determined using ABC. The evaporative oil systems costs estimates using CMC's methodology was nearly half the costs established using ABC.

TABLE 29. CHLORINATED SOLVENT CONSUMPTION BY DEGREASING APPLICATIONS			
Solvent	Total 1992 Demand (million lb/yr)	Percentage Consumed in Degreasing	Annual Degreasing Consumption (million lb/yr)
DCM	390	11	42.9
TCA	600	49	294.0
TCE	145	90	130.5
PCE	250	13	32.5
TOTAL	1,385	36.1^a	499.9

a Weighted average calculated from total 1992 demand figures and annual consumption percentages of columns 2 and 4, respectively.

Production of Detergent Ingredients

Industrial detergents are mixtures of a variety of chemical components, the most significant of which are surfactants, builders, and chelators. The possible combinations of these components are huge when it is considered that there are over 500 anionic or nonionic surfactants commercially available, and 42 chelating chemicals.⁴³ For this reason, typical product ingredients were evaluated instead of specific product formulations. Included in the evaluation are the two specified ingredients of CMC's detergent: tetrapotassium pyrophosphate and an ethoxylated secondary alcohol. To cover the potential range, additional ingredients which represent a significant portion of the market are also evaluated. Production releases and transfers are evaluated for the manufacturing processes of these chemicals to determine the environmental impacts associated with the production of detergent ingredients.

Surfactants. Commercially available surfactants are not single-component products; rather, they are 'polydispersed mixtures of molecules which are all the same type (i.e. identical functional groups), but which vary only in chain length or in some other structural detail.'⁴⁴ Figure 13 shows the production routes for several of the major surfactant polydispersion mixtures.⁴⁵ The complexity of surfactant polydispersions makes it difficult to specifically identify an isolated chemical species to represent all surfactants. Therefore, the polydispersions evaluated in this report are alcohol ethoxylates, ethoxylated nonylphenol, and alkylbenzene sulfonates.

activities that create them. Table 25 presents the hybrid analysis for the condenser manufacturing line. Table 26 compares the payback and NPV calculations using the hybrid analyses of Table 25 to the results of the traditional analyses.

TABLE 23. HYBRID COST ANALYSIS OF THE PROCESS CHANGES TO THE RADIATOR MANUFACTURING LINE		
Cost Category	Solvent Degreasing System (\$/yr)	Aqueous Wash System (\$/yr)
Annualized Capital Investment	0	\$66,230 ^a
Raw Materials	\$76,000	\$33,830
Energy Requirements	\$20,970	\$39,370
Waste Management	\$20,300	\$4,060
ABC Costs	\$341,100	\$125,330
TOTAL	\$458,370/yr	\$268,820/yr

a The annualized capital cost is based on a 7-year, straight-line depreciation schedule.

TABLE 24. COMPARISON OF HYBRID AND TRADITIONAL ANALYSES - RADIATOR MANUFACTURING LINE				
	Hybrid Analysis		Traditional, Direct Cost Analysis	
Analysis	Solvent System	Aqueous Wash System	Solvent System	Aqueous Wash System
Payback		2.4 years		11.6 years
NPV (5-year)	\$2,584,150	\$1,514,260	\$660,580	\$808,280
NPV (10-year)	\$5,725,530	\$3,073,640	\$1,464,270	\$1,508,720
NPV (15-year)	\$9,547,510	\$4,762,870	\$2,442,090	\$2,147,930

- Notes:
1. i = interest rate per interest period = four percent.
 2. the capital investment of the aqueous wash system was depreciated (straight-line) over seven years.
 3. assumptions: inflation rate of zero and equal costs per year.
 4. dollar values represent costs.

Alcohol ethoxylates are the general class of surfactants which includes the secondary ethoxylated alcohol surfactant identified by CMC's detergent's Material Safety Data Sheet. Various sources identify ethoxylated nonylphenol as a primary nonionic industrial surfactant,^{46, 47} and discussions with the Specialty Chemicals Manufacturing Association identified linear alkylbenzene sulfonates (hereafter referred to as LAS) as an example of an anionic industrial surfactant.⁴⁸ Dodecylbenzene sulfonic acid will represent the general LAS class of industrial surfactants.

Ethoxylated Alcohols: Figure 13 shows that ethoxylated alcohols can use petroleum, natural gas, animal fat, or plant oils as primary raw materials. The ethoxylation of secondary alcohols with ethylene oxide is the manufacturing scheme for ethoxylated secondary alcohols. Ethylene oxide is manufactured by the oxidation of ethylene over a silver catalyst. The source of secondary alcohols is either natural gas, petroleum, or natural feed stocks. Primary alcohols react in the ethoxylation reaction more readily than do secondary and tertiary alcohols. The ethylene chain build-up reaction occurs at a rate similar to the ethoxylation of the alcohol. As a result, the ethylene oxide chain is built up before all alcohol has been reacted, and a polydispersed mixture containing nominally eight ethylene oxides will contain significant amounts of other ethoxylates containing from 0 to 20 ethylene oxide units.⁴⁹

Eleven manufacturers at fifteen facilities produced the general category of ethoxylated alcohols within the U.S. in 1992. These facilities and their locations are presented in Table 30. No data were available on whether these were primary, secondary, or tertiary ethoxylated alcohols. Each of these manufacturers reported under multiple SICs to TRI indicating the manufacture of a variety of chemical products. Therefore, the 1992 TRI releases and transfers from these facilities, presented in Table 31, do not exclusively represent emissions from the production of ethoxylated alcohols. An evaluation of the TRI data indicates a variety of toxic chemical emissions. The chemical raw materials for the production of ethoxylated alcohols; ethylene, ethylene oxide, ethylene glycol, and methanol, were common chemicals released or transferred from these facilities. Emissions to air dominated on-site releases (more than 98 percent), while 'other' transfers dominated off-site emissions from these facilities (nearly 70 percent).

The basic raw materials for the production of ethoxylated alcohols; alcohols and ethylene oxide, result in additional chemical emissions during their production processes. The TRI releases and transfers presented in Table 31 may not reflect these emissions, and therefore, the following qualitative evaluation is given.

CHAPTER 7

NATIONAL ENVIRONMENTAL IMPACT EVALUATION

The extraction of raw materials, manufacturing processes, use, reuse and disposal represent the basic stages of a product's life-cycle. Each stage within this life-cycle emits a variety of wastes to the environment. The national environmental impact evaluation qualitatively assessed the life-cycle stages of chemical manufacturing, use, and disposal for solvents and their use in solvent degreasing applications, and detergent chemicals and their application in parts cleaning.

Within the U.S. there are an estimated 24,500 solvent degreasers which consume nearly 500 million lb/yr of chlorinated degreasing solvents.³⁵ Production processes, as well as the use and disposal of chemicals, result in significant chemical releases and transfers to the environment. The analyses of this project identified the use stage as the major contributor to the life-cycle releases and transfers of chlorinated solvents. EPA estimated over 283 million lb in air releases alone occur each year from solvent degreasing operations.³⁶

In contrast, aqueous wash systems consume less chemicals by volume in the use life-cycle stage. Based on order-of-magnitude calculations, this reduced chemical use probably reflect less chemical releases and transfers from production facilities. The predominant environmental emission from aqueous wash systems is wastewater. An assessment of the nation's municipal wastewater treatment infrastructure suggests that its treatment capacity and capabilities will be adequate to accommodate a large shift from solvent degreasing to aqueous wash systems.

NATIONAL ENVIRONMENTAL IMPACT BACKGROUND

The objective of this analysis is to identify and evaluate the national environmental impacts which are possible if entire industrial sectors were to replace chlorinated degreasing solvents with alternative cleaners and/or cleaning systems similar to those implemented by CMC. Data from the Environmental Evaluations of Chapter 5 are supplemented in this analysis with additional data from literature, on-line databases, and other sources.

Releases and transfers of chemicals to the environment occur throughout their life-cycles; from their production, use, and disposal. The replacement of chlorinated degreasing solvents with alternative cleaning systems by entire industrial sectors can greatly influence the releases and transfers from each of these life-cycle stages. Therefore, for this national environmental impact evaluation, the releases and transfers associated with the production of chemicals, as well as the releases and transfers due to their use and disposal, are evaluated. A multimedia approach for these evaluations, analyzing releases and transfers to land, air, and water, is applied.

TABLE 31. RELEASES AND TRANSFERS FROM ETHOXYLATED ALCOHOL PRODUCTION FACILITIES									
Producer	Releases and Transfers (lb/yr)								
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers	
BASF Corp. Spartanburg, SC	1,721	0	0	0	1,721	300	43,240	43,540	
Croda, Inc. Mill Hall, PA	15,524	0	0	0	15,524	1,412	0	1,412	
Harcros Organics Inc. Kansas City, KS	7,850	65	0	0	7,915	38,221	0	38,221	
Henkel Corp. Mauldin, SC	13,237	0	0	0	13,237	4,792	2,762	7,554	
Rhone-Poulenc Inc. Winder, GA	526	0	0	0	526	3,595	5,100	8,695	
Baltimore, MD	1,293	0	0	0	1,293	250	2,428	2,678	
Shell Oil Company Geismar, LA	1,338,184	1,999	0	0	1,340,183	0	157,840	157,840	
Reserve, LA	2,128	0	0	0	2,128	0	32,018	32,018	
Stepan Company Millsdale, IL	655,776	1,274	0	7,310	664,360	0	4,452,750	4,452,750	
Texaco Chemical Co. Port Neches, TX	986,507	25,801	0	80,540	1,092,848	0	151,091	151,091	

(continued)

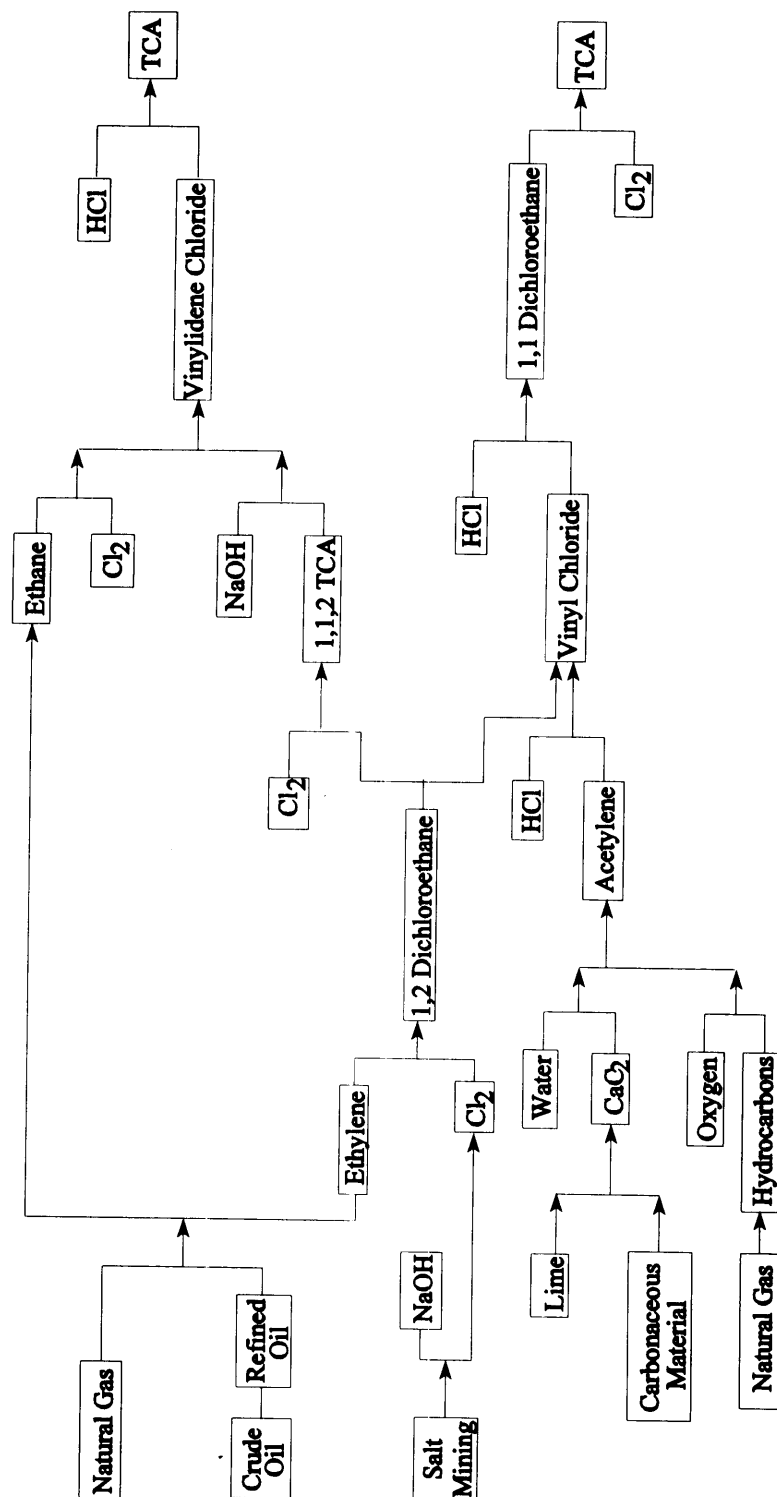


FIGURE 12. SIMPLIFIED MANUFACTURING SCHEME FOR 1,1,1-TRICHLOROETHANE

Nonylphenol Ethoxylates: Nonylphenol ethoxylate is manufactured by the ethoxylation of nonylphenol with ethylene oxide. Ethylene oxide is a widely used ethoxylating compound, and is manufactured by the oxidation of ethylene over a silver catalyst, as explained above. Nonylphenol is produced by the alkylation of phenol using propylene trimer, a derivative of the (alpha)-olefin propene. Phenol can be made by several oxidation processes which utilize toluene and derivatives of benzene as a feed stock. The most common feed stock in the phenol production process is cumene, which is manufactured by the alkylation of benzene with propene.⁵³ Figure 14 is a simplified process diagram for the manufacturing process of nonylphenol ethoxylate.⁵⁴ In 1980, nonylphenol ethoxylates accounted for 73.6 percent of U.S. production of alkylphenol ethoxylates.⁵⁵ The fifteen facilities that produce nonylphenol ethoxylate are listed in Table 32.

TABLE 32. PRODUCERS OF ETHOXYLATED NONYLPHENOL SURFACTANTS			
Producer	Location	Producer	Location
Harcros Organics Inc.	Kansas City, KS	Stepan Company	Millsdale, IL
Henkel of America, Inc.	Charlotte, NC		Winder, GA
	Mauldin, SC	Texaco Inc.	Port Neches, TX
Kao Corp. of America	High Point, NC	Union Carbide Company	Texas City, TX
Milliken & Co.	Inman, SC	Witco Corporation	Harahan, LA
PPG Industries, Inc.	Gurnee, IL		Houston, TX
Rhone-Poulenc Inc.	Winder, GA		Santa Fe Springs, CA
Rohm and Haas Company	Deer Park, TX		

Source: 1992 Directory of Chemical Producers, United States of America, SRI International

TABLE 27. SUPPLY AND DEMAND OF THE CHLORINATED DEGREASING SOLVENTS

Producer	1992 Capacity (million lb/yr)			
	DCM	PCE	TCA	TCE
Dow Chemical, USA				
Freeport, TX	110	--	500	120
Plaquemine, LA	120	90	--	--
Occidental Petroleum Corp.				
Belle, WV	111	--	--	--
PPG Industries, Inc.				
Lake Charles, LA	--	200	350	200
Vulcan Materials				
Geismar, LA	80	150	200	--
Wichita, KS	130	50	--	--
TOTAL SUPPLY	551	490	1050	320
1991 Demand	400	250	640	160
1992 Demand	390	250	600	145
1996 Demand	345	350	0 ^a	140

a U.S. production of TCA must be phased out by 1995.

Source: Chemical Marketing Reporter

Table 33 presents the 1992 TRI reported emissions from the production facilities of nonylphenol ethoxylate listed in Table 32. Due to the production of multiple products, and multiple SICs reported by some of these facilities, the releases and transfers of Table 33 cannot be wholly attributed to the production of nonylphenol ethoxylate. However, from a life-cycle perspective, some portion of the appropriate production emissions are the result of surfactant use in industrial detergents, and therefore, must be attributed to that use. Off-site transfers represent near three-quarters of all releases and transfers reported by these facilities. Air releases represent 98 percent of on-site emissions; 'other' transfers represent the vast majority of the off-site emissions (72 percent).

The production of nonylphenol ethoxylate, as stated above, relies upon phenol, propylene, and ethylene (ethylene oxide), all of which are distillation products of crude oil or natural gas. Phenol is produced from toluene and benzene, and propylene and ethylene are produced from straight-chain hydrocarbons from the distillation of crude oil or natural gas.⁵⁶ Again, the potential emissions from these chemical production processes must be evaluated when evaluating life-cycle environmental impacts. Toluene, benzene, phenol, propylene, ethylene, and other hydrocarbons must all be considered. As before, the release of several other hazardous air pollutants from petroleum refining processes must be considered, and their environmental impacts evaluated.

Linear Alkylbenzene Sulfonate: LAS is produced by the sulfonation of dodecylbenzene (commonly referred to as linear alkylbenzene, LAB) with sulfuric acid or sulfur trioxide. Almost 90 percent of the LAB made is consumed in the manufacturing of LAS. LAB is produced by the alkylation of benzene with dodecene in the presence of an aluminum chloride catalyst. Dodecene can be produced by the thermal cracking of wax paraffins to (alpha)-olefins.⁵⁷ Figure 15 is a simplified process diagram for the manufacturing process of LAS.⁵⁸ Dodecylbenzene sulfonic acid and its salts account for the majority of alkylbenzene sulfonates produced.⁵⁹

Three companies at six different locations manufacture dodecylbenzene sulfonic acid. These facilities are presented in Table 34. The releases and transfers reported by these producers of dodecylbenzene sulfonic acid, presented in Table 35, were retrieved from the 1992 TRI. On-site air releases represent nearly 95 percent of all releases and transfer, on-site and off-site, from these facilities. Evaluation of the chemicals emitted by these facilities identified an interesting fact; aromatic chemicals such as toluene or benzene were not among the chemicals reported. Benzene emissions from these facilities are probably regulated by the benzene NESHAP, which requires leak detection and repair, and stack emissions to be captured and destroyed. LAB, which is not required to be reported under TRI, may also be the raw material used to produce dodecylbenzene-sulfonic acid.

Table 28 (continued)

Producer	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
PPG Industries, Lake Charles, LA	103	3,990	0	0	4,093	0	45	45
	97,000	5,310	2	0	102,312	0	1,678	1,678
	70,000	3,540	1	0	73,541	0	373	373
	123,000	1,010	0	0	124,010	0	1,231	1,231
Vulcan Materials, Giesmar, LA								
	77,000	37	0	0	77,037	0	500	500
	1,100	14	0	0	1,114	0	250	250
	38,100	11	0	0	38,111	0	4,050	4,050
	85,200	9	0	0	85,209	0	750	750
Vulcan Materials, Wichita, KS								
	1,906	0	0	466	2,372	0	3	3
	44,782	0	0	22,567	67,349	0	220	220
	3,938	0	0	553	4,491	0	36	36
	38,053	0	0	12,780	50,833	0	3,166	3,166
TOTAL	1,206,721	14,877	243	36,366	1,258,207	1	28,615	28,616

Note: Total releases and transfers from U.S. producers of chlorinated degreasing solvents was 1,286,823 lb in 1992.

Source: TRI, 1992

Table 33 (continued)

Producer	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
Texaco Chemical Co. Port Neches, TX	986,507	25,801	0	80,540	1,092,848	0	151,091	151,091
Union Carbide Corp. Texas City, TX	4,170,148	0	0	0	4,170,148	796,608	2,179,385	2,975,993
Witco Corp. Harahan, LA	3,522	0	0	0	3,522	15,656	0	15,656
Houston, TX	4,259	0	21,962	0	26,221	0	0	0
Santa Fe Springs, CA	3,505	0	0	0	3,505	0	0	0
TOTAL	7,640,867	68,663	60,848	87,879	7,858,257	870,116	8,728,368	9,598,484

Source: TRI, 1992

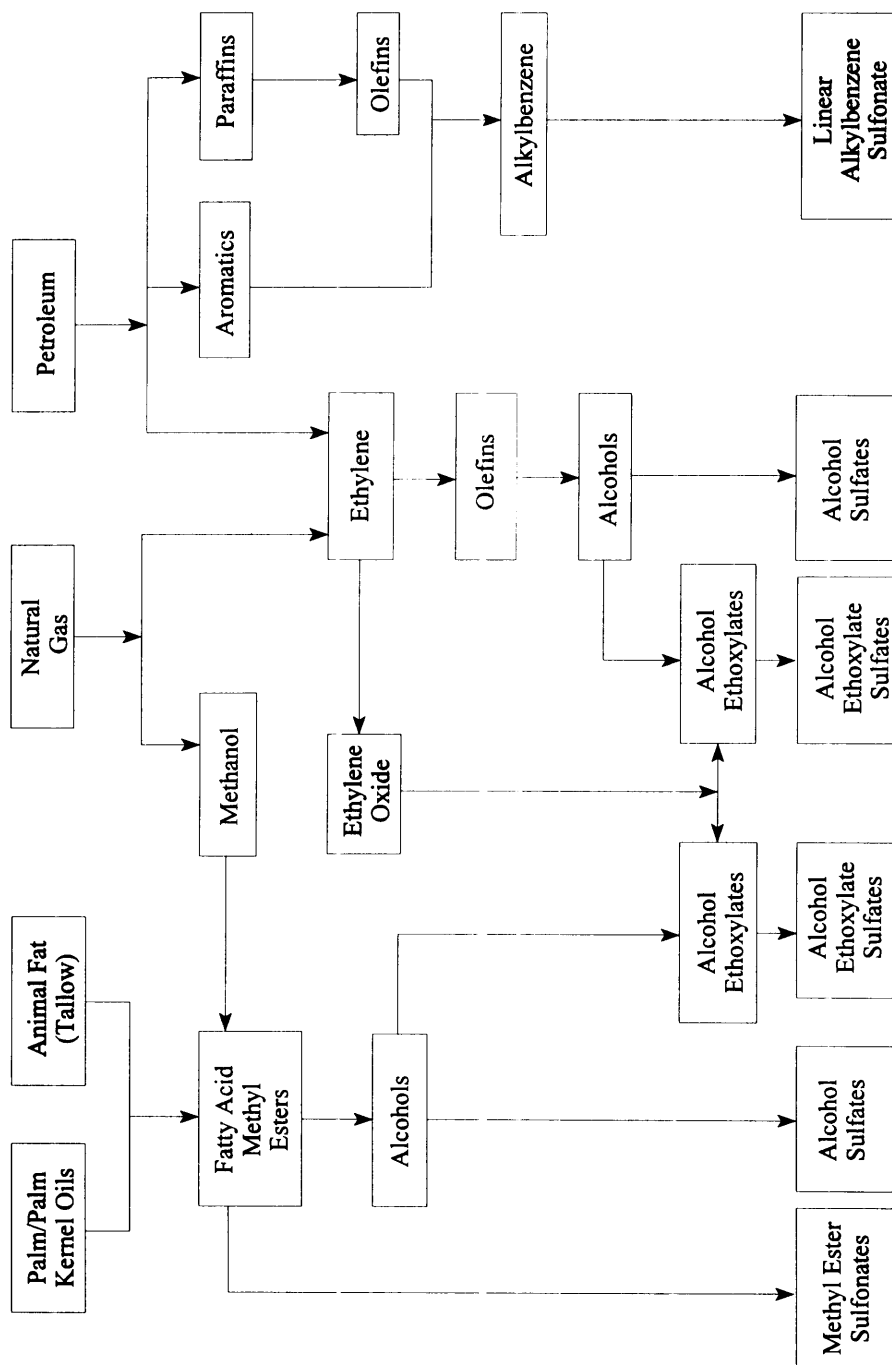


FIGURE 13. SURFACTANT MANUFACTURING

TABLE 34. PRODUCERS OF DODECYLBENZENE SULFONIC ACID	
Producer	Location
The Greyhound Dial Corp.	Chicago, IL
	St. Louis, MO
	South Gate, CA
Unilever United States, Inc.	Baltimore, MD
	Hammond, IN
Witco Corp.	Blue Island, IL

Source: 1992 Directory of Chemical Producers, United States of America, SRI International

The chemical structure of LAS, the most widely used surfactant, is based upon benzene. Benzene is predominantly produced from a petrochemical feed stock which is a distillation product of crude oil. In addition to the emissions during the production of benzene (presented under nonylphenol ethoxylates), the use of benzene in the production of linear alkyl benzene, the chemical intermediate in the formation of LAS, can result in further benzene emissions. In addition to benzene, petroleum refineries also release several other hazardous air pollutants, as previously discussed. These releases and transfers to the environment must be evaluated when applying a life-cycle perspective.

Overall TRI Releases and Transfers: Surfactant Manufacturers: Manufacturers of surfactants report TRI releases and transfers under SICs 2841 (soaps and detergents) and 2843 (surface active agents). Chemical Products, SIC 2800, is the general category of which these two manufacturing classes are found. The total emissions from SICs 2841 and 2843 were also retrieved from TRI 1992. These data are presented in Table 36. As previously mentioned with the producers of the surfactants discussed above, many of the manufacturing facilities reported multiple SIC codes in TRI 1992. For this reason, the emissions from these facilities may not specifically represent surfactant production emissions.

TABLE 30. PRODUCERS OF ETHOXYLATED ALCOHOL SURFACTANTS			
Producer	Location	Producer	Location
BASF Corp.	Spartanburg, SC	Stepan Company	Millsdale, IL
Croda, Inc.	Mill Hall, PA	Texaco Chemical Company	Port Neches, TX
Harcros Organics Inc.	Kansas City, KS	Union Carbide Corp.	Texas City, TX
Henkel of America, Inc.	Mauldin, SC	Vista Chemical Company	Lake Charles, LA
Rhone-Poulenc Inc.	Baltimore, MD	Witco Corp.	Harahan, LA
	Winder, GA		Houston, TX
Shell Oil Company	Geismar, LA		Santa Fe Springs, CA
	Reserve, LA		

Source: 1992 Directory of Chemical Producers, United States of America, SRI International.

The source of alcohol raw materials can either be vegetable oils or a petroleum feed stock, as presented in Figure 13. Most alcohols derived from vegetable oils are made by first converting the fatty acid in the triglyceride to its methyl ester by alcoholysis with methanol. The methyl ester is then hydrogenated to the fatty alcohol and methanol.⁵⁰ Therefore, potential chemical releases to the environment can include methanol and methyl ester.

Petroleum-based alcohols may result in the release of several hazardous air pollutants, including aldehydes, ammonia, benzene benzo(a)pyrene, biphenyl, carbon monoxide, ethyl benzene, formaldehyde, naphthalene, and xylene. They also add to the volatile organic compound loading in the lower atmosphere contributing to photochemical smog, are sources of significant water pollution including oil, phenols, BOD, COD, and ammonia, and generate significant quantities of solid waste.⁵¹

Ethylene oxide is produced from ethylene, which is a distillation product of either crude oil or natural gas.⁵² Potential environmental releases of chemicals from this process include ethylene oxide and releases of benzene, ethylene, and hydrocarbons from the production of ethylene.

These life-cycle environmental emissions of carcinogenic and/or toxic chemicals are presented to acknowledge chemical releases and transfers from the production of chemical intermediates, beyond the TRI reported releases and transfers from ethoxylated alcohol production facilities shown on Table 31. Estimates of the chemical emissions from various production sources are published by EPA in "Toxic Air Pollution Emission Factors - A Compilation for Selected Air Toxic Compounds and Sources." Selected environmental emissions can be drawn from this document.

TABLE 36. TOTAL RELEASES AND TRANSFERS FROM SURFACTANT AND SOAP/DETERGENT MANUFACTURERS									
SIC	Releases and Transfers (lb/yr)								
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers	
2841 (949 TRI entries)	3,480,165	41,774	267,632	55,343,914	59,133,485	10,997,217	23,061,819	34,059,036	
2843 (918 TRI entries)	5,873,175	1,125,576	212,794	22,212	7,233,757	5,386,686	23,167,952	28,554,638	
TOTAL	9,353,340	1,167,350	480,426	55,366,126	66,367,242	16,383,903	46,229,771	62,613,674	

Table 31 (continued)

Producers	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
Union Carbide Corp. Texas City, TX	4,170,148	0	0	0	4,170,148	796,608	2,179,385	2,975,993
Vista Chemical Co. Lake Charles, LA	665,373	11,106	0	0	676,479	0	3,719,609	3,719,609
Witco Corp. Harahan, LA	3,522	0	0	0	3,522	15,656	0	15,656
Houston, TX	4,259	0	21,962	0	26,221	0	0	0
Santa Fe Springs, CA	3,505	0	0	0	3,505	0	0	0
TOTAL	7,869,553	40,245	21,962	87,850	8,019,610	860,834	10,746,223	11,607,057

Source: TRI, 1992

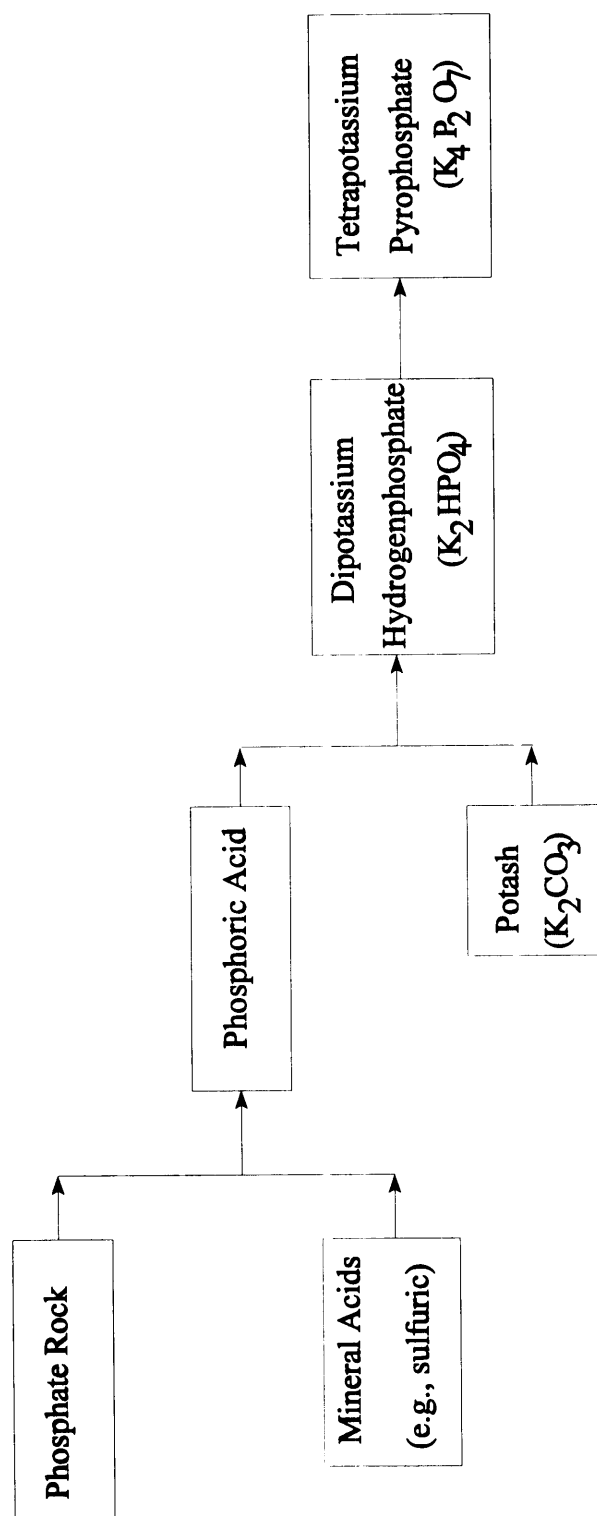


FIGURE 16. SIMPLIFIED MANUFACTURING SCHEME OF TETRAPOTASSIUM PYROPHOSPHATE

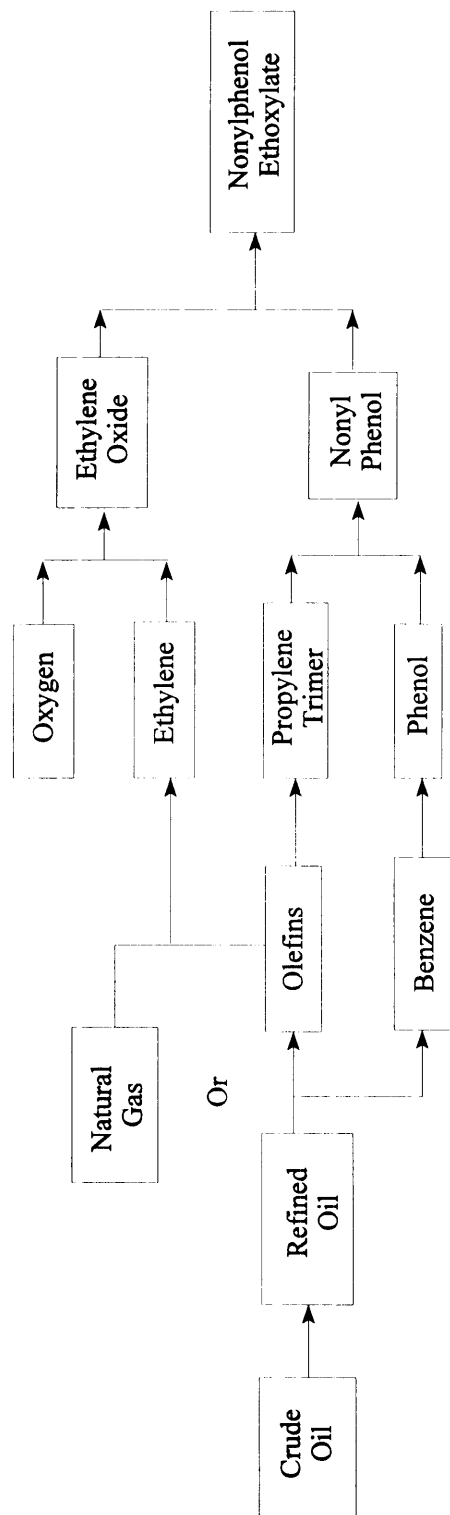


FIGURE 14. SIMPLIFIED MANUFACTURING SCHEME FOR NONYLPHENOL ETHOXYLATES

TABLE 38. TRI RELEASES AND TRANSFERS FROM TETRAPOTASSIUM PYROPHOSPHATE PRODUCTION FACILITIES								
Producer	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
Albright and Wilson Co. Cincinnati, OH	2,005	250	0	0	2,255	0	0	0
FMC Corp. Carteret, NJ	4,412	0	0	0	4,412	0	11,067	11,067
Neward, CA	8,149	0	0	0	8,149	0	1,346	1,346
Monsanto Company Augusta, GA	14	0	0	0	14	0	46,000	46,000
TOTAL	14,580	250	0	0	14,830	0	58,413	58,413

Source: TRI, 1992

TABLE 35. TRI RELEASES AND TRANSFERS FROM DODECYLBENZENE SULFONIC ACID PRODUCTION FACILITIES									
Producer	Releases and Transfers (lb/yr)								
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers	
The Dial Corp. Chicago, IL	500	0	250	0	750	5	0	5	
St. Louis, MO ^a	0	0	0	0	0	0	0	0	
South Gate, CA ^a	0	0	0	0	0	0	0	0	
Lever Brothers Co. Baltimore, MD	256	0	0	0	256	500	0	500	
Hammond, IN	755	0	0	0	755	1,480	0	1,480	
Witco Corp. Blue Island, IL	38,321	0	0	0	38,321	0	0	0	
TOTAL	39,832	0	250	0	40,082	1,985	0	1,985	

^a TRI chemical emissions in 1992 were not reported by these facilities.

Source: TRI, 1992

Ethylenediaminetetraacetic Acid: EDTA is a chelating agent made by reacting ethylenediamine with chloroacetic acid. Ethylenediamine is produced along with other mixed amines from ethylene dichloride and ammonia. Ethylene dichloride used in the EDTA manufacturing process is produced by the chlorination of ethylene. Chloroacetic acid is produced by the chlorination of glacial acetic acid in the presence of a sulfur or red phosphorus catalyst. More than 90 percent of the acetic acid used in this process is derived from either the direct liquid-phase oxidation of butane or the oxidation of acetaldehyde. Acetaldehyde, typically used in the same plant in which it is produced, is produced by the direct oxidation of ethylene.⁶² A simplified schematic of this process is presented in Figure 17.⁶³ The three producers of EDTA are listed in Table 41.

TABLE 41. PRODUCERS OF ETHYLENEDIAMINETETRAACETIC ACID	
Producer	Location
Ciba-Geigy Corp.	McIntosh, AL
Dow Chemical U.S.A.	Freeport, TX
W.R. Grace and Company	Nashua, NH

Source: 1992 Directory of Chemical Producers, United States of America, SRI International

The TRI releases and transfers from these production facilities were obtained for reporting year 1992. These emissions are presented in Table 42. On-site releases to air and 'other' off-site transfers represent 99 percent of all emissions from these production facilities. Air releases at 9,740,907 lb/yr contributed 97.6 percent of all on-site releases. With no reported releases to POTWs, other off-site transfers represented 100 percent of off-site emissions. As with the other production facilities identified above, multiple products are produced by these facilities, and TRI reporting is done under multiple SIC. Therefore, directly attributing a fraction of these emissions to the use of chelators and builders in industrial detergents is not possible.

Nitrilotriacetic Acid: Two processes, the alkaline process and the acid process, are currently used to manufacture NTA. In the alkaline process, aqueous sodium cyanide solution is fed into a reactor system along with a formaldehyde solution to produce NTA. Ammonia is liberated during the synthesis, one-third of which is consumed in the chain of reactions. The remaining ammonia produced must be removed from the reactor to suppress side reactions. By-products of the reaction include glycolic acid, hexamethylenetetramine, and amino acid.⁶⁴

TABLE 40. TRI RELEASES AND TRANSFERS FROM SODIUM TRIPOLYPHOSPHATE PRODUCTION FACILITIES								
Producer	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
FMC Corp. Green River, WY	81,595	0	0	0	81,595	0	0	0
Carteret, NJ	4,412	0	0	0	4,412	0	67	67
Lawrence, KS	125,238	45	0	0	125,283	0	12,150	12,150
Monsanto Chemical Co. Augusta, GA	14	0	0	0	14	0	46,000	46,000
Carondelet, MO	62	No Data	5,430	0	5,492	0	1,505	1,505
Long Beach, CA	321	No Data	0	0	321	0	130,000	130,000
Trenton, MI	119,032	32,000	0	0	151,032	3,720	277,409	281,129
Rhone-Poulenc Inc. Chicago, IL	7,461	33	0	0	7,494	1,041	0	1,041
TOTAL	338,135	32,078	5,430	0	375,643	4,761	467,131	471,892

Source: TRI, 1992

TABLE 42. TRI RELEASES AND TRANSFERS FROM ETHYLENEDIAMINETETRAACETIC ACID PRODUCTION FACILITIES								
Producer	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
Ciba-Geigy Corp. McIntosh, AL	1,750,867	30,450	0	5,764	1,787,081	0	14,276,753	14,276,753
Dow Chemical U.S.A. Freeport, TX	7,967,797	70,350	0	111,977	8,150,124	0	136,796	136,796
W.R. Grace and Co. Nashua, NH	22,243	24,137	0	0	46,380	0	80,642	80,642
TOTAL	9,740,907	124,937	0	117,741	9,983,585	0	14,494,191	14,494,191

Source: TRI, 1992

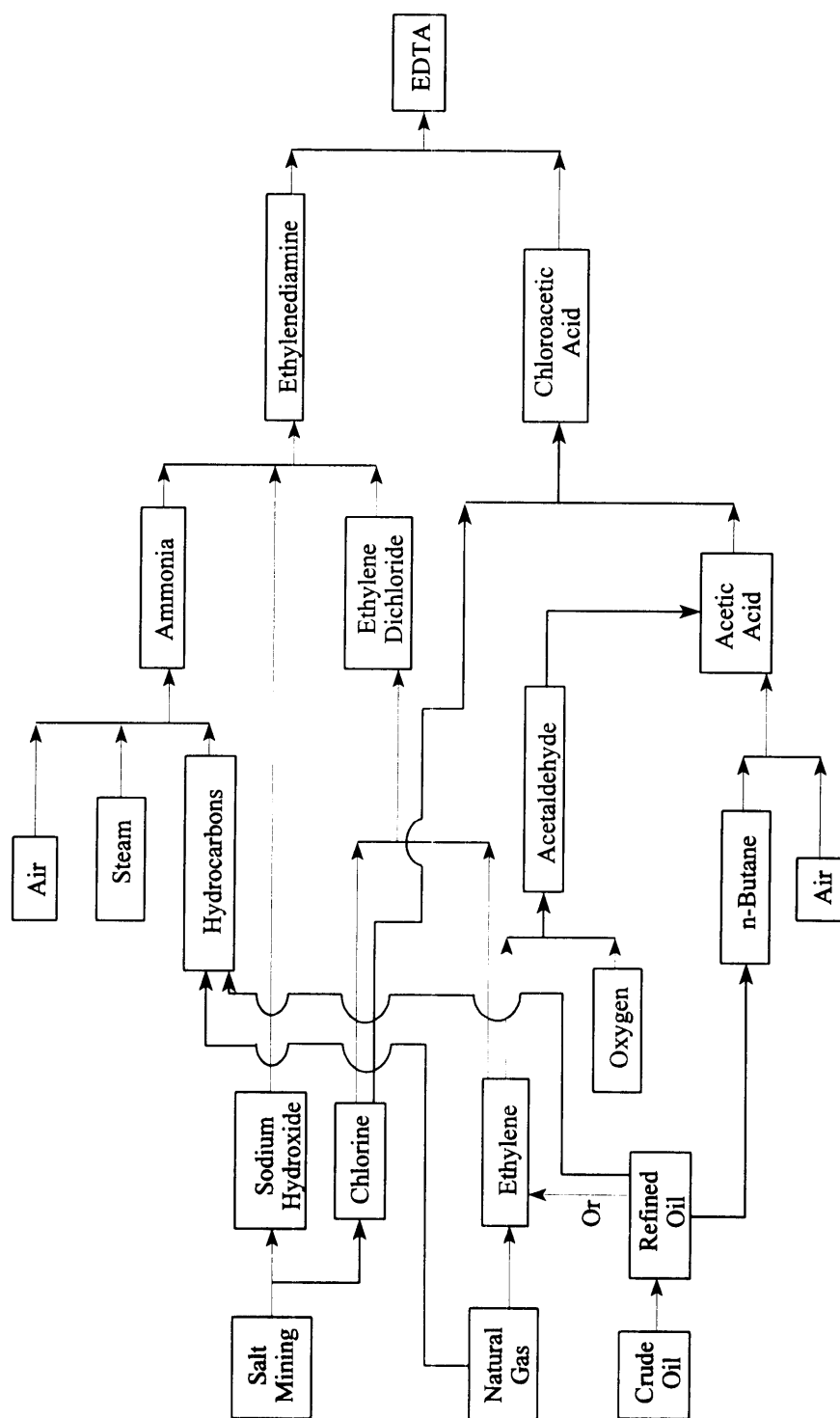


FIGURE 17. EDTA MANUFACTURING SCHEME

TABLE 44. TOTAL TRI RELEASES AND TRANSFERS FROM INDUSTRIAL INORGANIC CHEMICAL PRODUCERS								
SIC	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
2819 (3375 TRI entries)	108,433,237	101,454,856	332,504,428	332,504,429	874,896,950	113,341,504	277,699,633	391,041,137

Source: TRI 1992

The acid process used to manufacture NTA was originally designed to avoid the by-products produced in the alkaline process. The two-stage acid process begins by reacting formaldehyde with ammonia to give hexamethylenetetramine. This product is then reacted with hydrogen cyanide, another 33/50 chemical, in a sulfuric acid solution to yield tricyanomethylamine, which is a solid precipitate. This solid removed from the reactor chain, is saponified with sodium hydroxide to produce Na₃NTA. Acidification to a pH of 1 to 2 yields NTA. Both processes, alkaline and acid, are associated with stringent safety requirements due the use of hydrogen cyanide.⁶⁵ W.R. Grace and Company, in Nashua, NH was the only producer of NTA in 1991.⁶⁶ The 1992 TRI reported releases and transfers from this facility are presented in Table 43.

TABLE 43. TRI RELEASES AND TRANSFERS FROM THE PRODUCTION OF NTA - W.R. GRACE AND COMPANY	
Release or Transfer	lb/yr
Air Releases	22,243
Water Releases	24,137
Land Releases	0
Underground Injection Releases	0
Total On-Site Releases	46,380
POTW Transfers	0
Other Off-Site Transfers	80,642
Total Off-Site Transfers	80,642
TOTAL	127,022

Source: TRI, 1992

Overall TRI Releases and Transfers: Builders and Chelators Manufacturers: The producers of builders and chelators report TRI emissions under the SIC 2819, industrial inorganic chemicals. Though multiple SICs are reported by these facilities, the releases and transfers from the entire industrial class were retrieved, and the data are presented in Table 44.

TABLE 45. NATIONAL BASELINE AIR RELEASES (lb/yr)				
Type of Degreaser	DCM	PCE	TCA	TCE
Batch, Vapor				
small (4.3 ft ²)	485,020	1,212,540	7,716,180	4,232,880
medium (8.6 ft ²)	1,146,400	2,843,960	18,188,140	9,986,940
large (16.1 ft ²)	1,785,740	4,409,250	28,241,220	15,520,540
very large (37.7 ft ²)	3,328,980	8,223,240	52,602,300	28,902,600
In-line, Vapor	10,075,130	7,054,790	52,381,830	22,773,750
Batch, Cold	2,358,950	-	-	-
TOTAL	19,180,220	23,743,780	159,129,670	81,416,710

Source: NESHAP

Note: Total estimated chlorinated solvent air releases equals 283,470,370 lb/yr.

Five major industry groups use chlorinated solvents in degreasing operations. These groups are furniture and fixtures (SIC 25), fabricated metal products (SIC 34), electric and electronic equipment (SIC 36), transportation equipment (SIC 37, which includes CMC), and miscellaneous manufacturing industries (SIC 39).⁶⁹ The chlorinated solvent releases and transfers to the environment from these facilities are presented in Table 46. These releases and transfers of chlorinated solvents can not be directly attributed to their use in degreasing, since the reporting facilities could use the solvents in other applications.

TABLE 46. TRI RELEASES AND TRANSFERS OF CHLORINATED DEGREASING SOLVENTS FROM TOP INDUSTRY SECTORS								
SIC	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
SIC 25								
DCM	996,528	0	0	0	996,528	0	177,665	177,665
PCE	11,200	0	0	0	11,200	0	1,480	1,480
TCA	3,420,634	0	5,800	0	3,426,434	990	194,479	195,469
TCE	243,740	0	0	0	243,740	0	48,336	48,336
TOTAL	4,672,102	0	5,800	0	4,677,902	990	421,960	422,950
SIC 34								
DCM	3,619,512	6	0	0	3,619,518	26,357	627,441	653,798
PCE	3,662,022	10	3,590	0	3,665,622	555	1,416,326	1,416,881
TCA	19,616,277	164	39,778	0	19,656,219	5,117	5,771,601	5,776,718
TCE	9,604,328	2,622	2,500	0	9,609,450	11,626	3,090,094	3,101,720
TOTAL	36,502,139	2,802	45,868	0	36,550,809	43,655	10,905,462	10,949,117
SIC 36								
DCM	3,240,110	255	12	0	3,240,377	2,168	1,921,416	1,923,584
PCE	2,329,519	29	0	0	2,329,548	3,109	2,689,997	2,693,106
TCA	13,453,087	1,270	10	3	13,454,370	8,670	5,829,409	5,838,079
TCE	5,018,995	532	0	0	5,019,527	379	2,508,345	2,508,724
TOTAL	24,041,711	2,086	22	3	24,043,822	14,326	12,949,167	12,963,493

(continued)

Table 46 (continued)

SIC	Releases and Transfers (lb/yr)							
	Air Release	Water Release	Land Release	Underground Injection Release	Total On-Site Releases	POTW Transfer	Other Off-Site Transfers	Total Off-Site Transfers
SIC 37								
DCM	4,581,061	317	0	0	4,581,378	22,979	1,907,236	1,930,215
PCE	3,104,103	169	10	0	3,104,282	47	998,276	998,323
TCA	23,438,080	1,147	210	0	23,439,437	32,865	7,538,162	7,571,027
TCE	6,215,996	2,907	8,420	0	6,227,323	2,233	1,686,177	1,688,410
TOTAL	37,339,240	4,540	8,640	0	37,352,420	58,124	12,129,851	12,187,975
SIC 39								
DCM	2,180,505	0	0	0	2,180,505	1,000	268,951	269,951
PCE	87,454	26	0	0	87,480	0	154,511	154,511
TCA	3,526,521	11	9,100	0	3,535,632	330	865,491	865,821
TCE	630,481	5	0	0	630,486	250	270,975	271,225
TOTAL	6,424,961	42	9,100	0	6,434,103	1,580	1,559,928	1,561,508
TOTAL	108,980,153	9,470	69,430	3	109,059,056	118,675	37,966,368	38,085,043

Source: TRI, 1992

On-site emissions to air of the chlorinated degreasing solvents represent the majority of releases and transfers, just over 74 percent, for the industry sectors shown in Table 46. The NESHAP baseline air emissions and the industry sector air emissions are compared in Table 47. As shown by this comparison, the baseline emissions of the NESHAP seem to underestimate the potential air releases for DCM as a degreasing solvent as compared to the other chlorinated solvents. The 1992 TRI data represents 76.2 percent of the estimated baseline emissions, while TRI data represents 38.7, 39.9, and 26.7 percent of PCE, TCA, and TCE baseline estimates, respectively.

TABLE 47. COMPARISON OF 1992 TRI EMISSIONS AND NESHAP BASELINE EMISSION ESTIMATIONS		
Chemical	1992 TRI Data ^a (lb/yr)	NESHAP Baseline (lb/yr)
DCM	14,617,716	19,180,220
PCE	9,194,298	23,743,780
TCA	63,454,599	159,129,670
TCE	21,713,540	81,416,710
TOTAL	108,980,153	283,470,380

a Releases and transfers represent TRI reported air releases for each chemical from Tables 45 and 46.

Transfers to off-site treatment and disposal facilities from the industrial sectors presented in Table 46 represent nearly 26 percent of all emissions. Though not comparable to the present distribution of CMC releases and transfers, these percentages are consistent with CMC historic data for the years 1988 through 1990. Therefore, the direct extrapolation of CMC's experience to represent the national environmental impacts of solvent degreasing applications, and alternative processes, is appropriate.

Transfers to POTWs, contributing less than one-tenth of one percent, correspond to the findings of CMC's environmental evaluation. The national releases of chlorinated solvents to POTW, though small in relation to other releases and transfers, may create adverse environmental impacts. Though the chlorinated solvents are readily vaporized into the air at POTWs, they are not readily biodegradable. Their release to POTWs is restricted by federal regulations due to their toxicity to POTW operations and receiving waters. Therefore, the chlorinated solvent discharges presented in Table 46 may contribute to POTW treatment problems and receiving water contamination.

Other industry groups identified by the EPA which use degreasing processes include the following: food and kindred products (SIC 20), primary metals (SIC 33), nonelectrical machinery (SIC 35), instruments and clocks (SIC 38), and plastics (SIC 30).^{70, 71} Total releases and transfers from these industry sectors of chlorinated degreasing solvents are

presented in Table 48. Again, these releases and transfers of chlorinated solvents can not be directly attributed to their use in degreasing, since the reporting facilities could use the solvents in other applications. For example, the plastics industry (SIC 30) uses DCM in the extraction of certain polymers.

Use and Disposal of Detergents in Metal and Parts Cleaning Applications

As an alternative to chlorinated solvent degreasing, aqueous wash systems, if implemented by entire industry sectors, have the potential to eliminate the releases and transfers which occur during the use and disposal of the solvents. The potentially problematic solvent transfers to POTWs would also be eliminated. However, while eliminating these chlorinated solvent emissions, the aqueous wash alternative would result in the generation of additional waste streams unique to this process.

The aqueous wash system of CMC, while replacing five solvent degreasers and eliminating their associated solvent emissions, generated an average of 8,400 gallons of wastewater per day. This aqueous wash system consumed approximately 2,640 gal/yr of detergent. This new waste stream must be properly managed. When an individual industry implements an aqueous wash system such as this, regulatory and permit compliance are important management issues. These issues include prohibited discharges and categorical standards under national pretreatment standards (40 CFR, Part 403.5), as well as state/local restrictions. When entire industrial sectors implement aqueous wash systems, the issues, as a whole, shift from individual industry compliance issues, to national issues of POTW capabilities and the potential impacts such sector-wide changes would have on the POTW infrastructure and the environment.

As presented in the Environmental Evaluation of Chapter 5, the additional wastewater flow rate of 8,400 gal/d from the aqueous wash system did not impact CMC's pretreatment facility. Changes within other manufacturing process lines, to reduce water consumption and wastewater generation, more than compensated for this increase. However, the treatment scheme of CMC is primarily designed to remove metals and suspended solids from the wastewater; biological treatment of organics is not possible by this system. For this reason, treatment considerations concerning Shelbyville's POTW must be addressed. These concerns will be similar for other facilities implementing aqueous wash alternatives, and include the following:

- the additional wastewater flow rate to the POTW and the POTW's existing capacity; and
- regulated discharges to the POTW, and the POTW's capabilities of treating these discharges.

TABLE 48. TOTAL TRI RELEASES AND TRANSFERS OF CHLORINATED DEGREASING SOLVENTS FROM OTHER INDUSTRY SECTORS						
Chemical	Releases and Transfers (lb/yr)					
	Food & Kindred Products SIC 20	Primary Metals SIC 33	Plastics SIC 30 ^a	Non-Electronic SIC 35	Instruments & Clocks SIC 38	
DCM	893,973	2,245,811	31,743,051	5,040,160	14,873,847	
PCE	725	2,023,831	1,163,271	1,688,651	550,118	
TCA	190,772	16,405,928	20,732,797	13,304,202	7,104,410	
TCE	0	4,195,586	1,715,279	5,894,562	1,885,456	
TOTAL RELEASES AND TRANSFERS	1,085,470	24,871,156	55,354,398	25,927,575	24,413,831	

^a Rubber and plastic manufacturers

Source: TRI, 1992

These issues are addressed in the following sections. Using the knowledge of CMC's process changes and waste streams, the impact of replacing existing solvent degreasers with aqueous wash systems are estimated. CMC information are used as an example to identify and evaluate potential national environmental impacts.

Shelbyville POTW Capacity. The design capacity of Shelbyville's POTW is 4.9 million gallons per day (hereafter referred to as mgd) with an average flow rate of 3 mgd.⁷² The treatment facility employs eight people, two of whom are part-time. The receiving waters for the discharge from the POTW is the Duck River which has an average flow rate of 2,000 mgd.⁷³ Shelbyville's POTW treatment train includes bar racks to screen out large solids, a primary settling tank to remove gravel, sand, and similar materials, activated sludge for biological treatment, final clarifiers, and chlorine contact chambers for disinfection. Solids handling operations include an aerobic solids digester and sand-lined drying beds.

Over the past 20 years the flow rate to this treatment facility has tripled. To accommodate for this increase, the POTW has been expanded twice. Expansions included the following: doubling aeration basin and clarifier capacities; adding a grit chamber, the aerobic digester, and the sand-lined drying beds; and expanding the chlorine contact basins. Information from the South Central Development District and the State Department of Economic and Community Development show that the population of Shelbyville has not tripled in the last 20 years, and the industrial wastewater component to the POTW may constitute the majority of the increase identified by the POTW. Data available indicates that population growth averaged nearly one percent (1 percent) per year for the last 25 years, while industrial growth was over three percent (3 percent) per year. This reported population growth rate would not represent an increase in domestic wastewater equalling nearly 20,000 gal/d.

This discussion represents one company's potential impact on a single POTW. If entire industry sectors were to implement aqueous wash systems to replace solvent degreasing operations, the carrying capacity of the nation's POTW infrastructure must be evaluated, and the potential impacts identified and, if possible, quantified. The following is an evaluation of the nation's POTW capacity, treatment capabilities, and treatability of the potential aqueous wash wastewater.

National POTW Capacity. The "1992 Needs Survey Report to Congress" completed by the EPA states that there were 15,613 operational treatment facilities within the U.S. in 1992.⁷⁴ The total flow rate of these facilities was established at 29,490 mgd, with a total design capacity of 39,380 mgd. When the range of flow rates for individual treatment facilities is analyzed, as presented in Table 49, the majority of facilities (more than 80 percent) have an average flow rate of 1 mgd or less. Once the documented needs are met (by year 2012), 18,966 operating treatment facilities within the U.S. are expected. The design capacity of these facilities will be 45,542 mgd, a 15.6 percent increase from the 39,380 mgd 1992 treatment capacity. The new distribution of design flow ranges are also presented in Table 49; nearly 77 percent of the treatment facilities still have flow rates of 1 mgd or less.

TABLE 49. CAPACITY OF NATION'S TREATMENT FACILITIES				
	Existing POTWs		Expected by 2012	
Flow Range (mgd)	Number of Facilities	Total Flow (mgd)	Number of Facilities	Total Flow (mgd)
0.00 to 0.10	6,003	263	6,451	314
0.11 to 1.00	6,545	2,295	8,094	2,849
1.01 to 10.00	2,460	7,378	3,448	10,922
> 10.00	458	19,554	740	31,457
Other	147	0	233	0
TOTAL	15,613	29,490	18,966	45,542

Source: 1992 Needs Survey Report to Congress

This dominance of small facilities may represent a problem with treatment capacity if entire industrial sectors were to implement aqueous wash systems as an alternative to solvent degreasing. Using CMC's aqueous wash system as an example of a typical system discharging to a small POTW, an additional wastewater flow rate of 8,400 gal/d would represent nearly one percent of the POTW treatment capacity. With the smaller POTWs, such a wastewater flow increase from several industrial facilities could potentially exceed the POTW's treatment capacity resulting in inadequate treatment prior to discharge. Occurrences of inadequately treated discharges to surface waters could result in human health concerns and adverse environmental impacts. The presence of fecal coliform and other bacteria could cause increased health problems among persons who come in contact with this inadequately treated wastewater. The composition of a waste stream which represents one percent of the total wastewater flow could also cause adverse consequences even if the POTW is able to accommodate the increased flow. These consequences include treatment capabilities which are discussed in the following section.

POTW Treatment Capabilities. The "1992 Needs Survey Report to Congress," also presents the treatment capabilities of the 15,613 national facilities. These capabilities are presented in Table 50. This table also presents the level of treatment accomplished by the treatment infrastructure expected by 2012 if the documented needs are met. Note the significant change in the projected level of treatment from 1992 to 2012. Currently 82 percent of the existing facilities accomplish secondary treatment or greater. If the needs by the surveyed facilities are met, by 2012 'secondary', and 'greater than secondary' treatment levels will increase 14.6 percent, and 61.2 percent, respectively. 'Less than secondary' treatment levels will decrease more than 92 percent.

TABLE 50. LEVEL OF TREATMENT FOR THE NATION'S TREATMENT FACILITIES				
Level of Treatment	Existing POTWs		Expected by 2012	
	Number of Facilities	Design Capacity (mgd)	Number of Facilities	Design Capacity (mgd)
Less Than Secondary	868	3,724	68	390
Secondary	9,086	17,928	10,410	19,086
Greater Than Secondary	3,678	16,408	5,929	24,210
No Discharge	1,981	1,320	2,491	1,825
Other ^a	0	0	68	31
TOTAL	15,613	39,380	18,966	45,542

a Level of treatment data were unavailable for these facilities.

Source: 1992 Needs Survey Report to Congress

As federal and state treatment requirements continue to increase, the level of treatment for these facilities must also increase. EPA's estimates (1988, 1990, and 1992) of the investment necessary to address the nation's municipal wastewater treatment needs are presented in Table 51. The dollars needed to meet the national needs are estimated at \$111.9 billion; treatment needs alone represent \$41.8 billion. The total monetary needs increased \$28.2 billion from \$83.7 billion in the 1990 Needs Survey. In general, these increases are caused by one or more of the following five factors: 1) continued population growth and redistribution; 2) deterioration of older sewers and facilities; 3) more stringent standards to protect water quality; 4) newly eligible activities identified in the survey and funding sources; and 5) use of different methodologies for reporting 1990 needs.

Advanced treatment needs grew by \$10 billion between 1988 and 1992. This increase has occurred primarily because the installation of secondary treatment controls has proved to be insufficient in many cities to meet water quality standards. It is likely that this category of needs will continue to grow in the future as more states address the new water quality standards. The increases in secondary treatment and new collector sewers are attributable to population growth and population redistribution since 1990. Figure 18 presents a geographical distribution of the total documented needs.⁷⁵ Needs are generally concentrated in the highly populated northern and Sunbelt states, a generality that applied to past needs surveys. The less populated states have lower levels of documented needs.

**TABLE 51. SUMMARY OF DOCUMENTED NEEDS
FOR YEARS 1988, 1990, AND 1992**
(January 1992 dollars in billions)

Needs Category	1988 Survey	1990 Survey	1992 Survey
Secondary Treatment	29.1	25.9	31.3
Advanced Treatment	5.5	4.9	15.5
Infiltration/Inflow Correction	3.1	2.9	2.8
Replacement/Rehabilitation	4.0	3.7	3.6
New Collector Sewers	14.9	14.4	17.9
New Interceptor Sewers	16.2	14.7	14.7
Combined Sewer Overflows	17.7	17.2	22.4
Storm Water	-	-	1.8
Nonpoint Source	-	-	0.7
Ground Water, Estuaries, Wetlands	-	-	1.2
Total Need	90.5	83.7	111.9

- Notes: 1 Costs for operation and maintenance are not included in figures.
2 The 1990 estimates were derived using a methodology different from that used in 1988 and 1992. EPA simply adjusted the 1988 needs estimates for grant and loan awards and inflation.

Source: 1992 Need Survey Report to Congress

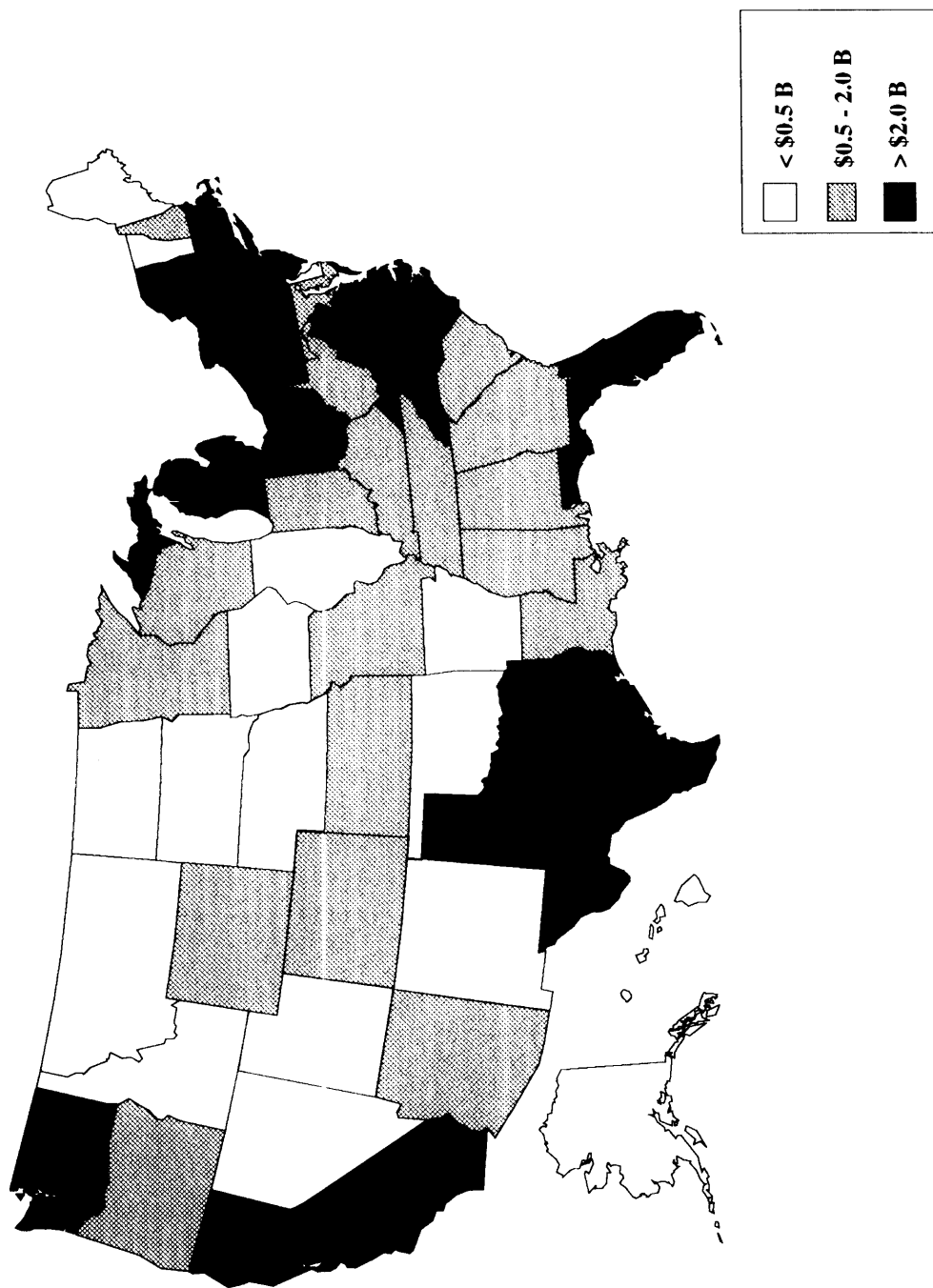


FIGURE 18. DISTRIBUTION OF DOCUMENTED NEEDS

Effects of Detergent Components on Receiving Waters. The introduction of detergent components into the environment, as part of the manufacturing process or after the use of detergents, is regulated by the Clean Water Act, the Clean Air Act, and the Resource Conservation and Recovery Act. Two areas of specific relevance to surfactants, builders and chelators are biodegradability and eutrophication. Though these issues first accompanied laundry detergents in the late 1940s (biodegradability) and 1960s (eutrophication), they must be addressed as detergent use grows beyond the traditional consumer market.

In early 1947, foam blankets on bodies of water were attributed to synthetic surfactants. These surfactants were less readily degraded than soap, which they replaced, by naturally occurring microorganisms. Studies used to confirm these facts concluded that the branched hydrophobic portion of a surfactant impedes the rate and extent of degradation by microorganisms. The most immediately apparent remedy was to replace the branched hydrophobe with a more degradable hydrophobe. Alkylbenzene sulfonate (ABS), the predominant surfactant in the 1940s and 50s, was replaced by linear alkanebenzene sulfonate (LAS). LAS replaced the tetramer alkyl group of ABS with a straight-chain hydrocarbon. The degradability of LAS, as well as other alternative surfactants (e.g., alcohol ethoxylates and alkylphenol ethoxylates), has been studied intensively under sewage-plant operation conditions. Results show that these surfactants readily degrade to carbon dioxide and water.⁷⁶

Eutrophication is a natural aging process of lakes and reservoirs. These waters become organically enriched, leading to the increased domination by aquatic weeds, the transformation of open waters to marshlands, and eventually to dry land. This natural aging process can be accelerated, however, by human input of nutrients. Phosphorous is typically the limiting nutrient in lakes and reservoirs, although the presence of nitrogen is also important. Detergent constituents containing phosphorous or nitrogen can impact the receiving waters causing excessive algal growth, which in turn contributes to oxygen depletion. Oxygen depletion can be detrimental to marine life, and eutrophication can eventually lead to the death of the body of water.

Detergent phosphates (builders and chelators) which reached receiving waters were singled out as the cause of incidents of eutrophication in the U.S. and Europe in the 1960s. For this reason, the concentration of phosphates in consumer laundry formulations has been restricted by many states and local jurisdictions. Though specifically designated for consumer laundry detergents, these restrictions may effect the use of detergents in industrial applications, particularly if large industrial sectors convert cleaning processes to aqueous cleaning. Phosphate substitutes applicable in industrial applications include sodium compounds such as NTA.

An advantage of the hot water wash system of the converter manufacturing line is apparent in the context of the above discussion of biodegradability and eutrophication. By eliminating the use of all chemical additives in this system, the hot water wash application eliminates eutrophication problems associated with detergent formulations. The oils and soils remaining in the wastewater from the hot water wash system represent potential treatability/biodegradability problems; their elimination from the wastewater, however is simplified with the absence of detergent. The oils, without the emulsification action of a detergent, float to the waters surface and can be skimmed off. This skimming greatly decreases the quantity of fats, oils and greases (FOG) leaving the process for treatment. Furthermore, ultrafiltration equipment can be utilized to create a closed loop system - all soils can be removed by the filtration process and the process water can be indefinitely reused.

Though ultrafiltration and closed loop systems are possible in all aqueous systems (e.g., with or without detergents), a hot water wash system simplifies the process.

Treatability of Detergent Components. In addition to the issues of surfactant degradability, eutrophication, and toxicity, regulated discharges to POTWs include prohibited discharges and categorical standards included in the National Pretreatment Standards of 40 CFR § 403.5 and 403.6. The following are two of eight prohibited discharges which may apply to parts cleaning:

1. "any pollutant, including oxygen demanding pollutants (BOD, etc.) released in a discharge at a flow rate and/or concentration which will cause interference with the POTW;"
2. "petroleum oil, nonbiodegradable cutting oil, or products of mineral oil origin in amounts that will cause interference or pass through."

Accompanying these federally regulated industrial discharges, POTW discharges have become subjects of federal and local standards, leading POTWs to exert even tighter controls upon industrial generators. The applicable prohibited discharges presented above are discussed in more detail below, with a focus on CMC-specific examples.

The constituents of CMC's detergent solution include tetrapotassium pyrophosphate and an ethoxylated secondary alcohol. Tetrapotassium pyrophosphate is the builder of the detergent. A builder normally represents the largest additive of detergents and augments the cleaning ability of the detergent's surfactant by removing hardness ions from the wash solution.^{77, 78} The discharge of cleaning solutions containing phosphates such as this are subject to regulation.⁷⁹ These regulations are intended to control eutrophication of the POTW's receiving waters; eutrophication, the uncontrolled overgrowth of plant matter may be caused by the insufficient removal of nutrients (e.g., phosphorous) by the POTWs' treatment train. The ethoxylated secondary alcohol is the surfactant of the detergent and gives the detergent its cleaning capabilities. Though most surfactants are easily biodegraded by the standard treatment methods of POTWs, the oxygen demand of these constituents must be considered.

POTW wastewater treatment predominantly relies upon the biodegradation of organic contaminants to achieve adequate levels of treatment (secondary and greater than secondary treatment levels). This biological decomposition is an aerobic process; one which requires oxygen. An increase in the biological oxygen demand of wastewaters entering a POTW may disrupt the oxygen level in the treatment process. This disruption may cause a decreased level of treatment, and, in turn, result in contaminants reaching receiving waters and advertently impacting the environment.

The significant increase in effluent BOD accompanying CMC's aqueous wash system represents such a potential wastewater disruption. To maintain adequate POTW treatment levels the transfer of oxygen to the wastewater must be increased as the BOD increases. Many POTWs may have the treatment capabilities to maintain oxygen levels in the wastewater. For those POTWs, however, that do not have the capabilities, the transfer of oxygen can be increased by the following methods: increase the oxygen transfer efficiency by increasing the mixing characteristics of the treatment vessel; install additional aerators or mixtures which circulate greater quantities of oxygen; or cover the treatment vessel and

transfer pure oxygen to the wastewater rather than the oxygen present in ambient air. Each of these methods require increasing capital investments, investments that may exceed the EPA estimates of Table 51.

The lubricating and hydraulic oils used by CMC fall within the petroleum oil class of chemicals addressed in the second prohibited discharge listed above. These constituents, often referred to as FOG (i.e. fats, oils, and greases) either float on the surface of the wastewater, or are suspended in the wastewater as an emulsion or on particulates. FOG, both floating and suspended, interferes with the POTW's biological action and cause maintenance problems. Fats are among the more stable of organic compounds, and are not easily decomposed by bacteria; pipes and moving parts of the POTW treatment train may also be clogged with FOG.⁸⁰ FOG are included in "prohibited discharge standards" for this reason; limits are traditionally specified in the discharge permits for industry, limits that may be exceeded when an aqueous system is implemented and the discharge is not pretreated. A metals tooling facility in W. Lafayette, Indiana, which changed their solvent degreasing operations to aqueous cleaning, encountered such permit violations. Without an existing pretreatment facility, this company had to install FOG removal units to treat the aqueous wastewater before discharging to the sewer and POTW.

The hot water wash system of the converter line possesses another advantage over aqueous wash (detergent) applications. Though the hot water wash system removes oils and greases from materials and parts, these impurities are easily separated from the aqueous phase by simple separation equipment (e.g., weirs, filtration processes, skimmers). The absence of a detergent simplifies the oil/water separation process by eliminating the oil emulsification properties characteristic of detergents. The simple separation of the oils from water minimizes potential FOG problems. Furthermore, if the separation process is of an adequate level, a closed-loop system may be possible. A closed-loop system is one in which the impurities are periodically removed while the water remains circulating in the unit. This system would result in zero water discharges to the sewer, a concentrated oily waste that would be disposed of off-site (e.g., fuel blended, recycled, landfilled), and make-up water added to the water reservoir to accommodate evaporative losses. Such a system eliminates not only the biodegradation, eutrophication, toxicity, and regulated discharge issues presented above, it greatly reduces the use of water and its associated costs.

SUMMARY OF NATIONAL ENVIRONMENTAL IMPACT EVALUATIONS

If entire industrial sectors change to aqueous systems similar to CMC's, the life-cycle national environmental releases and transfers would change significantly. While reducing the production, use and disposal releases and transfers of chlorinated degreasing solvents, such process alternatives produce other life-cycle releases and transfers that must be considered. As presented above, air releases of the chlorinated degreasing solvents dominate environmental emissions throughout their life-cycles. This is in contrast to the predominant off-site transfers presented for detergent ingredient production and use.

The evaluation of the life-cycle releases and transfers of the chlorinated degreasing solvent indicates that the use and disposal of these chemicals represent the vast majority of environmental emissions associated with solvent degreasing processes. As presented in the "Production of Chlorinated Solvents" section, an estimated 460,000 lb/yr of chlorinated

solvents were emitted from production facilities in 1992 that may be attributed to the use of these chemicals in degreasing applications. The use of chlorinated degreasing solvents from 1992 figures was estimated to be nearly 500 million lb/yr. This use resulted in significant air releases and hazardous waste transfers. EPA established an air emission baseline of 283.5 million lb/yr of chlorinated degreasing solvents emitted from degreasing applications. The five major industrial sectors which use solvent degreasers reported 147,144,099 lb of chlorinated solvent released or transferred in 1992.

These releases and transfers of chlorinated degreasing solvents were then contrasted to the releases and transfers associated with the life-cycle stages of detergent production and use. Information establishing the fraction of surfactants, chelators and builders used in industrial parts cleaning applications was not available. Therefore, directly comparing life-cycle emissions of the two alternative systems is not possible. Crude, order-of-magnitude estimates, however, can be drawn from the information of CMC's aqueous wash system. Relative chemical use rates between chlorinated solvents and detergents can then be established.

The aqueous wash system of CMC consumes 2,640 gallon of detergent per year. To clean identical parts at a comparable rate, TCA consumption by CMC was 170,000 lb/yr. Assuming CMC's aqueous wash system is representative of most aqueous wash systems, a simple comparison of these chemical consumption rates suggests that the life-cycle chemical emissions from aqueous wash systems are considerably less than those from solvent degreasing systems. The total TRI releases and transfers from the manufacturers of chosen detergent ingredients were significantly less than the releases from solvent producers, further supporting the conclusion that aqueous wash chemical emissions from production and use processes are less when compared to degreasing solvents.

However, the quantity of chemicals used (or released) by the aqueous wash systems is only part of the national environmental impacts that must be evaluated. The impact on the nation's POTW infrastructure is also an issue. This issue was also evaluated above. From the EPA's "Survey of Needs" publication, the capacity and treatment capabilities within the nation's POTW infrastructure can be considered adequate to accommodate entire industrial sectors replacing solvent degreasing systems with aqueous wash systems and the resulting water waste streams.

The relative toxicity and risk to the environment and human health were evaluated in Chapter 5, Environmental Evaluation. In general, if the various waste streams are managed according to current regulatory requirements, direct exposure to toxic air releases of TCA dominate human exposure potentials. Proper management of waste residuals (hazardous and nonhazardous) and the treatment of wastewaters from aqueous wash systems, represent limited risk to humans and the environment.

CHAPTER 8

CONCLUSIONS

In 1989 the management of Calsonic Manufacturing Corporation of Shelbyville, Tennessee established a goal to eliminate 1,1,1-trichloroethane from all cleaning processes by 1995. This goal was achieved by November 1994 with the implementation of a variety of parts cleaning alternatives. Two process changes which contributed to the accomplishment of this goal were the replacement of solvent degreasers with an aqueous wash system (detergent) on a radiator manufacturing line and a hot water wash system on a converter manufacturing line. A third alternative was the application of an evaporative lubricant that does not require cleaning for subsequent processing, therefore eliminating the need for solvent cleaning. These three specific process alternatives were the focus of this research.

The technical, environmental, and economic evaluations performed in this study were completed using CMC's historic records, information obtained from site visits and interviews with CMC employees, the on-line TRI data base, and literature searches. The radiator and condenser manufacturing lines were the main focus of the research. The merits of the hot water wash system were presented as supplemental information to the aqueous wash alternative. The environmental analysis of the substitutes was expanded to evaluate the national environmental benefits possible if entire industry sectors were to implement similar process changes.

The following conclusions were drawn from the analyses completed for this project:

1. The implementation of the cleaning process alternatives either improved or did not affect the performance of subsequent process steps or the quality of the products.
2. The process changes eliminated the toxic emissions of TCA while creating new waste streams of wastewater, in the case of the aqueous wash system, and VOCs, in the case of the evaporative lubricant. The quantity of chemicals consumed by the alternative processes is significantly less than that of the solvent systems.
3. Activity- based cost accounting showed that the alternative cleaning processes were considerably less expensive to operate and maintain than the TCA degreasing systems. The capital costs for the alternatives were more than justified by the savings in operations with payback periods ranging from 0.27 to 2.4 years.
4. The national environmental impact evaluation suggests that significant reductions in life-cycle chemical emissions will occur with implementation of alternative cleaning systems. Generally, for the aqueous wash systems, the shift would mean increased wastewater loads and oily pollutant discharges to POTWs. The nation's POTW infrastructure, in aggregate, can handle these increased loads, however, the shift in waste stream composition must be evaluated on a case-by-case basis.

A discussion of these conclusions follows

TECHNICAL EVALUATION

The technical evaluation analyzed the merits of the alternative cleaning systems (both the aqueous wash and the no-clean, evaporative lubricant systems) by comparing the production rate (e.g., the cleaning cycle time per unit manufactured) and the part reject rates between the old and new processes. Both historical data and interviews with CMC quality control staff established the results summarized in Table 52.

TABLE 52. SUMMARY OF THE TECHNICAL EVALUATION RESULTS		
Line	Cycle Time	Reject Rate
Radiator	50% reduction in cycle time due to aqueous wash implementation	76% reduction in part reject rate due to aqueous wash system
Condenser	no significant change	no significant change

Interviews with line personnel and management indicated that the solvent degreasing units represented the bottle-neck of the radiator manufacturing process. The aqueous wash system eliminated that bottle-neck by reducing the cleaning process time by half compared to that of the solvent system. The parts reject rates for the radiator line also decreased, significantly, after the implementation of the aqueous wash system. The decrease of 76 percent in part reject rates can be predominantly attributed to the improved cleaning characteristics of the aqueous wash system. The implementation of the aqueous wash process had been supported by an internal task force which was responsible for decreasing radiator rejects through process improvements.

The production and part reject rates for the condenser line were evaluated through employee interviews. Through these interviews it was established that the implementation of the no-clean process alternative had little effect on either rate.

ENVIRONMENTAL EVALUATION

The changes in chemical releases and transfers to the environment from CMC's manufacturing facilities due to the implementation of the alternative processes included the following:

- elimination of TRI reporting requirements of TCA releases and transfers from each process line;
- the creation of a state-regulated VOC air emission for the condenser line; and
- the creation of a wastewater stream for the radiator line and the separation and disposal of the oily waste removed from the parts.

These changes are summarized for the radiator and condenser manufacturing lines in the following table. Although it eliminated the use and disposal of TCA, the hot water wash system of the converter line was not quantitatively evaluated in this analysis. A qualitative evaluation of the advantages of this system are presented throughout Chapter 5, as well as in the national environmental impact evaluation of Chapter 7.

TABLE 53. SUMMARY OF ENVIRONMENTAL EVALUATION RESULTS				
Line	Total Waste Generation per Year			
	Solvent Degreasing Operations		Alternative Systems Operations	
Radiator	171,500 lb	TCA consumed	22,100 lb	detergent consumed
	114,900 lb	TCA haz. waste transfers	2.0 million gal	wastewater generated
	56,600 lb	TCA air releases	10,800 lb	non-haz., oily waste transfers
			64,780 lb	non-haz. wastewater treatment solids transfers
	(1990)		(1992)	
Condenser	121,500 lb	TCA consumed	12,200 lb	evap. lub. consumed
	14,400 lb	petroleum lub. consumed	12,200 lb	VOC air releases
	75,400 lb	TCA haz. waste transfers		
	46,100 lb	TCA air releases		
	(1992)		(1994)	

Though the aqueous wash system of the radiator line generates two million gallon of wastewater per year, chemical consumption, when compared to the solvent degreasing system, has greatly decreased. The consumption rate of detergent, 2,640 gal/yr per year (22,100 lb/yr), is minimal when compared to the 15,840 gal/yr (171,700 lb/yr) of TCA previously consumed. The evaporative lubricant system of the condenser line has similar advantages; the release of 12,200 lb/yr of VOCs is significantly less than the 121,500 lb/yr of TCA released by the degreasers.

These data clearly show the trade-off issues that must be considered when choosing between alternative cleaning systems. For the radiator line, releases of the toxic, ozone-depleting chemical TCA were eliminated, but a larger volume, lower toxicity wastewater stream was generated. Although hazardous waste management requirements have been eliminated for this line, pretreatment requirements for discharge into the local POTW must still be met. For the condenser line, hazardous waste and TCA were again eliminated. Air

releases decreased substantially, suggesting less potential employee exposure; complete data on the relative toxicity and risk of exposure to TCA and the mineral-spirit-based VOCs emitted by the evaporative lube, however, are not available. This is one of the reasons CMC is now switching to a non-petroleum based evaporative lube.

ECONOMIC EVALUATION

Two economic evaluations were completed for the analyses of the alternatives. The first evaluation used a traditional method focussing on direct costs. The second method utilized activity-based costing (ABC) to more accurately allocate overhead costs to the appropriate products and processes. Finally, a hybrid of these methods was used to fully represent the costs and benefits of the alternatives. The hybrid analyses resulted in the most accurate assessment of costs for both the solvent degreasing operations and the alternatives. The results of the hybrid analyses are discussed below. Tables 54 and 55 compare the hybrid analysis results with the traditional economic evaluation results for the radiator and condenser lines, respectively.

The analysis shows that the hybrid method identified additional direct costs associated with the solvent degreasing units of the radiator line that would have been part of an overhead cost factor in a more traditional analysis. Though the results of the traditional analysis of the evaporative lubrication system are positive, the benefits of the radiator's aqueous wash system were only apparent with the hybrid economic analysis method. The presentation of these results in Chapter 6 illustrate very clearly that traditional cost analyses are not adequate to fully estimate the benefits of pollution prevention projects. By properly allocating costs through ABC that would normally be part of an overhead factor, benefits beyond traditional costing techniques are realized.

TABLE 54. SUMMARY OF ECONOMIC ANALYSES RESULTS - RADIATOR MANUFACTURING LINE				
	Hybrid Analysis		Traditional, Direct Cost Analysis	
Analysis	Solvent System	Aqueous Wash System	Solvent System	Aqueous Wash System
Payback		2.4 years		11.6 years
NPV (5-year)	\$2,584,150	1,514,260	\$660,580	\$808,280
NPV (10-year)	\$5,725,530	\$3,073,640	\$1,464,270	\$1,508,720
NPV (15-year)	\$9,547,510	\$4,762,870	\$2,442,090	\$2,147,930

Note: dollar values represent costs.

TABLE 55. SUMMARY OF ECONOMIC ANALYSES RESULTS - CONDENSER MANUFACTURING LINE				
Analysis	Hybrid Analysis		Traditional, Direct Cost Analysis	
	Solvent System	Evaporative Oil System	Solvent System	Evaporative Oil System
Payback		0.27 years		0.45 years
NPV (5-year)	\$1,089,550	\$219,660	\$619,750	\$99,930

Note: dollar values represent costs.

NATIONAL ENVIRONMENTAL IMPACT EVALUATION

This evaluation utilized the life-cycle concept to evaluate the potential environmental impacts which could result throughout the life-cycle of the chemicals used in the traditional and alternative processes. The environmental evaluation of CMC's process changes was used to estimate the potential national environmental impacts if entire industrial sectors were to implement the alternatives to solvent degreasing. The elimination of chlorinated solvents for materials and parts degreasing could significantly impact the national emissions of these chemicals from their production, use and disposal. The implementation of the alternative systems, though having associated releases and transfers of other chemicals, could significantly decrease the environmental impacts now associated with the life-cycle of solvent degreasers and the solvents used.

Materials and parts degreasing systems consume an estimated 499.9 million lb/yr of chlorinated solvents, based on 1992 figures. This use results in significant air releases and hazardous waste transfers. In addition to these direct use and disposal emissions, solvent emissions as a result of chlorinated solvent production processes must also be attributed to materials and parts degreasing. An estimated 460,000 lb of chlorinated solvent from manufacturing emissions (1992 TRI) may be attributed to solvent degreasing processes based on current production rates and degreasing application figures.

The implementation of aqueous wash alternatives, though eliminating the production, use, and disposal emissions of the chlorinated degreasing solvents, has unique emissions of its own. Detergents, a mixture of surfactants, builders, chelators, and other ingredients, have associated chemical production releases and transfers. Emissions from commonly used ingredients (e.g., ethoxylated alcohols, alkylbenzene sulfonates, EDTA, and tetrapotassium pyrophosphate) include ethylene, ethylene glycol, benzene, glycol ethers, and a variety of acids. An estimate of the quantity of detergent ingredients applied to industrial applications was not available, and therefore an estimate of the amount of production releases which could be allocated to the industrial use of detergents was not possible. However, order-of-magnitude calculations show that life-cycle releases and transfers could be significantly reduced with the implementation of the aqueous alternative.

A second issue to address when considering the life-cycle attributes of aqueous wash systems is the water waste stream that must be properly managed. Pretreatment of the

wastewater from aqueous systems may be required to adequately remove oils, greases, BOD, and suspended solids. The evaluation of the POTW infrastructure suggests that both the nation's capacity and treatment capabilities are adequate to accommodate changes to aqueous systems by entire industrial sectors, but the capacity and pretreatment requirements of local POTWs must be taken into account for specific applications.

REFERENCES

- ¹ U.S. Environmental Protection Agency, Office of Pollution Prevention, "Pollution Prevention Fact Sheet: EPA's 33/50 Program," (Washington: GPO, August 1991).
- ² U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ³ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ⁴ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ⁵ U.S. Environmental Protection Agency, "Survey of Trichloroethylene Emission Sources," Pub. No. EPA-450/3-85-021, (Research Triangle Park, North Carolina), July 1985.
- ⁶ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ⁷ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ⁸ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ⁹ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ¹⁰ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ¹¹ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ¹² Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ¹³ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.

- ¹⁴ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ¹⁵ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ¹⁶ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ¹⁷ *Pollution Engineering*, "Aqueous Cleaners Challenge Chlorinated Solvents," December 1991.
- ¹⁸ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ¹⁹ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ²⁰ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ²¹ Aronson, Robert B., "It's Time to Panic," *Manufacturing Engineering*, September 1993.
- ²² Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ²³ *Water Quality and Treatment*, 4th Edition, American Water Works Association, 1990.
- ²⁴ "Regulatory Toxicology and Pharmacology," International Society of Regulatory Toxicology and Pharmacology, Vol. 20, No. 1, May 1994.
- ²⁵ 1,1,-Trichloroethane, Hazardous Substances Data Bank (HSDB), October 1990.
- ²⁶ "Regulatory Toxicology and Pharmacology," International Society of Regulatory Toxicology and Pharmacology, Vol. 20, No. 1, May 1994.
- ²⁷ Bartnik, F. and K. Kunstler, "Biological Effects, Toxicology and Human Safety," Surfactants in Consumer Products, 1987.
- ²⁸ Bartnik, F. and K. Kunstler, "Biological Effects, Toxicology and Human Safety," Surfactants in Consumer Products, 1987.
- ²⁹ Sodium Tripolyphosphate, Hazardous Substances Data Base (HSDB), May 1995.

- ³⁰ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1991.
- ³¹ Ethylenediamine Tetraacetic Acid, Hazardous Substances Data Base (HSDB), May 1995.
- ³² Kirk Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1991.
- ³³ Spitzer, Martin A. "Calculating the Benefits of Pollution Prevention," *Pollution Engineering*, September 1, 1992.
- ³⁴ Spitzer, Martin A. "Calculating the Benefits of Pollution Prevention," *Pollution Engineering*, September 1, 1992.
- ³⁵ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ³⁶ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ³⁷ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ³⁸ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ³⁹ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ⁴⁰ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ⁴¹ U.S. Environmental Protection Agency, Office of Research and Development, "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes," Pub. No. EPA/600/R-94/178, September 1994.
- ⁴² U.S. Environmental Protection Agency, "Survey of Methylene Chloride Emission Sources," National Emission Standards for Hazardous Air Pollutants, EPA-450/3-95-015, June 1985.
- ⁴³ SRI Directory of Chemical Producers United States. SRI International, 1992.
- ⁴⁴ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1993.

- ⁴⁵ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁴⁶ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁴⁷ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1993.
- ⁴⁸ Phone conversation with Speciality Chemical Manufacturing Association.
- ⁴⁹ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1993.
- ⁵⁰ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁵¹ Pittinger, Charles A., et. al., "Environmental Life-Cycle Inventory of Detergent - Grade: Sufactant Sourcing and Production," 1991.
- ⁵² Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁵³ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁵⁴ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁵⁵ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1993.
- ⁵⁶ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁵⁷ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁵⁸ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.

- ⁵⁹ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁶⁰ Ullmann's Encyclopedia of Industrial Chemistry, Vol. A17, 1985.
- ⁶¹ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁶² Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁶³ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁶⁴ Ullmann's Encyclopedia of Industrial Chemistry, Vol. A10, 1985.
- ⁶⁵ Ullmann's Encyclopedia of Industrial Chemistry, Vol. A10, 1985.
- ⁶⁶ SRI Directory of Chemical Producers United States. SRI International, 1992.
- ⁶⁷ Davis, Gary, et. al. , "Household Cleaners: Environmental Evaluation and Proposed Standards for General Purpose Household Cleaners," University of Tennessee, Center for Clean Products and Clean Technologies, prepared for Green Seal, Inc., July 1992.
- ⁶⁸ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ⁶⁹ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ⁷⁰ U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning - Background Information Document," Pub. No. EPA-453/R-93-054, (Research Triangle Park, North Carolina).
- ⁷¹ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.
- ⁷² Interview with Shelbyville, Tennessee's wastewater treatment operators.

⁷³ United States Geological Survey, "Water Resources Data Tennessee Water Year 1993," Water-Data Report TN-93-1, 1994.

⁷⁴ U.S. Environmental Protection Agency, Office of Wastewater Exposure and Compliance, "1992 Needs Survey Report to Congress," Pub. No. EPA 832-R-93-002, September 1993.

⁷⁵ U.S. Environmental Protection Agency, Office of Wastewater Exposure and Compliance, "1992 Needs Survey Report to Congress," Pub. No. EPA 832-R-93-002, September 1993.

⁷⁶ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 5, 1991.

⁷⁷ Kirk-Othmer Encyclopedia of Chemical Technology, 4th Ed., Vol. 7, 1993.

⁷⁸ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.

⁷⁹ Center for Emission Control, "Solvent Cleaning (Degreasing), An Assessment of Emission Control Options," November, 1992.

⁸⁰ Wastewater Engineering in Treatment, Disposal and Reuse, Metcalf and Eddy, Inc., 3rd Ed., McGraw Hill Publishing Co., 1991.

APPENDIX A

RAW DATA IN DATA REQUEST TABLES

CMC was asked to complete the following data request tables. These tables allowed for the collection of process information including capital costs, operating and maintenance costs, utilities consumption, and production data. Similar data were requested for both the solvent degreasing systems (historic data) and alternative systems (current data). Table A1 presents the data requested and received for the radiator manufacturing line; and Table A2 presents condenser manufacturing line data.

TABLE A1. COMPLETED DATA REQUEST TABLES - RADIATOR MANUFACTURING LINE		
Data Request	Solvent Cleaning System	Aqueous Wash System
Equipment type	not available	Ransohoff
Equipment model number	not available	H-2144
Number used	5	1
Capital Cost - Cleaning Equipment		
Equipment (indicate total cost if more than one unit)	not available	\$463,595.24
Year purchased	not available	1991
Installation (% of equip. cost or specify units)	not available	\$38,979.24
Year installed	not available	1991
Instrumentation (% of equip. cost or specify units)	not available	included above
Plant Engineering (% of equip. cost or specify units)	not available	included above
Materials (% of equip. costs or specify units)	not available	included above
Floor area required (sq ft)	385	470
Floor area cost (\$/sq ft)	30	30
Estimated pay-back period	not applicable	not calculated

Table A1 continued

Data Request	Solvent Cleaning System	Aqueous Wash System
Capital Cost-Ultrafiltration Unit		
Equipment	not applicable	An ultrafiltration system for the aqueous wash system to reuse spent water was a future plan of CMC's. No data on these units were currently available.
Year purchased	not applicable	
Installation (% of equip. cost or specify units)	not applicable	
Year installed	not applicable	
Instrumentation (% of equip. cost or specify units)	not applicable	
Plant engineering (% of equip. cost or specify units)	not applicable	
Materials (% of equip. cost or specify units)	not applicable	
Floor area required (sq. ft.)	not applicable	
Estimated pay-back period	not applicable	
Operating Cost		
Operators/shift	1	1
Hrs/shift/operator	8	8
Shifts/day	2	2
Operating days/year	237	237
Average wage rate, \$/hr	\$13.65	\$13.65
1,1,1-trichloroethane \$/lb or \$/gal (specify units)	\$7.90/gal	not applicable
1,1,1-trichloroethane lb or gal used/shift	65 gal/day	not applicable
Aqueous cleaner \$/lb or \$/gal (specify units)	not applicable	\$7.70/gal
Aqueous cleaner lb or gal used/shift	not applicable	5.5 gal
Supervision (as % of O&M cost or specify units)	5%	0
Maintenance Cost		
Labor (as % of capital costs or specify units)	not available	not available
Materials (as % of capital costs or specify)	not available	not available
Cleaning equipment down time/year	5%/day plus 2 wks/yr	3 days/year
Effect of cleaning method on downstream equip. maint.	not applicable	not available

Table A1 continued

Data Request	Solvent Cleaning System	Aqueous Wash System
Operating Parameters		
Initial hot water wash temperature (degrees F)	not applicable	145
Initial hot water wash chamber size (L x W x H in ft)	not applicable	7.5 x 3.5 x 1.5
Aqueous wash or degreasing chamber temp (degrees F)	not available	120
Aqueous wash or degreasing chamber size (L x W x H in ft)	not available	7.5 x 3.5 x 1.5
Hot water rinse no. 1 temperature (degrees F)	not applicable	100
Hot water rinse no. 1 chamber (L x W x H in ft)	not applicable	7.5 x 3.5 x 1.5
Hot water rinse no. 2 temperature (degrees F)	not applicable	90
Hot water rinse no. 2 chamber (L x W x H in ft)	not applicable	1.0 x 3.5 x 1.5
Drying method	not available	not applicable
Drying temperature (degrees F)	not available	not applicable
Drying chamber size (L x W x H in ft)	not available	not applicable
Number of parts cleaned per batch	2	continuous process
Residence time of parts in cleaning system (in minutes)	2.6 min	1.3
Conveyor speed (ft/min)	not applicable	5.7
Nozzle flow rate (gam)	not applicable	375
Nozzle pressure (psi)	not applicable	40
Utilities consumption (please indicate units)		
Power consumption (nameplate capacity, specify units)	4 heaters/unit	not available
Power consumption (% of capacity or specify units)	1,248 kW-hr/shift	672 kW-hr/shift
Power cost (\$/kW-hr)	0.035	0.035
Fuel consumption (nameplate capacity, specify units)	not available	not available
Fuel consumption (% of capacity or specify units)	not available	16240 SCF/shift
Fuel cost (\$/unit)	not available	\$58.46/shift
Water consumption (nameplate capacity, specify units)	not available	--
Water consumption (% of capacity or specify units)	not available	3710 gal/shift
Water cost (\$/gal)	not available	\$0.00134/gal

Table A1 continued

Data Request	Solvent Cleaning System	Aqueous Wash System
Production Data		
Name of part or assembly cleaned	Radiator Core	Radiator Core
Size of part (L x W x H in ft)	2.3 x 2.3 x 0.17	2.3 x 2.3 x 0.17
material of construction	Aluminum	Aluminum
Part configuration	Fine welded tubes, side and end plates	
Upstream manufacturing process	stamping, fin forming	stamping, fin forming
Downstream manufacturing process	brazing	brazing
Sensitivity of downstream process to cleanliness	high	high
Soil (e.g., oil, coolant, etc.) being removed (attach MSDS)	Oils and coolant	Oils and coolant
Cleanliness test methods	black light and leak tests	black light and leak tests
Frequency of cleanliness testing	monthly/daily	monthly/daily
Production rate (parts/hour)	not available	not available
% of parts cleaning capacity being utilized	not available	67%
Average part reject rate (%)	5%	0.5 - 1%
Cost of rejected part (\$/part)	not available	not available

**TABLE A2. COMPLETED DATA REQUEST TABLES - CONDENSER
MANUFACTURING LINE**

Data Request	Solvent Cleaning System	Aqueous Wash System
Equipment type	Conveyorized Vapor	Conveyorized Vapor
Equipment model number	Offpit OS-1337	In-house design
Number used	2	4
Capital Cost - Ultrafiltration Unit		
Equipment (indicate total cost if more than one unit)	\$76,000	\$44,000
Year purchased	1984	1993
Installation (% of equip. cost or specify units)	5%	2%
Year installed	1984	1993
Instrumentation (% of equip. cost or specify units)	25%	40%
Plant engineering (% of equip. cost or specify units)	10%	8%
Materials (% of equip. costs or specify units)	60%	50%
Floor area required (sq ft)	200	25
Floor area cost (\$/sq ft)	\$30	\$30
Estimated pay-back period	not applicable	0.3 years
Operating Cost		
Operators/shift	1	1
Hrs/shift/operator	8	8
Shifts/day	2	2
Operating days/year	240	240
Average wage rate, \$/hr	\$13.65	\$13.65
Supervision (as % of O & M cost or specify units)	3%	3%
1,1,1-trichloroethane \$/lb or \$/gal (specify units)	\$7.90/gal	not applicable
1,1,1-trichloroethane lb or gal used/shift	38 gal/shift	not applicable
Previous oil cost \$/gal or \$/lb	\$5.22/gal	not applicable
Previous oil lb or gal used/shift	1 gal	not applicable
Evaporative lube cost \$/gal or \$/lb	not applicable	9.84/gal

Table A2 continued

Data Request	Solvent Cleaning System	Aqueous Wash System
Evaporative lube lb or gal used/shift	not applicable	1 gal
Maintenance Cost		
Labor (as % of capital costs or specify units)	3%	0.5%
Materials (as % of capital costs or specify)	2%	1%
Cleaning equipment down time/year	200 hrs	12 hrs
Operating Parameters		
Vapor degreasing chamber temp. (degrees F)	160	not applicable
Vapor degreasing chamber size (L x W x H in ft)	20 x 6 x 6	not applicable
Post vapor degreasing drying method	Air	not applicable
Post vapor degreasing drying temperature (degrees F)	100	not applicable
Post vapor degreasing drying chamber size (L x W x H in ft)	6 x 6 x 2	not applicable
Fin dryer drying temperature (degrees F)	not applicable	392
Fin dryer length (ft)	not applicable	2 ft
Residence time of parts in cleaning system (in minutes)	1.6	0.167
Conveyor speed (ft/min)	12	12
Utilities Consumption (please indicate units)		
Power consumption (nameplate capacity, specify units)	124.8 kW-hr/hr	83.2 kW-hr/hr
Power consumption (% of capacity or specify units)	62.4 kW-hr/hr	33.28 kW-hr/hr
Power cost (\$/kW-hr)	\$0.035/kW-hr	\$0.035/kw-hr
Fuel consumption (nameplate capacity, specify units)	not applicable	not applicable
Fuel consumption (% of capacity or specify units)	not applicable	not applicable
Fuel cost (\$/unit)	not applicable	not applicable
Water consumption (nameplate capacity, specify units)	not applicable	not applicable
Water consumption (% of capacity or specify units)	not applicable	not applicable
Water cost (\$/gal)	not applicable	not applicable

Table A2 continued

Data Request	Solvent Cleaning System	Aqueous Wash System
Production Data		
Name of part of assembly cleaned	Corrugated fin	
Size of part (L x W x H in ft)	0.0531 x 0.0851 x 31	
Material of construction	aluminum	
Part configuration	horizontal continuous	
Upstream manufacturing process	assembly	
Downstream manufacturing process	furnace braze	
Sensitivity of downstream process to cleanliness	high	
Soil (e.g., oil, coolant, etc.) being removed (attach MSDS)	30 wt spindle oil	Daphne AF2AU
Cleanliness test methods	visual	visual
Frequency of cleanliness testing	2/shift visual	2/shift visual
Production rate (parts/hour)	not available	not available
% of parts cleaning capacity being utilized	100%	100%
Average part reject rate (%)	0	0
Cost of rejected part (\$/part)	not available	not available

The following information was requested from CMC outside of the data request tabular form. These forms appear as they were presented to CMC. Data supplied by CMC are presented in **bold** style font.

WASTE DATA: WASTEWATER TREATMENT FACILITY

1. What is the wastewater treatment design capacity? **30,000** gal/day
2. What is the wastewater treatment normal flowrate? **25,000** gal/day
3. Has this normal flowrate changed due to process changes to cleaning systems (i.e. change to aqueous)? ☐ yes ☒ no

If yes, by how much has the flowrate changed? **NA** gal/day

4. Is this flow rate ☒ measured ☐ estimated?
5. In the table below, please list required permits (operating, discharge, etc.) associated with the treatment facility, including permit fees, permit renewal fees, and frequency of permit renewal. Please attach copies of each permit identified below.

Permit	Permit Fee (\$)	Renewal Fee (\$)	Frequency
Industrial Discharge Permit	0.00	0.00	every 2 years

6. Have these permits required revisions to accommodate the changes to aqueous cleaning systems? ☐ yes ☒ no

If yes, what type of revisions were required, and how were they identified?

7. In the table below, list the treatment chemicals (acids/bases, polymers, etc.) used in the wastewater treatment and solids handling processes. Please include a description of the chemical application/deliverance system, quantity of chemicals used, and prices. Please attach MSDS sheets for each chemical identified below.

Chemicals used in treatment operations and a description of their application/delivery.	Quantity Used/Day	Price (\$/gal)
Chemical: Sodium Hydroxide	25 gal	1.40
Description: pH adjustment - metering pumps		
Chemical: Sulfuric Acid	45 gal	1.24
Description: pH adjustment - metering pumps		
Chemical: Anionic Polymer	5	\$2.74/lb
Description: flocculent		
Chemical:		
Description:		

8. Please indicate power consumption for the wastewater treatment system in the table below. **Unknown**

Specific Process Unit (check appropriate box on left)		Power Consumption (name plate or metered, kWhr.)
<input type="checkbox"/>	Power consumption of the system as a whole.	
OR		
<input type="checkbox"/>	Separate Process Units (please identify the number of units used):	
	Pumps	
	Mixers	
	Solids Press	
	Other (please specify)	

9. Please identify additional requirements and costs associated with the wastewater treatment facility, including the following items:

a. operating and maintenance

number of employees: 2

time/employee/day devoted to treatment plant: 12 hr/day

b. testing and analysis

parameters tested: see permit requirements

frequency of testing: every 4 months

Is this testing traditionally done ☐ in house
☒ contracted out?

cost of analyses: \$300.00 \$/test series

wastewater surcharges and/or disposal costs: \$0.00134 \$/gal

solids disposal costs: \$14.90 \$/drum, **30 drums/2 weeks**

Please attach waste manifest sheets/data if applicable.

- c. Have the aqueous cleaning systems resulted in an increased volume of solids to be disposed of from the treatment facility? If yes, what is the volume of, and the possible reasons for the increase. **No**
- d. other (please specify)

WASTE DATA: AQUEOUS CLEANING SYSTEM - RADIATOR LINE

1. Wastewater generation: ☒ continuous
both ☒ batch/intermittent
2. If continuous, at what flowrate is it generated? 7800 gal/day
3. If batch, please answer the following questions. **NA**
 - a. frequency of discharge: once/week (specify units)
 - b. volume of wastewater per discharge: approx. 3000 gal. gal/discharge
 - c. duration of discharge (e.g. hours, minutes, etc. please specify): 2 hrs.
 - c. discharge triggered by: ☐ chemical analysis of stream
☐ parts cleanliness/performance
☒ other shut down
 - d. please indicate specific parameters triggering discharge (e.g. black light test, oil/water ratio, etc.) Wash tanks are emptied weekly, approximately 3000 gallon total. Weekly dumps show best results for product cleanliness.
4. What other waste streams are generated from the radiator aqueous cleaning system (e.g. oil residual from skimmer, manual wash of tubes, etc.)?

Waste	Volume (gal/day)	Classification	Method of Disposal
oil and water	5.5	non-hazardous	disposal facility (fuel blending)

5. What analyses are performed on the wastewater and other waste streams presented above? Please attach any results of tests that have been performed. **NA**
6. On a separate page, please explain the procedures used to drain the aqueous cleaning unit including number of employees involved, electrical/mechanical equipment required, and the time required. **One employee opens valves on each tank. The tanks are emptied by in-line pump which discharges to on-site wastewater treatment plant. Time is approx. 2 hours.**

**WASTE DATA: HAZARDOUS: 1,1,1 TRICHLOROETHANE WASTE -
RADIATOR, CONVERTER AND CONDENSER LINES
(Please return by March 28, 1994)**

1. Total volume of 1,1,1 trichloroethane disposed of as hazardous waste from Buildings 1 and 2 for 1990, 1991, 1992, and 1993?
1991 = 338,525 lb 1992 = 206,345 lb 1993 = 194,975 lb
2. Total volume of 1,1,1 trichloroethane disposed of as hazardous waste from Building 3 for 1992 and 1993?
1992 = 3,480 lb 1993 = 11,140 lb
3. What permit(s) are required for these waste streams (please attach copy of permit (or application) and parameters)?
None, RCRA regulated; large quantity generator status.
 - a. are permits facility specific?
 - b. frequency of renewal?
 - c. cost of permit application and/or renewal?
\$900.00 annual haz. waste generation fee.
4. If available, please list the 1,1,1 TCA waste volume contributions from specific lines (see table below).

Year	Radiator	Convertor	Condenser
1990	10,600 gal	2,500 gal	6,960 gal
1991	8,000 ga.	2,500 gal	6,960 gal
1992	not applicable	unknown	unknown
1993	not applicable	unknown	unknown

5. Waste disposal operations
 - a. How frequently was 1,1,1 TCA drained from degreasing units?
 - radiator line **as needed**
 - convertor line **as needed**
 - condenser line **as needed**
 - b. How was this frequency determined (e.g. buildup of soils, parts failed cleanliness tests, smoking at welding operations, etc.)?
 - radiator line **build up of soils, parts did not braze**
 - convertor line **build up of soils, parts did not weld**
 - condenser line **build up of soils, parts did not braze**

- c. Please list in table below the personnel responsible for 1,1,1 trichloroethane disposal operations (designate either line operator or corporate environmental engineer and the time required for each step).

Operation	Radiator		Convertor		Condenser	
	who	time per occurrence	who	time per occurrence	who	time per occurrence
draining tanks and filling drums	tech.	various	tech.	various	tech.	various
labeling and sealing drums	tech.	various	tech.	various	tech.	various
drum transport to storage	tech.	various	tech.	various	tech.	various
manifest completion	env. eng.	various	env. eng.	various	env. eng.	various

6. How are these hazardous wastes disposed of?
☐ incinerated?
☒ recycled?
☐ other (please specify)
7. Where are they disposed of?
8. If incinerated, is it for energy conversion? ☒ yes ☐ no
9. If recycled, do you receive the material back for reuse? ☒ yes ☐ no
10. What are the costs of disposal (incineration, recycling, other) including disposal fees, transportation fees, taxes, etc.?
\$1.80 per gal, price includes transportation, recycling, but not resale revenue.

**WASTE DATA: AIR EMISSIONS: 1,1,1 TRICHLOROETHANE WASTE -
RADIATOR, CONVERTER AND CONDENSER LINES (Please return by March 28,
1994)**

1. Total volume of 1,1,1 TCA air emissions reported for 1990 and 1991 for Buildings 1 and 2. **1990 = 425,756 lb 1991 = unknown**
How are these volumes determined? **mass balance**
2. Total volume of 1,1,1 TCA air emissions reported for 1992 and 1993 for Building 3. **1992 = 13,840 lb 1993 = 9,000 lb est.**
How are these volumes determined? **mass balance**
3. What permit(s) are required for this stream (please attach copy of permit (or application) and parameters)? **air permit**
 - a. are these permits facility specific? **yes**
 - b. are these permits line specific? **no**
 - c. what is the cost of permit application and/or renewal? **NA**
 - d. how frequently are renewals required? **various**
4. Volume of 1,1,1 TCA air emissions from radiator line reported for 1990 and 1991? **unknown - emissions are building specific**
5. Volume of 1,1,1 TCA air emissions from converter line reported for 1992 and 1993? **1992 = 14,011 lb 1993 = unknown, approx. 6,000 lb est.**
6. Volume of 1,1,1 TCA air emissions from condenser line reported for 1992 and 1993? **unknown - emissions are building specific**

APPENDIX B

SCREENING TEST RESULTS FOR THE AQUEOUS WASH SYSTEM

Two screening tests were employed by CMC to determine the applicability of viable cleaning alternatives; a black light contamination check and a brazed core check. The black light contamination check, sample results presented in Table B1 for various detergent products, inspects cleaned parts (e.g., radiator cores) for remaining soils after washing. Table B2 is an example of results from a brazed core check. In these tests the assembled cores are cleaned using the alternative method under investigation, brazed, and finally tested for leaks. The results of Table B2 show leak occurrences and the reason for each leak.

TABLE B1. AQUEOUS WASH TRIALS BLACK LIGHT CONTAMINATION CHECK									
Chemical Supplier	Trial Core #	Size-Mm	Checked Area					Side Reinf.	Score
			Tube Inside	Tube/ Header	Fin	Fin/ Tube	Header		
DuBois	A3	16	M	S	S	S	S	M	70
	A7	32	M	S	S	S	M	S	70
	B2	32	S	S	N	N	S	S	40
	B6	16	VS	N	N	VS	VS	VA	20
								TOTAL	200
Parker & Amchem	C3	16	N	VS	N	S	N	VS	20
	C7	16	N	N	N	S	VS	VS	20
	C3	32	VS	S	VS	S	VS	S	45
	C7	32	VS	VS	N	VS	VS	VS	25
								TOTAL	110
Oakite	D3	16	S	VS	N	VS	N	N	20
	D7	16	S	VS	N	S	VS	VS	55
	D12	32	VS	VS	N	S	VS	VS	30
	D16	32	VS	VS	N	VS	S	S	35
								TOTAL	140

N = None
 VS = Very Slight
 S = Slight
 M = Moderate
 0 Points
 5 Points
 10 Points
 15 Points

prepared by: Mike Simpson

TABLE B2. AQUEOUS WASH TRIALS BRAZED CORE CHECK					
Chemical Supplier	Trial Core #	Size-Mm	Fin Bond >/= 95.00%	Leak Test Results	Comments
DuBois	A4	16	99.93%	-	Cracked Tank-No Test
	A5	32	-	OK	
	A6	32	-	OK	
	A8	32	99.07%	OK	
	A9	32	-	OK	
	B1	32	-	OK	
	B3	32	-	OK	
	B4	32	100%	OK	
	B5	16	-	OK	
	B7	16	-	OK	
	B8	16	100%	OK	
	C1	16	-	OK	
	C2	16	-	OK	
	C4	16	-	OK	
	C5	16	-	OK	
Parker & Amchem	C6	16	-	OK	Destroyed in side clinch Top End Clinch Leak
	C8	16	99.93%	-	
	C9	16	-	OK	
	C1	32	-	OK	
	C2	32	-	NG - 8.8 Seconds	
	C4	32	99.89%	OK	
	C5	32	-	OK	
	C6	32	-	OK	
	C8	32	-	OK	
	C9	32	100%	OK	

continued

Table B2 continued

Chemical Supplier	Trial Core #	Size-Mm	Fin Bond >/= 95.00%	Leak Test Results	Comments
Oakite	D1	16	-	OK	
	D2	16	-	OK	
	D4	16	-	OK	
	D5	16	-	OK	
	D6	16	100%	OK	
	D8	16	-	OK	
	D9	16	-	OK	
	D10	32	-	OK	
	D11	32	100%	OK	
	D14	32	-	OK	
	D15	32	-	OK	
	D17	32	-	OK	
	D18	32	99.89%	OK	
CMC TRI 1,1,1	E1	16	-	NG - 11.2 Seconds	Tube Leak Side Reinforcement/Header Leak
	E2	16	100%	NG - Rough Test	
	E2	32	-	OK	
	E4	32	99.96%	OK	

APPENDIX C

STATISTICAL EVALUATIONS

This appendix presents the methods and calculations of the three statistical evaluations performed on CMC's production and part reject rate data. The source of the calculation methods was "Experimental Statistics Handbook 91," United States Department of Commerce, National Bureau of Standards, 1966.

REJECT RATE STATISTICAL ANALYSIS

Two analysis were used to evaluate the difference in reject rates both before and after the aqueous wash system was installed to replace the solvent degreasers. The chi squared test determined if the data sets were statistically different, and the student t test calculated confidence intervals around each data set.

Chi Squared Test - Comparing Two Proportions when the Sample Sizes are Large.

The chi square test was used to evaluate whether the data sets were statistically different. The general methodology and calculations are presented below, followed by the final results of the analysis using CMC data.

Question: Does the characteristic proportion for Product A differ from that for Product B?

The characteristic of concern for this analysis was failure rate; is there a statistical difference between the failure rate of Product A (radiator before process change) and the failure rate of Product B (radiator after process change). The following calculations were made to determine statistical differences.

The following procedure was used to perform a chi squared analysis of proportions:

1. Choose α , the significance level of the test.
For the analysis, $\alpha = 0.1$ and 0.025 .
2. Look up $\chi^2_{1-\alpha}$ for one degree of freedom in a 'Percentiles of the χ^2 Distribution' table.
For the analysis, $\chi^2_{1-\alpha} = 2.71$ (for $\alpha = 0.1$) and 5.02 (for $\alpha = 0.025$).
3. Compute: $\chi^2 = [n(|r_a * s_b - r_b * s_a| - n/2)^2] / (n_a * r * n_b * s)$

Parameters are defined in Table C1.

TABLE C1. SAMPLE DATA			
Product	Failures	Passes	Total
A	r_a	s_a	n_a
B	r_b	s_b	n_b
Total	r	s	n

4. If $\chi^2 > \chi^2_{1-\alpha}$, conclude that the two types of products do differ with regard to the proportion of the characteristic (i.e., failures).

The results of this test are presented in Table C2. When using chi square analysis, if $\chi^2_{(calculated)} \geq \chi^2_{(1-\alpha)}$, it can be concluded that the two data sets are statistically different. In the analysis performed on the radiator part reject data, $\chi^2_{(calculated)} \gg \chi^2_{(1-\alpha)}$, thus the two sets are statistically different.

TABLE C2. RESULTS OF CHI SQUARE ANALYSES		
Significance Level, α	$\chi^2_{(1-\alpha)}$	$\chi^2_{(calculated)}$
0.1	2.71	1621.37
0.025	5.02	

Note: If $\chi^2_{(1-\alpha)} < \chi^2_{(calculated)}$, the data sets are statistically different.

Student T - Confidence Intervals for the Population Mean when Knowledge of the Variability Cannot be Assumed - Two-Sided Confidence Interval.

Once established that these sets were statistically different from one another, student T tests were used to establish confidence intervals around the means of each sample set. The question the analysis answers and the calculation procedure are as follows:

Question: What is a two-sided $100(1 - \alpha)$ percent confidence interval for the true mean m ?

The following procedure was used to calculate confidence intervals around each data set.

1. Choose the desired confidence level, $1 - \alpha$.
For the analysis of Chapter 4, $\alpha = 0.1$ and 0.05 , thus the intervals around the mean will be 90 percent and 95 percent confident.

2. Compute: \bar{X} = arithmetic mean = $(1/n) * (\sum X_i)$
 and: s = standard deviation = $[(n\sum X^2 - (\sum X)^2)/(n^2 - n)]^{1/2}$
 with: n = number of data points in each sample set
 X_i = data points
3. Look up $t = t_{1-0.5\alpha}$ for $n-1$ degrees of freedom in a 'Percentiles of the t Distribution' table.
4. Compute: X_U = upper limit = $\bar{X} + t * s/\sqrt{n}$
 X_L = lower limit = $\bar{X} - t * s/\sqrt{n}$

TABLE C3. PARAMETER FOR DATA SETS AND ANALYSES		
Parameter	Before Change	After Change
n	13	16
$t_{0.95}$	1.782	1.753
$t_{0.975}$	2.179	2.131

The reject rate means and intervals, both before and after the process changes are normalized to maintain confidentiality and presented in Table C4. The means represent the average percent of production that was recorded as rejects for the sample sets. Comparing the mean of each data set shows that the radiator core reject rate decreased 76.8 percent after the aqueous wash system was implemented. Figure C1 graphically depicts these statistically different data sets.

TABLE C4. RESULTS OF STUDENT T ANALYSES		
Confidence Level, $1-\alpha$	Averages and Ranges	
	Solvent Degreasing	Aqueous Wash
0.90	1 ± 0.145	0.232 ± 0.057
0.95	1 ± 0.177	0.232 ± 0.072
standard deviation, s	0.293	0.135

- Notes:
1. All values normalized to average solvent degreaser reject rate.
 2. solvent degreasing data set: 6/24/91 through 10/6/91, 13 data points.
 3. aqueous wash data set: 1/13/92 through 5/3/92, 16 data points.

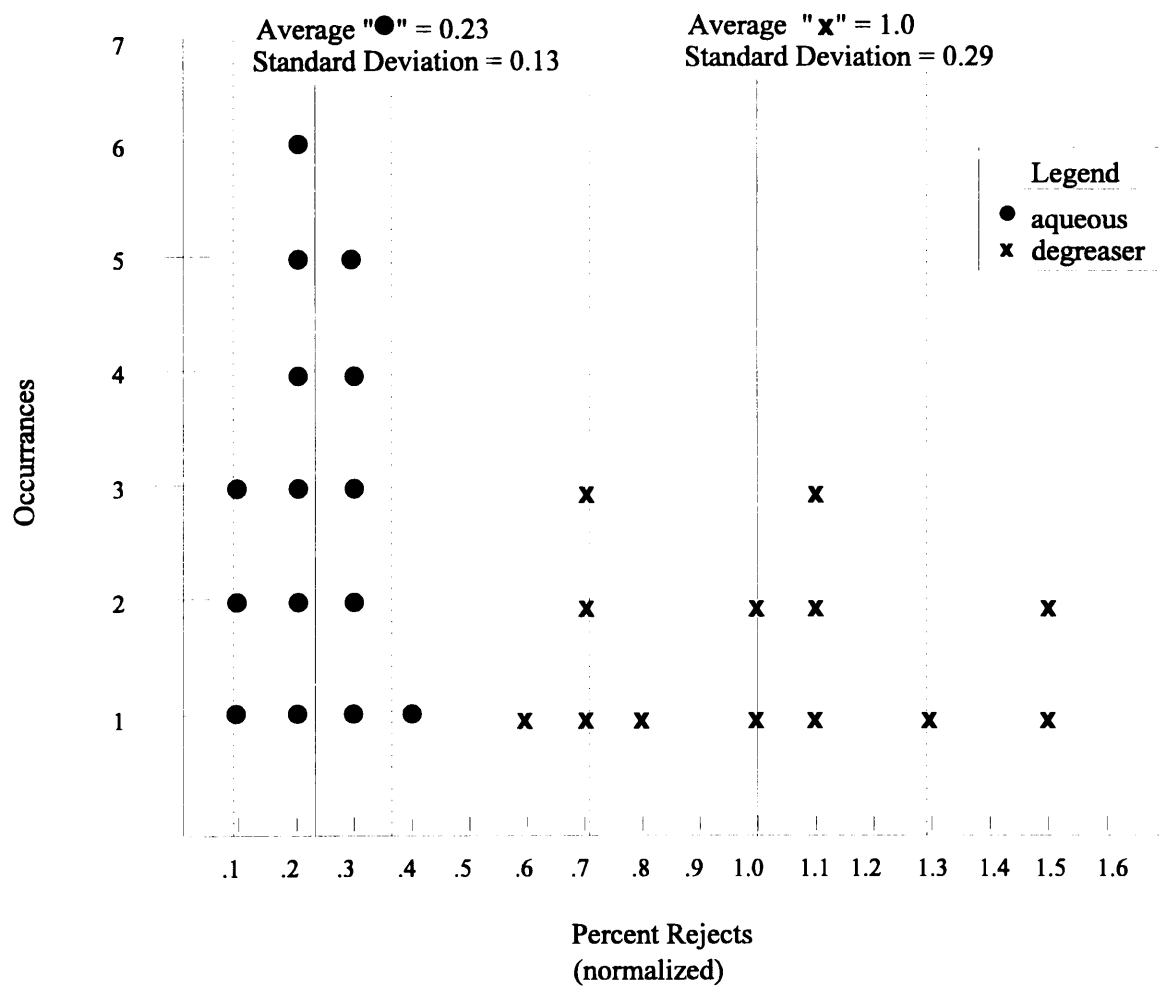


FIGURE C1. REPRESENTATION OF STATISTICALLY DIFFERENT DATA SETS

STATISTICAL EVALUATION OF WASTEWATER ANALYSIS BOD RESULTS

A two-sided t-test was used to determine whether the average BOD of the pretreated wastewater after the aqueous wash system was implemented differs from the average wastewater BOD while the solvent degreasing systems were operational. The evaluation method and the results of the analysis are presented below.

Question: Does the average of the new product differ from the standard (σ unknown)?

The following procedure was employed to analyze the data sets.

1. Choose α , the significance level of the test.
For the analysis, $\alpha = 0.1$ and 0.05
2. Look up $t_{1-0.5\alpha}$ for $n - 1$ degrees of freedom from a 'Percentiles of the t Distribution' table.
For the analysis, $t_{1-0.5\alpha} = 2.92$ (for $\alpha = 0.1$) and 4.303 (for $\alpha = 0.05$).
3. Compute: $X_{ave} = \text{arithmetic mean} = (1/n) * (\sum X_i)$
and: $s = \text{standard deviation} = [(n\sum X^2 - (\sum X)^2)/(n^2 - n)]^{1/2}$
with: $n = \text{number of data points in each sample set}$
 $X_i = \text{data points}$
4. Compute: $u = t_{1-0.5\alpha} s/\sqrt{n}$
5. If $|X_{ave} - m_o| > u$, then the averages of the two sets differ; you have two distinct sets.
where: $m_o = \text{the average of standard material}$

The results of this analysis are presented in Table C5.

TABLE C5. RESULTS OF PRODUCTION RATE STATISTICAL ANALYSES		
Significance Level, α	Computed u	$ X_{ave} - m_o $
0.1	36.0	23.9
0.05	53.1	

Note: If $|X_{ave} - m_o| < u$, the average of the new data set differs from that of the standard (i.e., the average wastewater BOD while the aqueous wash system was operational differs from the wastewater BOD while the solvent degreasers were operational).

APPENDIX D

CONVERSION TABLE

TABLE D1. CONVERSION FACTORS			
pascals (Pa)	x	9.86924×10^{-6}	= atmospheres (atm)
	x	0.101972	= kilograms per square meter (kg/m ²)
	x	1.450377×10^{-4}	= pounds per square inch (lb/in ²)
	x	0.0075	= millimeter of mercury @ 0°C (mmHg)
grams (g)	x	0.002205	= pounds, avdp (lb)
	x	0.035274	= ounces, avdp (oz)
meters (m)	x	3.28084	= feet (ft)
poise (P)	x	1	= grams per centimeter second (g/cm-sec)
	x	0.1	= pascal seconds (Pa-sec)
Joules (abs.)	x	9.4845×10^{-4}	= British thermal Units (BTU)
	x	1	= Watt-seconds (W-sec)
	x	0.23901	= gram calories (cal.)
Watt-hours (w-hr)	x	3.414426	= British Thermal Units (BTU)
	x	3600	= Joules (J)
liter (L)	x	0.035315	= cubic feet (ft ³)
	x	0.001	= cubic meters (m ³)
	x	0.26417	= gallons, U.S. liq. (gal)
grams per liter (g/L)	x	1000	= parts per million (ppm)
	x	0.0083452	= pounds per gallon (lb/gal)
mmHg @ 0°C	x	0.0013158	= atmospheres (atm)
	x	1.35951	= grams per square centimeter (g/cm ²)
	x	133.3224	= pascals (Pa)
Joules per kilogram	x	4.3021×10^{-4}	= British Thermal Units per pound (BTU/lb)
pounds (lb)	x	453.5923	= grams (g)
	x	16	= ounces, avdp (oz)
tons, short	x	2000	= pounds (lb)

Table D1 continued

	x	907.1847	= kilograms (kg)
gallons (gal)	x	0.1605436	= cubic feet (ft ³)
	x	1.200949	= gallons, U.S. liq. (gal)
pounds per gallon (lb/gal)	x	119.826	= grams per liter (g/L)

$^{\circ}\text{F} = 1.8\ ^{\circ}\text{C} + 32$

k = Kilo = 10^3

c = centi = 10^{-2}

M = mega = 10^6

m = milli = 10^{-3}

Source: "Avogadro's Numbers," Indelible Ink

APPENDIX E

CALSONIC CORPORATION'S ENVIRONMENTAL PROGRAM

A. OBJECTIVE

To properly manage and reduce usage and emissions of pollutants and hazardous materials, and to ensure strict compliance with all Federal, State and Local Environmental Regulations.

B. SCOPE

All Calsonic operations will minimize, where economically feasible, pollutants released to the air, land and water, and reduce generation and properly dispose of all hazardous and non-hazardous waste. Environmental compliance is a Calsonic Corporation objective at all company locations.

C. REFERENCES

Applicable Federal, State and Local Law and Ordinances.

D. RESPONSIBILITIES:

1. Each Calsonic operation will designate a person to be responsible for environmental compliance. This person will be given the authority to enforce environmental regulations at that location through the management organization.
2. The environmental designee at each location shall be responsible for identification, classification and reporting requirements regarding emissions, waste generation, hazardous material usage and disposal operations.
3. The environmental designee shall establish and monitor effective hazardous materials management programs at each location.
4. The environmental designee shall maintain usage logs, records, permits, etc. to ensure compliance to each applicable regulation.
5. The environmental designee shall develop expertise and understanding of environmental compliance as required within the Calsonic organization. The environmental designee shall keep current on any changes in the regulations that could effect the Calsonic organization. The designee shall communicate to

Calsonic's management any new legislation or regulation that could effect the Calsonic organization in the future.

6. The environmental designee shall interface with any Federal, State or local representatives concerning compliance to applicable regulations.
7. The environmental designee shall report to management any areas of non-compliance. Any areas of non-compliance shall be corrected as soon as possible.
8. The environmental designee shall perform an environmental audit of his or her facility(s) at least annually. The audit report is to be submitted to the top executive at that location. The top executive shall be responsible to coordinate proper follow-up.
9. The environmental designee shall develop, where feasible, ways to minimize or eliminate emissions of pollutants to the land, air and water. The environmental designee shall develop and manage a waste reduction program at each facility.
10. The environmental designee shall evaluate and approve hazardous waste trucking companies and treatment, storage, and disposal (TSD) facilities that are properly permitted, have adequate liability insurance, and appropriate operating procedures. Calsonic shall only use those transporters and TSD facilities so approved.
11. The environmental designee shall provide and document employee training as required in the handling and management of hazardous waste, and in requirements of environmental compliance.
12. The environmental designee shall be responsible to complete and submit all reports, notices, and permit applications required by environmental regulations.
13. The environmental designee shall relay, through the proper channels, Calsonic's commitment to being an environmentally conscious company.

**WASTE
MANAGEMENT
PLAN**

**CALSONIC
MANUFACTURING
CORPORATION**

I. Management Policy

Calsonic Manufacturing Corporation's policy is to reduce all hazardous and non-hazardous waste to the minimum levels economically and technically feasible. Also to be in full compliance with all federal and state waste regulations.

As both a responsible citizen and Calsonic employee, each individual is responsible for reducing waste, for complying fully with all waste reduction programs established by the company, and for not violating any federal or state waste regulations.

Employees are urged to come forth with suggestions for further reducing waste in their own work area and in other areas about which they may have ideas.

In order to obtain full cooperation at all levels of the company in implementing the waste reduction policy, the Corporate Engineering Manager has been assigned overall company responsibility for establishing training programs and operating procedures required to implement Calsonic's written policy

Bob Hofner
Executive Vice President

II. Objectives and Goals

The objective of Calsonic's waste reduction plan is to reduce or eliminate, where economically feasible, all generation of hazardous and non-hazardous waste.

Calsonic's goal is to reduce the total of all waste generation by at least thirty percent by the year 1995. The year 1989 will be used as a baseline.

Calsonic will review historical and current technologies as to how they can be applied to Calsonic's operations today and for the future.

III. Scope

Calsonic's waste reduction activities will involve all areas in which waste may be generated. Each area of waste generation will be identified and recommendations made as to reductions that can be achieved.

Waste reduction activities will involve all employees of Calsonic. Training will be provided, where needed, to all employees to aid in achieving the goals established.

Waste Generation (1989)

F001	1,1,1 Trichloroethane	76,169 kilograms
F003, F005	Flammable Liquid	4,300
F001	Trichlorotrifluoroethane	16,672
F002	Methylene Chloride	3,782
D002, D007	Chromic Acid	3,545
D002	Sodium Hydroxide	4,818
D002	Sodium Hydroxide	1,227
F005	Flammable Solid	1,352
D001	Petroleum Naptha	555
F019	Hazardous Waste Solid	30,186

Waste Reduction Activities

F001 Trichloroethane and F001 - 1,1,1 Trichloroethane - are generated by degreasing of metal parts prior to assembly. 92,841 kilograms of this waste was generated in 1989.

Goal - Ninety percent reduction of this waste stream by the year 1995.

Alternative Technologies -

- (1). Aqueous wash units to replace vapor degreasers.
- (2). Alternative replacements for degreasing.
- (3). Possible assembly of units without degreasing.

F003, F005 Flammable Liquid - is generated by painting of condensers, oil coolers and radiators. 5,652 kilograms of this waste was generated in 1989.

Goal - Eighty percent reduction by the year 1995.

Alternative Technologies -

- (1). Powder paint systems
- (2). Water based paints.

F001 - Methylene Chloride - is generated by stripping paint from hooks used to carry parts through the painting operation. 3,782 kilograms were generated in 1989.

Goal - One hundred percent reduction in the year 1992.

Alternative Technologies - Pyrolysis Oven

D002, D007 - Chromic Acid - is generated by chrome conversion coating of aluminum evaporator cores. 3,545 kilograms of this waste was generated in 1989.

Goal - One hundred percent reduction by the year 1995.

Alternative Technologies - At present time there is no replacement for chrome conversion coatings. Future technology will be evaluated.

D002 - Sodium Hydroxide - is generated by preparing aluminum for conversion coatings (chrome and zinc). 6,045 kilograms of this waste was generated in 1989.

Goal - One hundred percent elimination on the condenser line by the year 1994.
Elimination on the evaporator line is dependant on future technologies.

Alternative Technologies - (1). Redesign of condenser unit.
(2). Material substitution.

F005 Flammable Solid - is generated by the painting of condensers, radiators and oil coolers. 1,352 kilograms of this waste was generated in 1989.

Goal - Sixty percent reduction by the year 1995.

Alternative Technologies - (1). Powder paint.
(2). Water based paints.

D001 - Petroleum Naptha - is generated by the cleaning of small parts. 555 kilograms of this waste was generated in 1989.

Goal - One hundred percent reduction by the year 1995.

Alternative Technologies - Material substitution.

F019 Hazardous Waste Solid - is generated by the treatment of chrome conversion coating waste. 30,186 kilograms of this waste generated in 1989.

Goal - Numeric goal unavailable at present due to no available technology.

Alterative Technologies - At the present time there is no acceptable replacement for chrome conversion coatings. Future technology will be evaluated.

D002 - Sodium Hydroxide - is generated by preparing aluminum for conversion coatings (chrome and zinc). 6,045 kilograms of this waste was generated in 1989.

Goal - One hundred percent elimination on the condenser line by the year 1994.
Elimination on the evaporator line is dependant on future technologies.

Alternative Technologies - (1). Redesign of condenser unit.
(2). Material substitution.

F005 Flammable Solid - is generated by the painting of condensers, radiators and oil coolers. 1,352 kilograms of this waste was generated in 1989.

Goal - Sixty percent reduction by the year 1995.

Alternative Technologies - (1). Powder paint.
(2). Water based paints.

APPENDIX F

ANALYSIS RESULTS OF PRETREATED WASTEWATER EFFLUENT

TABLE F1. ANALYSIS RESULTS OF WASTEWATER DISCHARGES TO POTW							
Analysis	Date						
	8/2/90	11/30/90	6/20/91	12/12/91	7/15/92	12/10/92	9/8/93
ph	9.1	8.2	6.8	8.4	10	8.2	9.4
BOD	5.4	4.4	1.7	3.6	19	52	12
TSS	24	18	3	5	1	9	9
TD Al	12.4	2.9	1.9	1.8	21.8	1.9	12.3
Cd	0.21	0.09	0.12	0.09	<0.005	<0.005	<0.005
Tcr	0.09	0.01	<0.04	0.02	<0.02	0.12	<0.02
Cu	0.06	-	0.13	0.12	0.07	0.17	0.08
Pb	<0.05	<0.05	<0.05	0.05	<0.002	<0.002	0.004
Ni	0.09	0.08	0.12	0.13	<0.02	0.06	0.03
Ag	0.007	0.004	<0.002	0.003	<0.01	<0.01	<0.01
Zn	0.99	0.11	0.66	0.52	0.22	0.22	0.4
F-	58.75	15.1	14.2	0.3	21	17.5	29.1
CN	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01
TCA	0.0013	0.0082	0.0008	0.0097	<0.01	0.41	0.24
Temp.	28	20	23	26	-	26	-
Flow	17,500	19,000	22,000	20,500	18,500	22,000	-

- Note:
1. All values given in mg/L unless otherwise stated.
 2. Temperature is recorded in degrees Celsius.
 3. Flow rate is recorded in gallons/day (gpd).

APPENDIX G

UNIQUE BILLS OF ACTIVITIES

Unique bills of activities (BOA) were created for the radiator and condenser manufacturing lines to economically evaluate the processes using activity-based cost accounting. Table G1 and G2 present the unique BOAs for the old and new radiator manufacturing lines, respectively. Tables G3 and G4 present the unique BOAs for the old and new condenser manufacturing lines, respectively.

TABLE G1. RADIATOR MANUFACTURING LINE - OLD, TCA DEGREASING SYSTEM'S BOA		
Tier	Activity	Cost Driver
I	Process paperwork for order/receipt of TCA	\$/receipt
A	Manufacturing dept. determine materials needs	(included labor hrs throughout paper chase)
1	Fill out material needs paperwork	
2	File copy of paperwork	
3	Forward paperwork to purchasing	
a	Purchasing reviews paperwork	
b	Fill out proper order forms	
c	Locate and contact proper materials vendor	
d	File purchase order paperwork	
B	Distribution dept. manages inventory	
1	Locate order form	
2	Verify incoming materials with order form	
3	Forward paperwork to accounting	
a	Accounting reviews paperwork	
b	Accounting processes paperwork (pays bills)	
c	accounting files paperwork	
4	Input incoming inventory into computer system or management file	
II	remove TCA from truck to storage area by forklift	\$/receipt
III	clean radiator cores using vapor degreasers	\$/core
A	When core is assembled, place in rack of degreaser (one unit/clean)	(includes machine and labor hrs.)
B	Close door and press button to start cleaning process (automated)	

Table G1 continued

Tier	Activity	Cost Driver
C	while cleaning, assemble another core	
D	Open door and press button to start cleaning process (automated)	
E	Stack radiator core on wheeled cart for further processing	
1	Wheel carts, once full, to flux and braze unit	
2	Remove cores from carts and place on Conveyorized flux/braze machine	
F	Place second core in rack of degreaser and repeat the process	
IV	Maintain five (5) batch degreasing systems -DAILY	\$/labor hr.
A	Monitor TCA reservoir level	
B	Fill reservoir with TCA (replenish)	
1	Determine reservoir is low	
2	Transport 55 gal drum from outdoor storage to process line	
	(drum is kept at degreasers, so this step is only periodically)	
3	utilize pump and tube to fill reservoir	
4	Return remaining TCA (or empty drum) to storage, or store	
	short-term at process line	
C	Change-out TCA from degreasers - PERIODICALLY	
1	Shut down degreaser	
2	Allow solvent reservoir to cool	
3	Move empty drums from storage to line	
4	Drain reservoir with pump and tube (fill drums)	
5	Call environmental engineer	\$/shipment
a	Properly label drums	
b	Ensure 90-day limit is not exceeded for haz. waste storage	
6	Transfer labeled drums to outdoor storage area by forklift	
7	Call contractor to pick up hazardous waste shipment	
8	Waste management paperwork	
a	Properly complete manifest	
b	Fill out other in-house paperwork (accounting	
c-	Send paperwork to accounting	

Table G1 continued

Tier	Activity	Cost Driver
9	Contractor picks up shipment	
a	Shipping verifies manifest with drums	
b	Transfer drums from storage to truck	
c	Shipper signs manifest	
10	Manifest files are maintained by environmental engineer for 5 yrs	
V	Operational maintenance on five batch degreasers	\$/labor hr.
VI	Leak Testing	\$/core
A	Cores with plastic tanks are delivered one by one to test station	(includes labor and machine hrs)
B	Connect radiator to tester	
C	Push foot peddle to begin automated leak test	
D	Move to next of four test units and perform same activities for next rad.	
E	Disconnect tested radiator	
F	Determination of test	
1	Good radiators are individually moved onto packaging station	
2	Rejected radiators are placed on separate rack	
a	Water testers remove rejects four at a time	
b	With water test, confirm leak and determine if it can be reworked	
c	For rework, mark lead	
d	Send to reworking	
i	Remove two plastic tanks by manually folding back teeth	
ii	Straighten teeth using machine	
iii	Determine if tanks can be reused, place in box for reuse or dumpster for scrap	
iv	Mark unit and leak area	
c	Send to rebraze	
i	Reflux leaking area	
ii	Resubmit part to braze ovens	
iii	Retest for leaks, pass = production, fail = scrap (place in scrap recycle bin)	
3	Complete report on number of rejects	

Table G1 continued

Tier	Activity	Cost Driver
VII	Apply for and maintain permits	\$/labor hr.
A	Air permits	
1	Monitor air releases (Calsonic uses eng. judgment rather than measurements)	
2	Maintain TCA use logs (purchasing records	
3	Report air releases	
a	TRI Reporting requirements	
b	Forward report to EPA	
c	Retain copy for company records	
4	Re-apply for permit	
B	Hazardous waste generation	
1	Maintain spill containment around hazardous materials storage	
2	Maintain manifest records	
3	Report hazardous waste transfers (disposal)	
a	TRI Reporting requirements	
b	Forward report to EPA	
c	Retain copy for company records	
C	Train personnel on hazardous materials management and OSHA	
D	Maintain records on every employee of training	
E	Maintain files of Material Safety Data Sheets for every chemical in facility	

TABLE G2. RADIATOR MANUFACTURING LINE - NEW, AQUEOUS DETERGENT SYSTEM'S BOA		
Tier	Activity	Cost Driver
I	Process paperwork for order/receipt of detergent	\$/receipt
A	Manufacturing dept. determine materials needs	(includes labor hrs throughout paper chase)
1	Fill out material needs paperwork	
2	File copy of paperwork	
3	Forward paperwork to purchasing	
a	Purchasing reviews paperwork	
b	Fill out proper order forms	
c	Locate and contact proper materials vendor	
c	File purchase order paperwork	
B	Distribution dept. manages inventory	
1	Locate order form	
2	Verify incoming materials with order form	
3	Forward paperwork to accounting	
a	Accounting reviews paperwork	
b	Accounting processes paperwork (pays bills)	
c	Accounting files paperwork	
4	Input incoming inventory into computer system or management file	
II	Receipt of detergent shipment	\$/receipt
A	Line forklift operator is informed of shipment	(includes labor hrs)
B	Remove detergent from truck to staging area by forklift	
C	Move detergent from staging area to storage by forklift	
III	Assembly of cores	\$/core
A	Line personnel combine cut fins and tubes into jib	(includes labor and machine hrs.)
B	Stack radiator core on wheeled cart for further processing	
1	Wheel carts, once full, to aqueous cleaning, flux, and braze unit	
2	Remove cores, one by one, from carts and place on conveyor	
IV	Maintain aqueous detergent wash system	\$/labor hr.
A	Operation and maintenance - DAILY	
1	Blowers	

Table G2 continued

Tier	Activity	Cost Driver
2	Spray nozzle pressure	
3	Chemical tests (detergent)	
a	Detergent is added from drum at line, & system is allowed to equilibrate	
4	Temperature	
5	Scim oil from first rinse reservoir	
B	Periodically drain the three tanks	
1	Open valves of first rinse tank and turn on pump	
2	Wait for tank to drain	
3	Close valves and turn off pump	
4	Repeat B 1-3 for second rinse tank	
5	Inform wastewater treatment of detergent wastewater flow	
6	Wastewater treatment switches water flow to separate tank	
7	Repeat B 1-3 for detergent tank	
8	Clean aqueous cleaning system	
a	High pressure water spray	
b	Vacuum	
c	Change filters	
9	Fill each tank with fresh water	
10	Turn on heater coils in detergent/rinse bath	
11	Add detergent to detergent bath	
a	Periodically transfer detergent from storage area to process line	
b	Measure detergent	
c	Pour detergent into tanks	
d	Circulate tank to mix detergent (may be accomplished with spray system)	
C	Operation and maintenance of aqueous system	
1	Grease mechanisms of blowers	
2	Pump oil from holding tank	
3	Check spray pressures	

Table G2 continued

Tier	Activity	Cost Driver
V	Leak testing	\$/core
A	Determination of test	(includes labor & machine hrs)
1	Good radiators are moved onto packaging station	
2	Rejected condensers are placed on separate rack	
a	Water testers remove rejects four at a time	
b	With water test, confirm leak and determine if it can be reworked	
c	For rework, mark leak	
d	Send to reworking	
i	Remove two plastic tanks by manually folding back teeth	
ii	Straighten teeth using machine	
iii	Determine if tanks can be reused, place in box for reuse or dumpster for scrap	
iv	Mark unit and leak area	
3	Complete report on number of rejects	
VI	Wastewater treatment activities	\$/labor hr.
A	continuous processes	
1	Drain equilization basin into treatment train	
2	Lower pH	
3	Raise pH	
4	Add polymer and mix	
5	Allow to settle	
6	Filter sludge/solids	
a	Prepare plate-in-frame filter press	
b	Flow water/slurry through press by pumping from bottom of settling tank	
c	Open plates and scrap off solid, dropping them on the floor	
d	Collect solids in 55 gal drum	
B	Batch processed	
1	Shock detergent wastewater in separate tank	
a	Add acid	

Table G2 continued

Tier	Activity	Cost Driver
b	Add lime	
c	Pump pretreated wastewater into main equilization basin	
C	Maintain polymer and acid inventories	
D	Maintain base inventory	
E	Maintain pumps for these delivery systems	
VII	Apply for and maintain permits	\$/labor hr.
A	Water/wastewater treatment and discharge	
1	Sample wastewater quarterly	
B	Maintain files of Material Safety Data Sheets for every chemical in facility	

TABLE G3. CONDENSER MANUFACTURING LINE - OLD, TCA DEGREASING SYSTEM'S BOA		
Tier	Activity	Cost Driver
I	Process paperwork for order/receipt of TCA	\$/receipt
A	Manufacturing dept. determine materials needs	(includes labor hrs throughout paper chase)
1	Fill out material needs paperwork	
2	File copy of paperwork	
3	Forward paperwork to purchasing	
a	Purchasing reviews paperwork	
b	Fill out proper order forms	
c	Locate and contact proper materials vender	
d	File purchase order paperwork	
B	Distribution dept. manages inventory	
1	Locate order form	
2	Verify incoming materials with order form	
3	Forward paperwork to accounting	
a	Accounting reviews paperwork	
b	Accounting processes paperwork (pays bills)	
c	Accounting files paperwork	
4	Input incoming inventory into computer system or management file	
II	Remove TCA from truck to storage area by forklift	\$/receipt
III	Setup fin corrugation machine	
A	Maintain vapor degreasing system - DAILY	\$/labor hr.
1	Monitor TCA reservoir level	
2	Fill reservoir with TCA (replenish)	
a	Determine reservoir is low	
b	Transport 55 gal drum from outdoor storage to process line	
c	Utilize pump and tube to fill reservoir	
d	Return remaining TCA (or empty drum) to storage, or store short-term at process line	
3	adjust for proper cleaning	
B	Change-out TCA of degreaser - PERIODICALLY	

Table G3 continued

Tier	Activity	Cost Driver
1	Shut down degreasers	
2	Allow solvent reservoir to cool	
3	Move empty drums from storage to line	
4	Drain reservoir with pump and tube (fill drums)	
5	Call environmental engineer	
a	Properly complete drum labels (date, identification, etc.)	
b	Ensure 90-day limit is not exceeded for haz. waste storage	
c	Transfer labeled drums to outdoor storage area by forklift	
d	Call contractor to pickup hazardous waste shipment	
e	Waste management paperwork	
i	Properly complete manifest	
ii	Fill out other in-house paperwork (accounting)	
iii	Send paperwork to accounting	
f	Contractor picks up shipment	
i	Shipping verifies manifest with drums	
ii	Transfer drums from storage to truck	
iii	Shipper signs manifest	
g	Manifest files are maintained by environmental engineer for 5 yrs	
IV	Operational maintenance on corrugator and vapor degreaser-DAILY	\$/labor hr.
V	Operational maintenance on corrugator and vapor degreaser-YEARLY	\$/labor hr.
VI	Apply for and maintain permits	\$/labor hr.
A	Air permits	
1	Monitor air releases (Calsonic uses eng. judgment rather than measurements)	
2	Maintain TCA use logs (purchasing records)	
3	Report air releases	
a	TRI Reporting requirements	
b	Forward report to EPA	
c	Retain copy for company records	
4	Re-apply for permit	

Table G3 continued

Tier	Activity	Cost Driver
B	Hazardous waste generation	
1	Maintain spill containment around hazardous material storage	
2	Maintain manifest records	
3	Report hazardous waste transfers (disposal)	
a	TRI Reporting requirements	
b	Forward report to EPA	
c	Retain copy for company records	
C	Train personnel on hazardous materials management and OSHA	
D	Maintain records on every employee of training	
E	Maintain files of Material Safety Data Sheets for every chemical in facility	

TABLE G4. CONDENSER MANUFACTURING LINE - NEW, EVAPORATIVE LUBRICANT SYSTEM'S BOA		
Tier	Activity	Cost Driver
I	Operational maintenance on dryers (DAILY or PERIODICALLY)	\$/labor hr.
II	Maintain files on Material Safety Data Sheets for every chemical in facility	
III	Apply for and maintain permits	\$/labor hr.
A	Air permits	
1	Monitor air releases (Calsonic uses eng. judgment rather than measurements)	
2	Report air releases	
a	State requirements	
b	Forward report to state	
c	Retain copy for company records	
3	Re-apply for permit	