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SOLVENT-BASED TO WATERBASED ADHESIVE-COATED SUBSTRATE RETROFIT
VOLUME I: COMPARATIVE ANALYSIS

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16. ABSTRACT This volume represents the analysis of case study facilities' experience with waterbased adhesive use and retrofit requirements. (NCTE: The coated and laminated substrate manufacturing industry was selected as part of NRMRL's support of the 33/50 Program because of its significant air emissions of toluene and methyl ethyl ketone (MEK). NRMRL-RTP reviewed the potential equipment cleaning benefits of retrofitting equipment for the use of waterbased adhesives. During the investigation, it became apparent that retrofitting solvent-based equipment to accept waterbased adhesives can be very complicated.) The volume is divided into six chapters. Chapter 2 describes the information-collection phase used to screen out facilities most appropriate for case study visits. Chapter 3 contains the methodology used for site visits and briefly summarizes each case study site visit. Chapter 4 details the comparative analysis results of the case study site visits in conjunction with additional information obtained from other sources in the industry. Chapter 5 summarizes the comparative analyses described in Chapter 4. Chapter 6 describes information obtained during the case study site visits and from other industry sources on alternative coating technologies such as hot melt and radiation-curable adhesives.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Substrates	Stationary Sources	11D
Equipment		14G
Cleaning		13H
Adhesives		11A
Coatings		11C

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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 groundwater; 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

EPA REVIEW NOTICE

ABSTRACT

The coated and laminated substrate manufacturing industry was selected as part of APPCD's support of the 33/50 Program because of its significant air emissions of toluene and methyl ethyl ketone (MEK). APPCD reviewed the potential equipment cleaning benefits of retrofitting equipment for the use of waterbased adhesives. During the investigation, it became apparent that the retrofitting of solvent-based equipment to accept waterbased adhesives can be a very complicated task. This volume represents the analysis of case study facilities' experience with waterbased adhesive use and retrofit requirements.

The volume is divided into six chapters. Chapter 2 describes the information collection phase used to screen out facilities most appropriate for case study visits. Chapter 3 contains the methodology used for site visits and includes a brief summary of each case study site visit. Chapter 4 details the comparative analysis results of the case study site visits in conjunction with additional information obtained from other sources in the industry. Chapter 5 contains a summary of the comparative analyses described in Chapter 4. Chapter 6 describes information obtained during the case study site visits and from other industry sources on alternative coating technologies such as hot melt and radiation-curable adhesives.

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LIST OF ACRONYMS

AEERL	EPA, Air and Energy Engineering Research Laboratory (now APPCD)
AGST	above ground storage tanks
APPCD	EPA, Air Pollution Prevention and Control Division of NRMRL
BOD	biological oxygen demand
Btu	British thermal unit(s)
CAAA	Clean Air Act Amendments of 1990
CBI	confidential business information
CMM	converting machinery/materials
CO	carbon monoxide
EB	electron beam
EPA	U.S. Environmental Protection Agency
EVA	ethylene vinyl acetate
HAP	hazardous air pollutant(s)
IPA	isopropyl alcohol
IR	infrared
LAER	lowest achievable emission rate
LEL	lower explosive limit
LQG	large quantity generator
MACT	maximum achievable control technology
MEK	methyl ethyl ketone
N_2	nitrogen
NO_x	oxides of nitrogen
NRMRL	EPA, National Risk Management Research Laboratory
OSHA	Occupational Safety and Health Administration
OTA	Massachusetts Office of Technology Assistance
OWR	North Carolina Office of Waste Reduction
PIES	Pollution Prevention Information Exchange System
PLC	polymers, laminations, and coatings
POTW	publicly owned treatment works
PPIC	Pollution Prevention Information Clearinghouse
PSA	pressure sensitive adhesive
PSTC	Pressure Sensitive Tape Council
PVC	polyvinyl chloride
R&D	research and development
SBS	styrene-butadiene-styrene
SIC	Standard Industrial Classification (code)
SIS	styrene-isoprene-styrene
SQG	small quantity generator
TAPPI	Technical Association of the Pulp and Paper Industry
TCLP	toxicity characteristic leaching procedure
TLMI	Tag and Label Manufacturers Institute
TRI	Toxic Chemical Release Inventory

LIST OF ACRONYMS (Continued)

UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound(s)
WWT	wastewater treatment

EXECUTIVE SUMMARY

As a result of the Pollution Prevention Act of 1990, the U.S. Environmental Protection Agency (EPA) established the 33/50 Program which calls for voluntary industry reductions in releases of the following 17 high-priority toxic chemicals, which are listed by mass of emissions:

Toluene
Xylenes
1,1,1-Trichloroethane
Methyl Ethyl Ketone
Dichloromethane
Chromium and Compounds
Lead and Compounds
Trichloroethylene
Methyl Isobutyl Ketone
Tetrachloroethylene
Benzene
Chloroform
Nickel and Compounds
Cyanide and Compounds
Carbon Tetrachloride
Cadmium and Compounds
Mercury and Compounds

The goal of the 33/50 Program is to reduce the total amount of these chemicals released into the environment and transferred off-site by 33 percent by the end of 1992 and by 50 percent by the end of 1995. These reductions will be based upon the Toxic Chemicals Release Inventory (TRI), with 1988 as the base year.[1]

In support of the 33/50 Program and the Agency's pollution prevention goals, EPA's Air and Energy Engineering Research Laboratory (AEERL)* is investigating ways to reduce air emissions of these 17 chemicals through pollution prevention. The Pollution Prevention Act of 1990 defines pollution prevention as source reduction or "any practice which reduces the amount of any hazardous substance, pollutant, or contaminant entering the waste stream or otherwise released to the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants."[2] Pollution prevention efforts offer economic and reduced health and ecological risk benefits to many sectors of society that may not be available through traditional pollution control methods.

In 1991, AEERL representatives met with industry, academia, and State environmental agency representatives to identify several source categories deserving of pollution prevention

* Now EPA's Air Pollution Prevention and Control Division.

research. Two criteria were used to select the industrial categories for study: annual toxics emissions and the potential for pollution prevention opportunities. First, the TRI was reviewed to identify categories with the greatest mass emissions of the 33/50 chemicals. Categories with the greatest emissions were then ranked according to the potential for successful pollution prevention projects resulting in significant reductions of 33/50 chemical releases. One of the industries identified during the 1991 meeting was the adhesives-coated and laminated paper manufacturing industry [Standard Industrial Classification (SIC) 2672]. This industry was chosen because of significant air emissions of 33/50 Program chemicals methyl ethyl ketone (MEK) and toluene as reported through the TRI.

In October of 1991, a Focus Group Meeting was held between AEERL, pollution prevention experts, and representatives of the adhesives-coated and laminated paper manufacturing industry to discuss specific pollution prevention projects that would support the 33/50 Program. Meeting participants indicated that the coatings and coating application steps are the largest source of toluene and MEK emissions, and, therefore, retrofitting equipment for the use of waterbased adhesives would present a good opportunity for the implementation of pollution prevention techniques. As a result of this meeting and preliminary industry inquiries, the scope of the industry investigation was later expanded to include other coating and substrate varieties (such as those included in SIC 2671-Coated and Laminated Packaging Paper and Plastics Film) because the manufacturing methods are similar; therefore, technology transfer is possible over a wider range of industries. The retrofit research project fulfills part of EPA's goal to stimulate the development and use of products and processes that result in reduced pollution.

PROJECT OBJECTIVES

As part of the original scope of work for the *Improved Equipment Cleaning in Coated and Laminated Substrate Manufacturing Facilities (Phase I)* project, TRC reviewed the potential equipment cleaning benefits of retrofitting equipment for the use of waterbased adhesives.[3] During the investigation, it became apparent that the retrofitting of solvent-based equipment to accept waterbased adhesives can be a very complicated task. This report presents the results of TRC's review of the issues and obstacles associated with retrofitting.

Using this report as a starting point, AEERL is examining the technology transfer potential of demonstrating a retrofit and outlining the requirements for conversion so that other coated and laminated substrate manufacturers can consider the benefits of retrofitting.

REFERENCES

1. U.S. Environmental Protection Agency. *Pollution Prevention Fact Sheet: EPA's 33/50 Program.* Office of Pollution Prevention, Washington, DC. August 1991.

2. Pollution Prevention Act of 1990, 42 U.S.C. §13101, et seq.

3. McMinn, B. W. and J. B. Vitas. *Improved Equipment Cleaning in Coated and Laminated Substrate Manufacturing Facilities (Phase I).* EPA-600/R-94-007 (NTIS PB94-141157). Air and Energy Engineering Research Laboratory. Research Triangle Park, NC. January 1994.

CONVERSION FACTORS

To Convert From	To	Multiply by
LENGTH		
feet (ft)	meters (m)	0.3048
meters (m)	feet (ft)	3.281
inches (in)	centimeters (cm)	2.54
yard (yd)	meters (m)	0.9144
MASS OR WEIGHT		
ounces (oz)	kilograms (kg)	0.02835
pounds (lb)	kilograms (kg)	0.454
pounds (lb)	tons	0.0005
tons	pounds (lb)	2000
tons	kilograms (kg)	907.2
kilograms (kg)	pounds (lb)	2.205
kilograms (kg)	tons	0.001102
VOLUME		
gallons (gal)	liters (l)	3.785
gallons (gal)	cubic inches (in^3)	231
gallons (gal)	fluid ounces (oz)	128
gallons (gal)	cubic meters (m^3)	0.00379
milliliters (ml)	fluid ounces (oz)	0.03381
liters (l)	gallons (gal)	0.2642
cubic inches (in^3)	gallons (gal)	0.004329
fluid ounces (oz)	gallons (gal)	0.007813
fluid ounces (oz)	milliliters (ml)	29.57
CONCENTRATION		
pounds/gallon (lb/gal)	grams/liter (g/l)	119.8
grams/liter (g/l)	pounds/gallon (lb/gal)	0.008345
DENSITY		
pounds/gallon (lb/gal)	grams/milliliter (g/ml)	0.1198
grams/milliliter (g/ml)	pounds/gallon (lb/gal)	8.345
PRESSURE		
pounds/inch^2 (psia)	mmHg or torr (mmHg)	51.71
pounds/inch^2 (psia)	atmospheres (atm)	0.0680
millimeters of mercury or torr (mmHg)	pounds/inch^2 (psia)	0.1934
TEMPERATURE		
Fahrenheit (°F)	Celsius (°C)	subtract 32, then multiply by 0.5556
Celsius (°C)	Fahrenheit (°F)	multiply by 1.8, then add 32

CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

As a result of the Pollution Prevention Act of 1990, the Environmental Protection Agency (EPA) established the 33/50 Program which calls for voluntary industry reductions in releases of the following 17 high-priority toxic chemicals, which are listed by mass of emissions:

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Dichloromethane	Cyanide and Compounds
Chromium and Compounds	Carbon Tetrachloride
Lead and Compounds	Cadmium and Compounds
Trichloroethylene	Mercury and Compounds
Methyl Isobutyl Ketone	

The goal of the 33/50 Program is to reduce the total amount of these chemicals released into the environment and transferred off-site by 33 percent by the end of 1992 and 50 percent by the end of 1995. These reductions are based upon the Toxic Chemicals Release Inventory (TRI), with 1988 as the base year.[1]

In support of the 33/50 Program and the Agency's pollution prevention goals, EPA's Air and Energy Engineering Research Laboratory (AEERL) is investigating ways to reduce air emissions of these 17 chemicals through pollution prevention. The Pollution Prevention Act of 1990 defines pollution prevention as source reduction, or "any practice which reduces the amount of any hazardous substance, pollutant, or contaminant entering the waste stream or otherwise released to the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants."[2] Pollution prevention efforts offer economic benefits reduced health and ecological risk to many sectors of society that may not be attainable through traditional pollution control methods.

In 1991, AEERL representatives met with industry, academia, and State environmental agency representatives to identify several source categories deserving of pollution prevention research. Two criteria were used to select the industrial categories for study: annual emissions of toxic substances and the potential for pollution prevention opportunities. First, the TRI was reviewed to identify source categories with the greatest mass emissions of the 33/50 chemicals. Categories with the greatest emissions were then ranked according to the potential for successful pollution prevention projects resulting in significant reductions of 33/50 chemical releases. One of the industries identified during the 1991 meeting was the adhesives-coated and laminated paper manufacturing industry [Standard Industrial Classification (SIC) 2672]. This industry was chosen because of significant air emissions of 33/50 Program chemicals methyl ethyl ketone (MEK) and toluene as reported through the TRI.

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1.2 PROJECT OBJECTIVES

As part of the original scope of work for the project *Improved Equipment Cleaning in Coated and Laminated Substrate Manufacturing Facilities (Phase I)*,[4] the potential environmental and economic impacts related to equipment cleaning when retrofitting equipment to use waterbased adhesives were reviewed. During the investigation, it became apparent that the

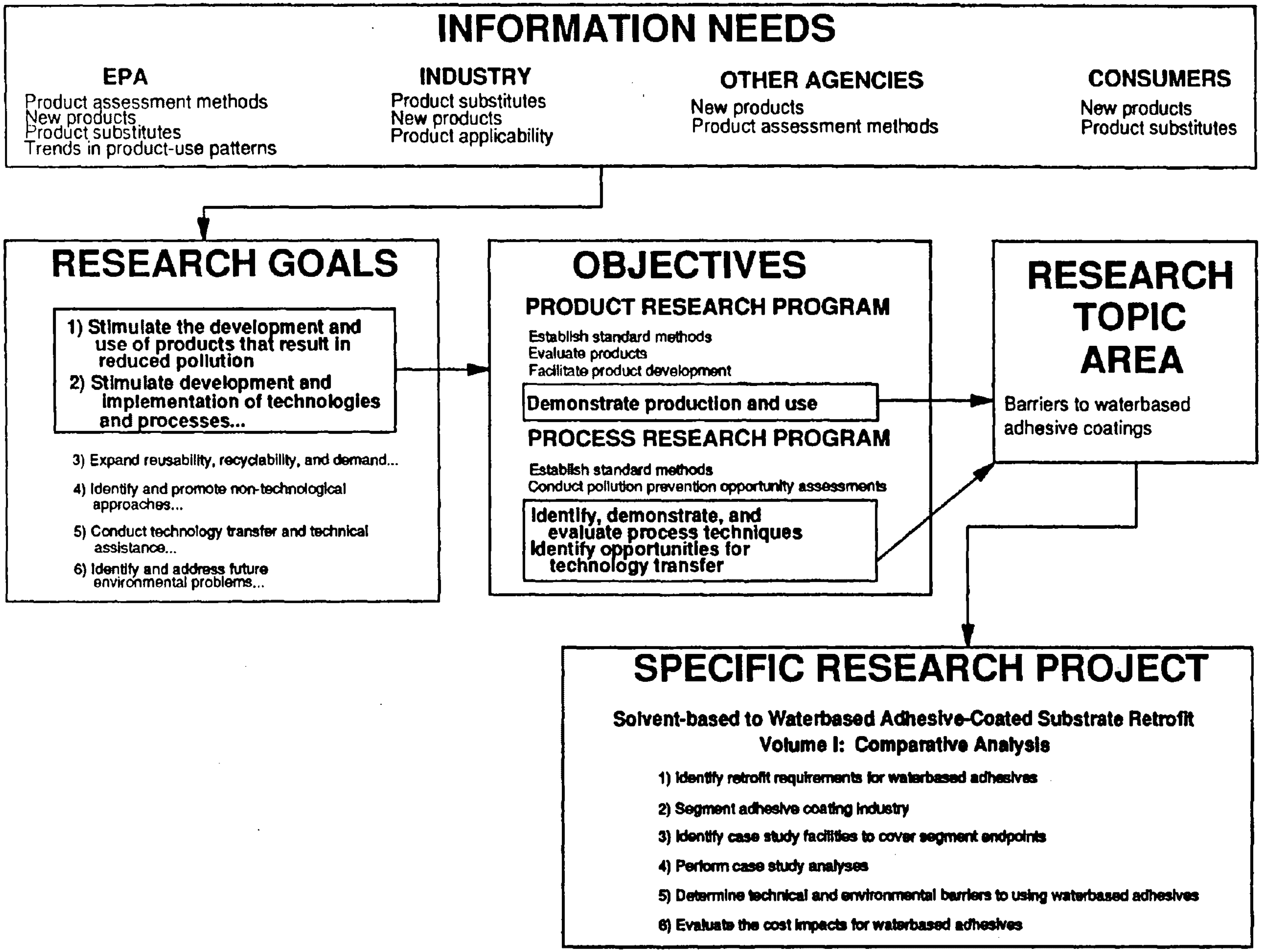

Figure 1-1. EPA's Pollution Prevention Research Plan.[3]

conversion from solvent-based adhesive-coated products to waterbased adhesives can be a very complicated task. Therefore, EPA invested resources in documenting this conversion. The results of this study are presented in a four volume series with the following titles.

SERIES: *Solvent-based to Waterbased Adhesive-Coated Substrate Retrofit*

Volume I: *Comparative Analysis*
Volume II: *Process Overview*
Volume III: *Label Manufacturing Case Study: Nashua Corporation*
Volume IV: *Film and Label Manufacturing Case Study: FLEXcon Company*

This document is Volume I in this series. It provides an overview of the results of the study to identify the issues and barriers associated with retrofitting existing solvent-based equipment to accept waterbased adhesives, and compares the compatibility of waterbased adhesive performance levels with current solvent-based adhesive applications. Using this report, AEERL is examining the technology transfer potential of documenting the impacts to several coated and laminated substrate manufacturers who have converted some or all of their coating capacity from solvent-based to waterbased adhesives so that other manufacturers can consider the benefits of retrofitting. Volume II of this series contains a detailed description of the raw materials and processes used in the adhesive coated and laminated substrate industries. These descriptions are, for the most part, generated from current literature, technical publications, and textbooks on adhesive coating and laminating technologies industries. Volume II also contains detailed technical information on adhesive coating processing and technology, and introduces the retrofit concepts which are more fully explored in this report. Volume III of this series contains a case study of the waterbased retrofit for Nashua Corporation (Nashua). Volumes IV describes the implications of and barriers associated with waterbased adhesive use at FLEXcon Company (FLEXcon).

1.3 REPORT ORGANIZATION

This report is divided into five chapters. Chapter 2 describes the process used to collect the facility-specific retrofit information contained in this report. Chapter 3 summarizes the results of the site visits performed for this project. Chapter 4 contains a comparative analysis among industry segments including the technical, economic, and environmental barriers and benefits associated with retrofitting existing solvent-based processing equipment to equipment used to process waterbased adhesives. Chapter 5 summarizes the results and conclusions of the comparative analysis. Appendix A contains a list of questions which were developed to guide discussions during site visits. These questions were mailed to host sites prior to the visits. Appendix B contains a comparison of the capital costs for a new solvent-based and a new waterbased line, the costs to retrofit an existing solvent-based line to waterbased adhesives, and annual operating costs for both line types. Appendix C lists 1992 TRI data for the adhesive coating industry, encompassing SIC codes 2641, 2671, and 2672. SIC 2641 TRI data are presented because some facilities still report under this SIC even though the SIC was discontinued in the late 1980s and subdivided into SICs 2671 and 2672.

1.4 RESEARCH METHODOLOGY

To assess the potential for waterbased adhesive coating use in the adhesive-coated and laminated web substrate industries, two site visits to facilities performing adhesive coating operations were conducted. Before these site visits were undertaken, a methodology for categorizing the adhesive coated and laminated substrate industries was developed. This methodology, which is discussed in Chapter 2 of this report, bisects the industries along three dimensions: size (large or small), coating line processing mode (batch or dedicated), and product types (high performance or low performance). To ensure complete coverage of the dimension endpoints, an effort was made to locate a large number of facilities with a mix of these characteristics.

An extensive literature search was used to locate facilities. Databases at three local university libraries were searched to find information on adhesive coating and laminating. These searches located numerous documents, journals, periodical reports, conference proceedings, and textbooks containing information on various aspects of adhesive coating and laminating. This information was used to provide background data, and to locate suitable facilities for site visits.

Information was also available from other EPA-sponsored projects that investigated the adhesive-coated and laminated substrate industry. A previous study on equipment cleaning practices at adhesive coating and laminated facilities became an important resource during the initial phases of this project.[4] Additionally, contacts in both government and industry had been developed during conference visits and previous project activities. These contacts included representatives of regulatory agencies, trade associations, raw material suppliers, and equipment suppliers who proved valuable in completing this project.

1.5 REFERENCES

1. U.S. Environmental Protection Agency. *Pollution Prevention Fact Sheet: EPA's 33/50 Program*. Office of Pollution Prevention, Washington, DC. August 1991.

2. Pollution Prevention Act of 1990, 42 U.S.C. §13101, et seq.

3. U.S. Environmental Protection Agency. *Pollution Prevention Research Plan: Report to Congress*. EPA-600/9-90-015. Office of Research and Development, Washington, DC. March 1990.

4. McMinn, B. W. and J. B. Vitas. *Improved Equipment Cleaning in Coated and Laminated Substrate Manufacturing Facilities (Phase I)*. EPA-600/R-94-007 (NTIS PB94-141157). Air and Energy Engineering Research Laboratory. Research Triangle Park, NC. January 1994.

CHAPTER 2
INFORMATION COLLECTION

2.1 GENERAL

To meet the objectives of this comparative analysis, information specific to the retrofit of adhesive-coating processes for web substrates was obtained from various sources. These sources included current literature, various databases, industry and trade association contacts, conference proceedings, and facility visits. The information obtained from these sources was used to determine the technical, economic, and environmental obstacles associated with retrofitting solvent-based adhesive coating processes to waterbased adhesives. This chapter presents the techniques used and background information collected during the information-gathering phase. Topics covered include industry segmentation, process descriptions, emissions characterization, and facility site visit selection.

2.2 SCREENING CURRENT SOURCES FOR INFORMATION

To gain a broad perspective of the adhesive-coating industry, information was collected from several sources including literature and database searches, facility visits, pollution prevention experts, and industry and trade association personnel. In addition, industry-sponsored conferences such as the Technical Association of the Pulp and Paper Industry's (TAPPI's) Polymers, Laminations, and Coatings (PLC) conference and Converting Machinery/Materials (CMM) conference/exposition were attended. These conferences/expositions provided the opportunity to discuss coating technologies first hand with raw material and equipment suppliers and manufacturing firms. This section discusses the sources used in developing this comparative analysis report.

Current literature sources were screened for background and specific information regarding the retrofit of solvent-based adhesive systems to waterbased systems. Literature searches of EPA library and journal article databases, local university library databases, and Dialog® were conducted. These searches identified trade magazines such as *Tappi Journal*[1] and *Adhesives Age*[2], books, conference proceedings, and supplier literature. Newsletters such as the *Adhesives and Sealants Newsletter*[3] were also surveyed for current events and potential facility contacts in the adhesive coating industry.

The Pollution Prevention Information Clearinghouse (PPIC) and the Pollution Prevention Information Exchange System (PIES) were accessed monthly. The E-Mail capabilities of PIES were also used to communicate with other PIES users with knowledge of the coated and laminated substrate manufacturing industry.

In addition to conducting literature searches, contacts were made with industry and pollution prevention experts with the Massachusetts Office of Technology Assistance (OTA), the North Carolina Office of Waste Reduction (OWR), the Pressure Sensitive Tape Council (PSTC), the Tag and Label Manufacturers Institute (TLMI), and equipment manufacturing firms. Also, raw material and equipment suppliers, consultants, and facility personnel were contacted about their experience with retrofitting solvent-based adhesive coating systems to waterbased adhesives.

Finally, project and industry information was compiled during a total of seven site visits, five of which were conducted under previous EPA efforts.[4] Facilities which have tried to convert to waterbased adhesives were contacted to provide operational experience of the retrofit process. The trip reports and associated data for these facilities were combined with information from two additional trips. Many of the facilities expressed concern over the confidentiality of their process lines and operations, which resulted in limits to the data which could be obtained from the facilities. For this comparative analysis, those facilities which met the specifications for widest industry coverage were selected for background information and case study visits.

Together, these information gathering efforts provided the background to accurately describe the technical, economic, and environmental barriers associated with retrofitting solvent-based adhesive coating processes to waterbased adhesives.

2.3 INDUSTRY SEGMENTATION[5]

To better determine the retrofit requirements for various manufacturers in the web adhesive coating industry, the industry was segmented in three areas: (1) size of facility, (2) production scheduling method, and (3) end product performance. This segmentation was based on information obtained from and conversations with industry representatives. Each facility selected for a site visit was categorized in these three areas to ascertain its place in these three areas. These classifications were designed to be used in this comparative analysis report and were not meant to provide an accurate classification of the web adhesive coating market.

The first classification area was facility size. For this report, **large** facilities are defined as those employing more than 100 full-time production workers, or those operating more than two adhesive coating lines on a regular basis. Other facilities were considered **small** for the purposes of this analysis.

The second classification area was production scheduling method. This classification differentiates between those facilities who **dedicate** their equipment to the production of a relatively small number of specific end products and those who manufacture a relatively large number of end products in a **batch** mode on available equipment. Elements of each production style are present in virtually all plants, therefore, this classification was evaluated carefully to ensure adequate coverage among the facilities visited. One arbitrary element used to discern between dedicated and batch facility was the average amount of time a production run would last. If an average run lasted eight or more hours, the facility was more likely to be classified as a dedicated facility. If an average run lasted less than eight hours, the facility was more likely to be considered a batch facility.

The final classification area was end product performance. The performance requirements of an end product, including tack, bond, shear strength, and durability under adverse exposures determined whether the end product was classified as high performance or low performance. **High performance** end products are generally products designed to adhere under extreme environmental conditions or high stress applications. Many high performance products are specialty products, meaning that they are produced for specialized, often unique, applications. For instance, a circuit board manufacturer may require a tape for sealing electrical connections. This tape may have to meet very stringent conductivity and heat transfer standards. Some high performance products are produced in bulk for a variety of uses. In this case, the high performance products are aimed at commodity markets. One common example of such a high-performance product is a bumper sticker, which must withstand temperature and exposure extremes.

Low performance end products are designed to perform in moderate to low stress conditions in moderate environments. Most low performance products are aimed at commodity markets. One example of such a product is food packaging labels, which are generally exposed to cold to moderate temperatures, and no other environmental extremes. However, some low performance products, like masking tapes with individualized logos or imprinting, can be considered specialty products. Performance level judgements for the facilities discussed in this report were subjective, and were made relative to the end market for which the product was intended.

2.4 GENERAL INDUSTRY DESCRIPTION

2.4.1 Introduction

This section provides a brief overview of the coated and laminated substrate manufacturing industry. The section is divided into three subsections: (1) industry structure, (2) raw materials and products, and (3) manufacturing process description. The industry structure subsection briefly addresses the current market, materials used in the manufacturing process, products manufactured, and product end uses. The raw materials and products subsection briefly addresses the materials used in the manufacturing process, products manufactured, and product end uses. The manufacturing process subsection gives an overview of the manufacturing process with emphasis on the equipment and procedures used. Volume II in this series contains a more detailed discussion of the industry structure, raw materials, and production processes.

2.4.2 Industry Structure

The coated and laminated substrate industry, as defined by SIC 2671 and 2672, consists of firms that manufacture coated or flexible materials made of combinations of paper, plastic films, metal foils, and similar materials for packaging (SIC 2671) and other purposes, including pressure sensitive tapes (SIC 2672).[6] According to the 1987 Census of Manufacturers, companies in SIC 2671 employed 15,000 people in 21 states, and companies in SIC 2672 employed nearly

31,000 people in 23 states. The leading states in employment of 2671 personnel, accounting for 42 percent of the industry's employment, were Wisconsin, Indiana, Pennsylvania, and Illinois. Massachusetts, Ohio, Illinois, and Pennsylvania accounted for 38 percent of SIC 2672's employment. Over 93 percent of SIC 2671 and 55 percent of SIC 2672 plants are small facilities employing less than 20 people.[7] These smaller facilities often provide a highly customized product line marketed within a small geographic region. Some of the larger companies own multiple manufacturing facilities and distribute products nationwide.

There are several additional SICs in the flexible packaging industry which are related to SICs 2671 and 2672. These are SIC 2673 (plastics, foil, and coated paper bags), SIC 2374 (uncoated paper bags and sacks, and multiwall shipping sacks and bags), and SIC 3497 (metal foil and leaf). Industries in these SICs may have an adhesive coating or lamination step in the production of their products. However, coating and lamination activity occurs primarily in SICs 2671 and 2672. In addition, a facility that reports under a different SIC may perform coating activities like those found in SICs 2671 and 2672. For instance, a facility that produces film or coats only films may report under SIC 3081 (unsupported plastic films and sheets). However, that facility could maintain extensive adhesive coating and laminating facilities.

2.4.3 Raw Materials and Products

2.4.3.1 Introduction

The products manufactured by the coated and laminated substrate industry are used in a variety of applications. Generally, these products can be categorized as one of three product types: tapes, labels, or miscellaneous products. Each of these product types consists of some combination of backings and coatings that can be described in terms of raw material construction or function. End use categories include hospital and first aid products, office and graphic arts products, packaging and surface protection products, building industry materials, electrical products, and automotive industry products.

2.4.3.2 Raw Materials

The raw materials used in the coated and laminated substrate manufacturing process consist of product backings, adhesives, and other coatings. Backings are the materials to which adhesive coatings are applied by the coating head. Backings, which are generally used in roll form, may include paper, film, foil, foam, or cloth materials. Backings are also referred to as substrates in the adhesive coating industry. In this report, the term backing will be used to describe all materials coated with adhesive in a process line. Adhesives include solvent-based and waterbased formulations of rubber, acrylic, silicone, or other polymers. Other coatings include release coatings, topcoats, and barrier coatings. A more detailed discussion of these raw materials is found in the Volume II report.

2.4.3.3 Finished Products and End Uses

There are several types of products manufactured by coated and laminated substrate manufacturers. Two of the largest product categories are tapes and labels. Classes of tape, identified by construction, include woven and nonwoven fabric tape, paper tape, film tape, foil tape, and foam tapes. Some of the backing materials identified in Section 2.4.3.2 are used with glass, rayon, nylon, polyester, or acetate fibers to produce reinforced backings. Films such as polyethylene, polyester, or polypropylene are often combined with these fibers to produce tapes used in heavy-duty packing and bundling applications. Two-faced tapes are backings, usually a foam or film, with an adhesive coating applied on both sides of the backing. Two-faced tapes have both heavy-duty uses (*e.g.*, carpet tapes and securing plates to a printing cylinder) and light-duty uses (*e.g.*, business forms and nametags).

Label manufacturing is similar to pressure sensitive tape manufacturing, with the primary defining characteristics being backing, printability, flatness, ease of die cutting, and release paper components. A label manufacturer may sell its product either in rolls or sheets as a final product, or as a raw product to printing and die cutting operations.[8,9] Other adhesive-coated and laminated product lines include adhesive-coated floor tiles, wall coverings, automotive and furniture woodgrain films, and decorative sheets.

2.4.4 Manufacturing Process Description

2.4.4.1 Introduction

Coated and laminated substrate facilities use numerous methods to process a wide variety of products. Manufacturing variables include the design and capabilities of the coating equipment, the type of backing, the type and viscosity of the coatings being applied, and the drying or curing method. The manufacturing process generally consists of the following four steps:

- raw material mixing
- coating application
- drying/curing
- rolling, printing, cutting, packaging, and product shipment

Each of these steps is described briefly in the following subsections.

2.4.4.2 Raw Material Mixing[4]

Many coating and laminating facilities formulate their coatings on-site in a central mix room. The complexity of the mixing process depends on the size of the facility and the number of products manufactured. Large facilities operating dedicated lines often formulate their own coatings from raw materials. Smaller coating and laminating facilities and batch facilities may choose to purchase premixed coatings which they can modify to satisfy customer needs. Modification of premixed coatings typically consists of directly adding small amounts of performance-enhancing chemicals, such as tackifiers or defoamers, into the adhesive shipping container. Once the coatings are formulated, they are either pumped to storage tanks or transferred via barrel-type containers or dedicated piping to specific process lines for immediate use.

A number of solvents, most typically toluene and MEK, are used in solvent-based adhesive formulations. The function of the solvent in a solvent-based adhesive formulation is to dissolve adhesive solids and other additives, allow easy transfer of the adhesive to a coating device, and permit smooth, even coating of adhesive on a backing. The solvent is then forced to evaporate in a drying oven, leaving the backing coated with a uniform layer of adhesive. Most of the solvents used for solvent-based adhesives contain volatile organic compounds (VOC), some of which may also be hazardous air pollutants (HAP).

2.4.4.3 Coating Application[4]

The application of a coating to a flexible web involves four major functions: (1) transport of the web, (2) delivery of the coating supply, (3) metering of the coating, and (4) transfer of the coating from the supply vessel to the backing. In web transport, the mechanisms used to tension and advance the web may require minor adjustments to compensate for the different speeds and transport requirements of waterbased coatings. These mechanisms include items such as rollers, gear boxes, belts, and equipment housings. Their design is influenced by the properties of waterbased and solvent-based adhesives. The mechanisms used to supply, meter, and apply coating may also require adjustment. The following paragraphs briefly describe the supply, metering, and application functions, along with some common coating equipment configurations.

After mixing, coatings are stored in permanently installed tanks, movable tote vessels, or drums. The coating is then transferred from storage locations to a reservoir on the coating head, from which it is made available to the coating apparatus. The reservoir normally uses dams and spill pans to capture any spilled coating. Transfer to the reservoir is accomplished through permanently installed piping and manifold systems or through portable lines that are attached to mobile storage vessels. Various types of pumps are used to maintain a flow of coating materials through these distribution networks.

Transfer of a coating from a reservoir to a web is most commonly accomplished with a roll coating mechanism. Roll coaters are a series of one or more cylinders that remove coating from the reservoir and then contact the web, transferring a portion of the coating to the web surface. If the cylinder that contacts the coating in the reservoir also contacts the web the roll coater is known as a direct roll coater. If a roller removes the coating from the reservoir and then transfers the coating to a counter-rotating cylinder before it reaches the web, the device is called an offset roll coater. Offset roll coaters are capable of greater control of the coating deposit, but require more exacting process control. Gravure coaters may also be used for coating application. These are similar to roll coaters in that they transfer coating to the surface of a web through the rotational motion of a cylinder. The major difference is that gravure cylinders are engraved while the surface of standard coating rollers is mirror smooth.

The coating roller must completely wet the web surface with coating, but not in excess of the design thickness for the application. The thickness of the applied coating can be partially controlled through adjustment of the supply system and the coating's viscosity. Fine adjustments are accomplished by a metering device. Metering occurs before or after the coating is applied to the web. The most common metering mechanisms are (1) a metering roller, (2) a doctor blade, (3) a metering rod, and (4) nip rollers. A metering roller removes excess adhesive from the coated web by reverse rolling action against the web. A doctor blade is typically a metal blade which extends the width of the web and removes excess adhesive by scraping the surface of the web. A metering rod works in much the same way as a metering roller, although it generally has a tightly wound wire around it to assist in the transfer of adhesive away from the web. Nip rollers follow the coating rollers. The web passes through a small space between two rollers. The width of this space, which is called the nip, is the desired coating and web thickness. Additional metering mechanisms include air knives, high speed curtains of air that blow excess coating back as an application roller rotates towards the web, and mechanisms uniquely associated with a single coating application, such as the engravings in a gravure cylinder.

2.4.4.4 Drying and Curing

Ovens serve two primary functions: to dry the coating by evaporating the vehicle (solvent or water) and/or to cure a polymer coating. Curing involves the chemical crosslinking of polymeric adhesives. Important characteristics of an oven are the source of heat, the operating temperature, the residence time (a function of web speed and the length of web path through the oven), the allowable hydrocarbon concentration, and the oven circulation (a function of air velocity).

Ovens are of two types: indirect-fired and direct-fired. An indirect-fired oven involves heat exchange. An incoming air stream is heated by steam or combustion products, but does not mix with them. The steam may be heated by fuels, such as natural gas or propane, or by electricity. Combustion products used for heat exchange are generally derived from natural gas or propane. Direct heating routes the hot products of combustion (blended with ambient air to achieve the desired temperature) directly into the drying zone. The fuels for a direct-fired oven are usually either natural gas or liquefied petroleum gas (*e.g.*, propane) because they both burn cleanly and are easily controlled.[8,10]

Oven drying involves raising a coating's temperature to evaporate the vehicle solvent quickly while keeping the temperature elevated long enough for entrapped solvents to migrate to the surface of the adhesive and evaporate. The time required to drive off vehicle solvents at the boiling temperature is known as the drying residence time. In most coating processes, approximately 80 to 95 percent of the vehicle solvent evaporates and exits with the oven exhaust either to the atmosphere or to a control device, depending on the nature of the exhaust, the quantity of release, and the location of the facility.[10] Another important oven consideration is the oven's temperature profile. Most ovens have a number of zones in which the temperature and airflow can be independently controlled. If the initial drying proceeds too quickly, voids may develop in the coating. Conversely, if drying occurs slowly at low temperatures, longer ovens may be necessary to achieve sufficient residence time. Multi-zone ovens can generally be optimized to overcome these difficulties. Large drying and curing ovens may have six or more zones ranging in temperature from 110° to 400°F (43° to 204°C). Facilities may also employ recirculating ovens to provide better drying efficiency.

2.4.4.5 Rolling, Printing, Cutting, and Product Shipment[4]

Many coating operations also offer value-added converting services to their customers. Such services include custom slitting and roll winding, printing, die-cutting, and sheeting. A roll of coated product may weigh up to 5,000 pounds (2,268 kilograms) and be 30 inches (76 centimeters) wide when it comes off the production line. Such products are generally slit to a customer-specified width, and automatically rolled onto standard cores for customer use in automatic dispensers. Many facilities have the ability to slit and wind product on-site, however, some facilities send finished rolls to contract converters to be sized. Coaters may customize label and packaging products by printing a logo and die-cutting to size. The product is generally cut, with the waste removed and the web rolled and packaged for shipping.

2.5 EMISSIONS AND WASTE STREAMS

2.5.1 Introduction

This section discusses the emissions and waste streams associated with web adhesive coating manufacturing. Characterization and, where available, quantification of the air emissions, liquid wastes, and solid wastes from adhesive coating processes are presented. Facility-specific information is also provided based on site visit assessments, TRI reporting requirements, and permit information.

2.5.2 Air Emissions from Solvents

2.5.2.1 Emissions from the Industry

A number of solvents, most typically MEK and toluene, are used in solvent-based adhesive formulations. These solvents typically contain both VOC and HAP. In 1992 the total of all MEK releases to the air by facilities operating under SIC 2671 was 1.1 million pounds (500,000 kilograms). Toluene air releases totalled 6.4 million pounds (2.9 million kilograms). SIC 2672 facilities emitted nearly 5.2 million pounds (2.4 million kilograms) of MEK and 19 million pounds (8.6 million kilograms) of toluene.[11] Most coated and laminated substrate manufacturing facilities calculate these emissions based on raw material consumption. Therefore, total emissions reflect solvent losses occurring during raw material mixing, coating processing (including fugitive releases), equipment cleaning, and material storage.

The primary impacts of VOC and HAP reductions depend on the facility location. In heavily industrialized areas, the reduction of VOC emissions may produce a corresponding reduction in local hydrocarbon levels, and thus a reduction in ozone formation. In rural areas, lower VOC and emissions may result in lower overall ambient hydrocarbon levels, helping to reduce the transport of ozone precursors to urban areas. In addition, the reduction of VOC emissions will lead to reduced environmental impacts on other media. For example, improperly handled chlorinated materials (*e.g.*, methyl chloroform) often result in contaminated soil and groundwater. Reducing the quantities of these materials used for cleaning will reduce the potential for contaminated aquifers, drinking water wells, and soils.

Emissions during the application of solvent-based coatings are often directed to an emissions control device. The devices most often employed for emissions control are carbon absorption systems, catalytic incinerators, or thermal incinerators. Most facilities utilizing these devices control emissions from the drying/curing ovens. However, some facilities also add to the emissions stream exhaust from the raw material storage/mixing area, coating application room, and coating head trough. While such control devices reduce VOC and HAP emissions, the use of incineration will actually increase ambient levels of carbon monoxide (CO) and oxides of nitrogen (NO_x) in the ambient air.

The following subsections (subsections 2.5.2.2 through 2.5.2.6) describe solvent emissions from specific areas of the adhesive coating process.

2.5.2.2 Solvent Storage

Facilities that formulate their own solvent-based adhesives can have both breathing and working losses resulting in emissions during storage of the solvent. Air emissions may result from vapor displacement during solvent delivery to solvent storage tanks, which may be above-ground storage tanks (AGSTs) or underground storage tanks (USTs). Also, solvents stored in 55-gallon (208-liter) drums located within the facility may release evaporated solvent when opened.

2.5.2.3 Transfer and Formulation Losses

During transfer of the solvent from the formulation tank, air emissions may result from equipment leaks or the opening of solvent drums. Also, equipment leaks may occur during the adhesive formulation process. Facilities which buy pre-formulated adhesives may conduct additional blending during which solvent vapor may escape from the blending tanks or drums. Dedicated coating equipment normally includes dedicated closed-loop adhesive delivery systems which reduce solvent evaporation during transfer of the adhesive to the coating head trough. Batch coating equipment may experience somewhat higher evaporation rates due to more frequent transfer of the solvent-containing coatings to the coating equipment. Spills and/or accidents involving solvent-based adhesives are also a potential source of VOC and HAP emissions.

2.5.2.4 *Adhesive Coating/Coating Application*

Another potential source of solvent evaporation is the adhesive trough. Upon delivery of the adhesive to the coating head, the coating is placed in a trough where the pick-up roll contacts the adhesive and transfers it directly to the web or to the application roll. Solvent can evaporate from the trough during this operation. Many facilities maintain a partial enclosure over the coating trough to minimize solvent evaporation to the atmosphere. Air circulating in the enclosure is often vented through the oven to a control device.

2.5.2.5 *Ovens*

The primary source of VOC and HAP emissions in a solvent-based coating line is the oven. During the drying/curing stage, the solvent is evaporated from the coating and is exhausted through the oven vent. Many facilities employ a destruction or recovery device to destroy or capture and reclaim these solvent vapors. The capture and destruction efficiencies of these devices are the most critical factor determining solvent emissions.

2.5.2.6 *Equipment Cleaning*

Industry representatives estimate that one to ten percent of total solvent releases are due to equipment cleaning.[4] The amount emitted depends on the degree to which the facility operates in batch or dedicated mode. Generally, more batch coating results in higher levels of equipment cleaning releases, as more equipment cleaning is necessary in batch operations. These emissions represent the greatest source of fugitive emissions from coated and laminated substrate manufacturing. These emissions are difficult to control with add-on devices, so some facilities are attempting to find alternative cleaning products and methods. Depending upon the cleaning chemicals used (*e.g.*, toluene, methyl chloroform, mineral spirits), VOC and/or HAP may be emitted.

2.5.3 Liquid Wastes

Liquid wastes, both hazardous and non-hazardous, are generated from waste or spent adhesive and cleaning solvents, cleaning wastes, and spills and accidents. Spent cleaning solvents are the largest liquid waste produced by coated and laminated substrate manufacturers. Spent cleaning solvents include those used to flush coating delivery systems (*e.g.*, tanks, piping, coating head trough) and those used to wipe or soak coating equipment. Many of these solvents are recoverable through distillation and can be incorporated in a coating; however, they may also be sent off-site for disposal. A second liquid waste stream consists of excess or off-specification coating. Waste or spent adhesives include those whose shelf-life has expired or batches that were incorrectly formulated.

Another source of liquid wastes may be air emissions control equipment. Facilities using carbon adsorption systems (usually associated with controls on dryers or ovens) have the potential to discharge contaminated water from condensation of the steam used to desorb the carbon beds. Facilities typically have three options for disposing of this waste: (1) use the water for boiler feed; (2) use the water for cooling towers; or (3) discharge the water into a wastewater treatment facility or local sewer for further treatment. Spills and/or accidents involving solvent-based adhesives are also a potential source of liquid waste.

Facilities are responsible for the environmental impacts their water may have on a sewer or water system. A facility should always consider the effects of a new liquid waste stream on plant wastewater treatment (WWT) operations or on publicly owned treatment works (POTW). Some cleaners may reduce toxicity, hazardous waste, and air emissions, but can create excursions from effluent limitations.

Facilities that formulate their own waterbased adhesives will generate deionized water. The chemicals and minerals deposited during the deionization process must be disposed of in some manner. These materials may be included in the effluent and sent to the POTW, or disposed of as solid wastes. In addition, the deionization process will create a wastewater stream which may be sent to the POTW or collected and sent off-site for disposal as a non-hazardous waste.

2.5.4 Solid Wastes

Solid wastes from the manufacturing operations may be classified into three areas: cleaning waste, waste adhesive-coated backing, and solidified coating waste. Solid waste from cleaning includes items such as rags, floor coverings, machinery coverings, and coating filters. Disposal requirements for waste adhesive-coated backing generated from the edge of paper rolls, at the beginning and ending of a run, and from cutting and packaging operations depend on local and state regulations. The characteristics of the solvent on the substrate affect its classification as solid waste.

Solid waste may be created by emissions control equipment. Activated carbon from carbon adsorption systems must be replaced periodically, and spent carbon must be disposed of according to state and local regulations. The remains from incineration or catalytic oxidation must also be disposed of as solid waste. The carbon may be able to be reused for fuel or recycled for other uses. Waste from incineration or oxidation may also have alternative uses.

As stated in Section 2.5.3, facilities which formulate waterbased adhesives onsite generate deionized water. The chemicals deposited during the deionization of water are often disposed of as solid wastes.

2.6 FACILITY SELECTION

2.6.1 Introduction

Although information on conversion to waterbased adhesives was obtained during a number of facility site visits under previous EPA projects in the adhesive coating industry, two additional site visits were conducted specifically for this study. These site visits consisted of one background information gathering visit at FLEXcon Company in Spencer, Massachusetts, and one case study of a waterbased retrofit effort at Nashua Corporation in Omaha, Nebraska. These site visits covered several of the categories of industry segmentation (*i.e.*, large and small facilities, dedicated and batch facilities, and high and low performance products) which were described in

Section 2.3 of this report. A brief description of the criteria for selecting of these sites is presented in this section.

2.6.2 FLEXcon Company

FLEXcon Company (FLEXcon) located in Spencer, Massachusetts, was chosen as a site at which to gather background information on waterbased adhesive retrofit because it met the industry classification categories of (1) a large facility that (2) used a batch mode of operation to generate (3) high performance end products. FLEXcon's Spencer, Massachusetts facility employs approximately 600 production personnel. FLEXcon officials describe their coating lines as operating in a batch mode. FLEXcon coats both waterbased and solvent-based adhesives on a wide variety of backings including vinyl, polyester, acrylic, acetate, polyethylene, polypropylene, and polystyrene.

2.6.3 Nashua Corporation

Nashua Corporation (Nashua) located in Omaha, Nebraska, was chosen as a case study site because of its current retrofit efforts. Nashua fulfilled the industry categories of (1) a relatively large facility operating primarily in (2) a dedicated mode manufacturing (3) commodity, generally low performance, end products. Nashua's Omaha, Nebraska facility employs approximately 200 to 300 production personnel and operates two adhesive coating lines. Nashua officials also described their operations as primarily dedicated, although some batch operations are performed. Nashua manufactures approximately 30 to 40 end products using eight or nine waterbased adhesive formulations and about ten different types of paper face stock (*i.e.*, label backing). At the time of the site visit, Nashua was nearing the end of a six-year effort to convert their coating processes from solvent-based to completely waterbased adhesives. This conversion was completed by December 31, 1993.

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CHAPTER 3
FACILITY VISITS

3.1 METHODOLOGY FOR SITE VISITS

3.1.1 Methodology Overview

The methodology for the site visits conducted during this project began with identifying potential host facilities. As information was gathered on the waterbased adhesive coating industry, potential candidate facilities for case studies were identified. Any facility performing waterbased adhesive coating operations was considered a potential candidate. For each of the 18 facilities identified, an initial telephone contact describing the project goals was made. Initial telephone contacts that responded favorably were sent an information packet containing a cover letter, the project's background, and a list of specific questions concerning facility operations and retrofit experience. The list of questions was developed to guide discussions during the site visits and was meant to provide the facility with examples of the kind of information sought during site visits. The questions are included in Appendix A and covered the following topics:

- General facility information (size, market profile, etc.)
- Costs of retrofitting solvent-based adhesive equipment to process waterbased adhesives
- Product performance and quality issues related to the use of waterbased adhesives
- Process equipment requirements of waterbased adhesives
- Environmental impacts associated with the use of waterbased adhesives
- Labor impacts associated with retrofitting to waterbased adhesives

After receiving the information packet, a follow-up call was placed to the potential candidate facilities. Receipt of the information packet was confirmed and the candidate facilities were further questioned on their end products, processes, and adhesives. If a facility proved to be an appropriate candidate for the project, it was asked for its agreement to participate.

Ten of the 18 facilities contacted for this project were unwilling to participate; six of the remaining eight facilities were only willing to participate at a minimal level. Minimal participation consisted of developing a one-page summary of the facility and its operations, with no site visit or additional information-gathering activities occurring. The two remaining facilities, in addition to participating at the minimal level, also agreed to participate further as case study subjects. Nashua Corporation in Omaha, NE, and FLEXcon Company, Inc. in Spencer, MA, agreed to host site visits by TRC personnel to gather information related to the use of waterbased adhesives. Upon agreeing to participate, site visit dates were scheduled.

Each facility site visit conducted for this project began with a opening discussion of the site visit purpose, project goals, and confidential business information (CBI) issues. Specific questions were evaluated by the facilities to ensure the information gathered during the site visit was not confidential. A subsequent plant tour was conducted followed by a closing meeting to discuss final issues related to report generation, facility review, and project schedule.

After completing the site visits, reports were generated detailing each facility's process equipment and waterbased adhesive coating experience. Each report covered four general topics: (1) a general facility description, (2) the facility's attempted conversions to waterbased adhesive or a discussion of the obstacles to converting, (3) environmental issues of coating both solvent-based and waterbased adhesives, and (4) a summary of the conclusions about waterbased adhesive use at the facility. Although discussed in each report, these four topics were organized differently as applicable to each facility.

After completing a draft report on each site visit, the document was sent to the applicable facility for review. The facility was responsible for ensuring the technical accuracy of the report and appropriately marking any information considered proprietary. Both the Nashua and FLEXcon site visit reports were found to contain a minor amount of CBI which was removed or altered to preserve the report's status as entirely nonconfidential. A revised copy of each report was then submitted to EPA.

3.1.2 Facility Profile Development

The foci of the facility visit investigations were the potential for use of waterbased adhesives as replacements for solvent-based adhesives and the modification of current solvent-using activities (*e.g.*, equipment cleaning with solvents, process and fugitive solvent emissions control) to reduce solvent emissions. A profile of each facility was developed to obtain a complete understanding of the factors affecting emission levels and their potential reduction. Three areas were critical to the development of these profiles: the facilities' processing techniques, end product lines, and future plans.

3.1.3 Process Equipment and Techniques

Although many similarities exist between the coating and laminating processes used by the various facilities in the industry, differences in these processes can account for significant differences in emissions sources. For example, one facility may enclose and ventilate a coating head to an emissions control system to capture releases from the trough and coating application. Facilities not employing total or partial enclosures around the coating application apparatus often release substantially more fugitive emissions.

A number of process-related issues were studied during the site visits. Most important among these were coating line operating techniques. As discussed in Chapter 2, the distinction between batch and dedicated processing of the coating line is one key factor in determining the potential for waterbased adhesive use at a facility. The coating head configuration used at a facility is also key to determining which backings and adhesives can be used in the coating head, and at what processing speeds the line can operate. Facilities with more than one coating head configuration have increased flexibility among backings, adhesives, and application speeds which can be used.

Adhesive delivery systems were also analyzed. These systems generally consist of pumps and piping used to transfer adhesive from a storage vessel [*e.g.*, a large storage tank or a 55-gallon (208-liter) drum] or holding tank used for temporary storage or additive mixing. Oven operations were also studied during the plant visits. The three criteria used to evaluate oven operations were the number of separate temperature zones within the oven, the maximum and minimum potential temperatures within those zones, and the distribution of temperature and airflow generally used during coating line operation. Finally, other process-related equipment, such as heat exchangers or infrared (IR) heaters, were noted during the site visit.

Process-related issues and practices were also examined during site visits. Equipment cleaning practices were observed to determine the differences in solvent-based and waterbased practices, emission losses, and potential emissions reduction. Emissions control equipment used by each facility, such as thermal and catalytic oxidizers, carbon adsorbers, and outside ventilation systems, were examined. Using data provided by the facilities on solvent purchasing, utilization, and destruction or recovery by emissions control devices, emissions levels at the sites were roughly estimated.

3.1.4 End Product Lines

A complete assessment of a facility's product lines includes an examination of its current mix of end products, marketing strategies for selling product, performance requirements for end product application, and the future changes, additions, and goals of product line development. Generally, manufacturers of adhesive-coated products either supply a specific type of product or attempt to fully service specific customers. Batch processors, who often use solvent-based adhesives or a mix of mostly solvent-based adhesives with a small amount of waterbased adhesives, often attempt to provide complete product lines for each of their clients. To accomplish this, varied adhesives and backings are employed to generate products suitable for a wide spectrum of applications. These full-service batch-processing operations may not manufacture every product in their product lines; instead, they may purchase some products from other manufacturers to complete their client's product lines. By providing complete product lines for their clients, these facilities allow discounts to their loyal clients and discourage them from looking elsewhere for adhesive-coated products.

While batch coaters generally produce relatively small amounts of a large number of adhesive-coated products, dedicated coaters generally produce large amounts of a small number of adhesive coated products. These firms rarely attempt to produce full-service product lines for their clients. Instead, they manufacture a relatively small number of end products. Because dedicated processors do not possess the diversity of product output, and therefore the flexibility of batch processors, it is imperative that their end products are in relatively high demand markets. An excellent example of a high demand market product is adhesive-coated paper labels used in room temperature or colder applications. Paper labels are used extensively in food packaging, supermarket labeling, and office supplies. Since the end product demands do not vary widely over time, paper labels make an excellent dedicated-line output product.

During the site visits, each facility's product line was assessed to determine to which of the two categories it belonged. Once the product line categorization was assessed, marketing targets were established. Each facility uses certain marketing strategies in order to sell end products and expand its markets. Some facilities have a loyal clientele that they depend on for consistent sales without significant marketing efforts. If marketing efforts can be kept to a minimum, product prices may be kept low. Other facilities pursue more aggressive marketing strategies. Marketing strategists may travel domestically or internationally to cultivate client growth. Most adhesive coating firms develop an extensive catalog of brochures and mailers containing information on their end products and applications. These facilities may also be members of various adhesive coating and laminating trade associations where they can develop client contacts and leads for business development. Some facilities assist their marketing efforts by presenting themselves as specialists in certain application areas. For instance, a facility may concentrate product line development within a small number or even a single industrial or commercial area to become recognized as a specialist in this area.

Although coordinated marketing efforts assist in developing a client base, a client's major considerations when purchasing adhesive-coated products are price and performance. The adhesive coated and laminated substrate industry is highly competitive, so it is imperative that manufacturers maintain competitive pricing. Competitive pricing is most critical in low performance, generally commodity markets, while product performance is most critical in high performance, generally specialty markets. For high performance manufacturers, end product performance must meet exacting, often extreme customer specifications. While cost of product is important to high performance manufacturers, performance levels cannot be sacrificed. Individual coating facilities must maintain an optimum balance between low pricing and high performance suitable for their client's applications.

3.1.5 Potential Future Changes in Processes and Product Lines

The information contained in this paragraph was derived from the case study facilities and others in the adhesive coating industry. The future plans for both process and product additions, changes, and improvements are critical factors to ensure the long-term profitability of a company. In the past several years, adhesive coating and laminating firms have undergone tremendous pressures on a number of fronts including environmental constraints, increasing competition, a turbulent economy, and changing foreign trade conditions. Facilities must remain flexible in the short-term and still plan for the long-term. An effective gauge of a facility's long-term strategies is its plans for additions, changes, and improvements to its process manufacturing profile, such as the addition of a new coating line, change of its coating head, or conversion of a solvent-based adhesive product to waterbased adhesives. Planned end product line changes are also indicators of a facility's strategy for the future. New product introductions, elimination of products, and product improvements must be planned to meet changing market conditions.

3.2 GENERAL RESULTS FROM THE SITE VISITS

3.2.1 Site Summary

As discussed previously, two facility site visits were conducted to obtain information about potential conversions from solvent-based to waterbased adhesives. The two sites selected were Nashua Corporation in Omaha, Nebraska; and FLEXcon Company, in Spencer, Massachusetts. Nashua recently completed a six-year effort to convert its paper label end products from solvent-based to waterbased adhesives. This effort is documented in Volume III of this report series.[1] FLEXcon is a batch operation which coats a wide variety of backings using solvent-based and waterbased adhesives. The site visit report to FLEXcon comprises Volume IV of this report series.[2] The results of the two site visits are discussed in this section.

3.2.2 Nashua Corporation

3.2.2.1 Introduction

Nashua Corporation began operating its Omaha, Nebraska plant in 1966. The plant was originally built in 1959 and operated by the International Paper Company. Nashua's Omaha facility currently employs approximately 90 administrative and management personnel and 200 to 300 production personnel. Since it employs 300 to 400 personnel and annually produces approximately 200 to 300 million square yards (167 to 251 million square meters) of end product, Nashua is designated a large facility. The Omaha plant operates 24 hours per day, five to seven days per week, depending on customer demand, and produces pressure sensitive labels, roll-stock, and custom label products.

Nashua produces 30 to 40 adhesive coating and paper backing combinations (*i.e.*, finished products) for its customers. At first glance Nashua might be considered a batch operation, since it produces different products on its individual coating lines. However, Nashua generally sets up a coating line to run for many hours (ten or more) before switching to another product. Also, while an adhesive's chemical makeup and the paper backing to which it is applied may differ, the coating process generally remains the same for each product line, excluding several relatively easily controlled variables such as line speed, coating thickness, and oven temperature and airflow. In light of these attributes (*e.g.*, long product runs, similar coating processes for different products), Nashua believes the term dedicated processor most accurately describes its operations.

Nashua is a commodity (*i.e.*, lower performance) processor. While possessing the capability to manufacture end products meeting a wide range of specifications, Nashua generally produces large amounts of a small number of end products for application in moderate environmental conditions (*e.g.*, low humidity, small temperature exposure range).

*3.2.2.2 **Waterbased Adhesive Use at Nashua***

Nashua currently produces all of its end products using waterbased adhesive formulations. Nashua discontinued their last solvent-based adhesives before December 31, 1993. The reasons for this conversion, which included the various regulatory costs associated with solvent-based adhesives and environmental considerations, are discussed in detail in Reference 1. Nashua discontinued one product line in order to meet this goal, since it could not find a suitable waterbased adhesive formulation to replace the solvent-based coating used for the product line. However, this product line was a relatively small percentage of the plant's output, and Nashua expects that the loss can be offset with increased sales of its other products.

Nashua operates three coating lines in the Omaha plant. Prior to 1989, Line 1 ran 100 percent solvent-based adhesives. Line 2 is the release coating line which applies a 100 percent solid-catalyzed silicone release coating to paper stock. This line formerly applied a solvent-based silicone release coating. Line 3 is another pressure sensitive adhesive coater/laminator label line which has operated with 100 percent waterbased coatings since 1982 when it was converted from a waterbased heat seal coating line.

Nashua started the change to waterbased adhesives in 1982 because company executives felt that waterbased products would have a strong future in the label manufacturing industry. To make the changeover, Nashua purchased several new adhesive holding tanks, made of glass-fiber, in which adhesive could be stored and agitated before use. Polyvinyl chloride (PVC) piping and new pumps were installed to transfer the product to the coating heads. Nashua experimented with coating speeds, thicknesses, and drying oven temperatures to determine the optimum conditions. Within one week, Nashua was able to produce a viable waterbased adhesive-coated product.

Nashua began a complete facility conversion from solvent-based adhesives to waterbased adhesives in the Omaha plant in 1987. Conversion was a corporate decision although the time frame for the changeover apparently was not specified. The main factors driving the conversion were the economic and environmental advantages of waterbased adhesives. Nashua adopted a policy to replace its solvent-based products with waterbased products which had qualitative improvements, such as lower production cost and increased temperature range before adhesive failure. Nashua's research and development (R&D) department was charged with seeking out and testing new waterbased formulations. Where product improvements were feasible, Nashua incorporated new waterbased adhesives into its products and offered the improved products to its customers. The products were not marketed as replacement products for its solvent-based adhesive-coated products (both were offered as alternatives).

With the passage of the Clean Air Act Amendments of 1990 (CAAA), Nashua decided to expedite its conversion to waterbased coatings, and to eliminate all solvent use. At that time, Nashua set a goal of complete conversion to waterbased adhesives by December 31, 1993. Despite some setbacks, it managed to remain on schedule, and met its goal of complete conversion to waterbased adhesives.

3.2.2.3 Nashua's Waterbased Adhesive Performance Requirements

For Nashua's niche in the marketplace, there are two primary environmental exposures to which its products are subject: temperature extremes and varying surface energy of the adherents (*i.e.*, the surface to which the product is applied). Since each adhesive formulation generally has limited environmental conditions in which it properly functions, Nashua has designed its entire adhesive product line to cover a broad range of temperatures and surface conditions. Nashua's product lines attempt to cover application temperatures from -30° to 150°F (-34° to 66°C) on surfaces ranging from corrugated cardboard to smooth plastics.

Nashua was able to cover this spectrum of environmental exposures using solvent-based adhesives. In its move to waterbased adhesives, it was necessary for Nashua to retain coverage of this spectrum of applications, or risk losing market segments. For the most part, Nashua has had success finding waterbased adhesive formulations which met or exceeded the spectrum of applications of the solvent-based adhesive formulations they replaced.

Nashua described a recent successful waterbased adhesive replacement of two solvent-based adhesives. Nashua had one client who formerly purchased two label products manufactured with solvent-based adhesives. One product was used by the client for room temperature applications, while the other was used at low temperatures. The room temperature solvent-based adhesive cost Nashua approximately $1.00 per pound ($2.20 per kilogram) of wet adhesive. The low temperature solvent-based adhesive cost Nashua approximately $1.50 per pound ($3.30 per kilogram) of wet adhesive. Nashua was able to obtain one waterbased adhesive product which, at a cost of approximately $1.15 per pound ($2.53 per kilogram), performs in both the room temperature and cold environments.

Nashua found that some inherent qualities possessed by waterbased adhesives are superior to solvent-based adhesives for some of Nashua's end product applications. For example, the tack of waterbased adhesives is generally somewhat lower than for solvent-based adhesives. For the application of some labels, lower tack is beneficial. If a label is improperly placed, it can be removed and reapplied without destroying the label. This property leads to additional applications for waterbased adhesives, including removable/reusable labels. Nashua found that final adhesive bond strength is generally greater with waterbased formulations, so permanent bonding can be stronger than with solvent-based adhesives.

While Nashua has had success replacing most of its solvent-based adhesives with waterbased adhesives, duplicating the performance of every product has not been possible. Nashua personnel had to cease production of one product for which a suitable waterbased adhesive alternative was not found. This product represented a small portion of Nashua's production volume.

3.2.2.4 Costs of Waterbased Adhesive Conversion

Nashua's conversion to waterbased adhesives required a significant investment of time and capital. Since 1987, Nashua has purchased 13 glass-fiber tanks for blending and storing waterbased adhesives. These tanks range in cost from $5,000 to $75,000, excluding installation costs which are approximately two to three times the purchase cost of each tank. Nashua purchased new piping and air pumps to transfer the waterbased adhesive to the coating heads on an as-needed basis as its capacity to coat waterbased adhesives has increased. Piping is relatively inexpensive while air pumps range from $500 to $2,000 each. Nashua also installed three heat exchangers to ensure that the waterbased adhesive remains at a constant temperature during coating. The heat exchangers cost up to $5,000 each with additional installation costs of $2,000 to $3,000 each.

Nashua has incurred additional cleaning costs associated with waterbased coatings. While the stainless steel tanks and piping of the solvent-based system rarely required cleaning, the glass-fiber tanks used with waterbased adhesives must be cleaned every six months. Cleaning the tanks requires approximately 16 man-hours and a labor cost per tank of about $1,000 per year. Also, waterbased adhesives are more difficult to clean from equipment, resulting in increased labor.

Nashua also stated that increased output of wastewater has resulted from the conversion. Wastewater disposal costs are approximately $350 per week higher than before conversion. This cost includes increased wastewater generated and shipping costs.

In addition to these relatively quantifiable costs, Nashua has incurred some costs associated with learning to use waterbased coatings. The amount of time spent by Nashua personnel learning to mix, transfer, coat, and dry waterbased adhesives was significant, although not easily quantified. Nashua's largest learning costs revolved around the pumping system for transferring waterbased adhesives to the coating head. Nashua found that waterbased acrylics have a strong tendency to dry in the valves of the pumps, causing them to stick. Cleaning the pumps is costly, time consuming, and can interfere with the production process. Nashua could not quantify the labor hours that have been spent on pumping problems; however, Nashua considers it a significant cost of using waterbased adhesives.

3.2.2.5 Reasons for the Conversion

Nashua personnel indicate that there were three motives behind the corporate decision to switch to waterbased adhesives. One motive was to avoid future regulatory costs. Nashua felt that future regulations might become stringent enough to make solvent-based adhesive use unprofitable. Nashua believed that the trend towards higher emissions fees would continue, so solvent-free waterbased adhesives seemed an appealing alternative to solvent-based adhesives.

A second motive for converting to waterbased adhesives was to become involved in a developing field of adhesive technology. Nashua plays an active role in professional organizations and in development work with adhesive formulators and equipment suppliers. According to Nashua personnel, there was essentially no continuing research aimed at improving current solvent-based adhesives. Nashua personnel believed that adhesive formulators realized that solvent usage would be phased out, so the formulators were concentrating their research and development efforts on other adhesive technologies, such as waterbased, hot melt, and two-part reactive adhesives. Nashua found that, for its purposes, waterbased adhesives possessed the performance levels (*e.g.*, tack, adhesion, temperature sensitivity) required by its customers. Currently, the costs of formulating solvent-based adhesives and purchasing waterbased adhesives are approximately the same for Nashua [$1 to $4 per dry pound ($2.20 to $8.81 per dry kilogram)]. With continuing research, Nashua feels that future waterbased adhesive prices may drop as performance levels increase.

A third motive expressed by Nashua personnel for the conversion to waterbased adhesives was the company executives' belief that moving towards waterbased adhesives was environmentally correct. Nashua personnel indicated that the company had other compelling reasons to convert to waterbased adhesives, as mentioned in the previous paragraphs. However, they believed that the executive decision to convert to waterbased adhesives was an attempt to move into a more environmentally sound means of production, above and beyond monetary considerations.

3.2.3 FLEXcon Company

3.2.3.1 Introduction

FLEXcon Company, Incorporated began operating one adhesive coating plant in Spencer, Massachusetts in 1955. Five additional FLEXcon plants have been added to the Spencer complex since 1955 as increased capacity has been required. Additional production facilities are located in Connecticut, Minnesota, and Nebraska. Warehousing facilities are located in six different locations throughout the Unites States and Canada. FLEXcon currently operates within SIC code 3081 (Unsupported Plastics Film and Sheet), although their operations are more typical of an SIC 2671 or SIC 2672 facility. In 1993, FLEXcon had approximately $220,000,000 in sales.

FLEXcon employs approximately 1,100 people company-wide. Of those, 800 employees, including 600 production staff, are located in the Spencer complex. Normal operating schedules are two 12-hour shifts per day seven days per week. FLEXcon's Spencer complex has approximately 570,000 square feet (53,000 square meters) of production space and is composed of six plants, including coating plants and finishing plants. These six plants differ in their age, capacity, and end products manufactured.

FLEXcon manufactures six main categories of pressure-sensitive products: graphic films, packaging labels, electronic printing labels, microembossed films, medical films and labels, and custom-performance products. The company coats various types of films and many of their end products require high performance standards such as humidity and corrosion resistance. For these reasons, FLEXcon considers itself a high performance, specialty pressure-sensitive film manufacturer.

3.2.3.2 Waterbased Adhesive Use at FLEXcon

FLEXcon made an effort to convert some of its solvent-based coating lines to waterbased adhesives in 1983. This effort, which is discussed in detail in Volume IV of this report series,[2] was abandoned shortly after its inception. FLEXcon's current waterbased product lines are not replacements for solvent-based products, but are new product lines aimed at different market segments. FLEXcon uses a total of approximately 50 adhesive-coating formulations in manufacturing. Approximately ten of these are waterbased adhesives, while the remainder are solvent-based adhesives. Waterbased product lines have been growing at an annual rate of 30 to 35 percent per year in the last few years.

FLEXcon began producing a waterbased adhesive-coated product approximately 20 years ago, using existing equipment. FLEXcon's next experience with waterbased adhesives came nearly ten years later when they experimented with a large number of waterbased adhesive coatings before selecting two new products to introduce in 1984. Since 1984, FLEXcon has steadily increased the number of waterbased adhesive-coated products it manufactures. However, almost all of FLEXcon's increases in waterbased production have been due to new products, not replacements for solvent-based adhesive-coated products.

FLEXcon is not currently contemplating any additional waterbased adhesives as replacements for current solvent-based adhesives. However, it actively pursues improvements in waterbased adhesives that will allow it to develop new products to expand waterbased adhesive use in the future.

3.2.3.3 Limitations of Waterbased Adhesives

FLEXcon personnel indicated that significant adhesive performance issues must be addressed before waterbased adhesives can be fully used in FLEXcon's market segments. According to FLEXcon, there are currently no waterbased adhesive formulations that can meet the performance requirements of its clients. The main limitations of waterbased adhesives in FLEXcon's product market are their lower peel strength, lower sheer strength, limited backing compatibility, lower humidity resistance, and unsuitability for direct skin contact.

Many of FLEXcon's products must withstand exposure to extreme temperatures, humidity, rain, ultraviolet radiation, and high stress conditions. Its products must also be suitable for direct skin contact and use on low energy backings (*e.g.*, plastic films). FLEXcon manufacturers adhesive-coated products for use in the electronics industry, which must meet rigorous performance standards. Its adhesive products designed for medical applications must also meet exacting performance characteristics. The current spectrum of available waterbased adhesive coatings does not encompass the breadth of environmental conditions to which FLEXcon's products are subject.

Additional difficulties in processing waterbased adhesives increase the barriers to their more widespread use. These processing difficulties are discussed in detail in Volume IV of this report series.[2] However, as previously discussed, the lower performance characteristics associated with waterbased adhesives are the limiting factor to more extended use. For FLEXcon to adequately service the needs of its current client base, it must continue to use solvent-based adhesives.

3.2.3.4 *Future Potential for Waterbased Adhesives*

Although FLEXcon personnel noted that it would currently be impossible to eliminate solvent-based adhesive use without drastically altering its client base and market segments, there are many opportunities for waterbased adhesive use at FLEXcon in the future. As the performance characteristics of waterbased adhesives continue to improve, new markets are becoming accessible. FLEXcon continually searches for these new markets in which to sell waterbased adhesives. It does not see similar opportunities for solvent-based adhesives. For FLEXcon, sales of solvent-based adhesive-coated products over the past few years have stayed fairly constant. As a result, FLEXcon is increasing production of waterbased adhesive-coated products while maintaining current production levels of solvent-based adhesive-coated products.

In the future, there may be opportunities for FLEXcon to reduce the use of solvent-based adhesives. Other adhesive technologies, like radiation-cured and two-part reactive adhesives, might achieve performance breakthroughs allowing replacement of solvent-based adhesives. Key factors in the development of a radiation-cured system would be a significant reduction in the cost for radiation sources and the introduction of lower toxicity chemicals than those currently used in the process. Waterbased and hot melt adhesives are currently better suited for low performance applications, but continuing research may increase their applicability. FLEXcon personnel predicted that performance levels of these various adhesive technologies might be high enough to warrant replacement of many high performance solvent-based adhesives within ten years. As the performance and marketability of waterbased and other adhesives continue to increase, FLEXcon personnel believe they will be able to achieve significant conversions from solvent-based adhesives.

3.3 REFERENCES

1. McMinn, B.W., W.S. Snow, and D.T. Bowman. *Solvent-Based to Waterbased Adhesive-Coated Substrate Retrofit - Volume III: Label Manufacturing Case Study: Nashua Corporation*. EPA-600/R-95-011c (NTIS publication number not yet available). National Risk Management Research Laboratory. Research Triangle Park, NC. December 1995.

2. McMinn, B.W., W.S. Snow, and D.T. Bowman. *Solvent-Based to Waterbased Adhesive-Coated Substrate Retrofit - Volume IV: Label Manufacturing Case Study: FLEXcon Company Incorporated*. EPA-600/R-95-011d (NTIS publication number not yet available). National Risk Management Research Laboratory. Research Triangle Park, NC. December 1995.

CHAPTER 4.0
COMPARATIVE ANALYSIS

4.1 GENERAL DESCRIPTION OF PROCESS RETROFIT CYCLE

4.1.1 Technical, Environmental, and Economic Considerations

Despite the enormous variety of products manufactured using waterbased and solvent-based adhesive coating and laminating equipment, the processes used to manufacture these products are generally quite similar. All adhesive coating and laminating involves depositing an adhesive layer of some thickness onto a backing. In waterbased and solvent-based coating, the types of equipment used to perform this function at different facilities are almost identical: an adhesive delivery system consisting of pumps and piping, a coating head of some design to apply adhesive to a backing, an oven to dry the adhesive, and a roller to rewind the backing and dried adhesive. Some systems also employ a transfer coating system to move adhesive from one backing to another.

Coating head and oven design are often identical for waterbased and solvent-based adhesive coating. Only the settings used in these devices (*i.e.*, coating application thickness, oven temperature and zoning, etc.) vary significantly. Waterbased and solvent-based adhesives must employ separate adhesive delivery systems, but the cost for these systems is minimal (*i.e.*, tens of thousands of dollars) when compared to coating head and oven costs (*i.e.*, hundreds of thousands of dollars).

For most adhesive coaters, the primary factor affecting the decision to convert to waterbased adhesives is the available performance levels of the adhesives. Waterbased adhesives do not provide the variety of adhesive strengths of solvent-based adhesives nor the diversity of environmental conditions in which solvent-based adhesives function well. Waterbased adhesive performance levels are improving, as many companies are conducting research and development efforts to enhance their applicability. However, limited performance is still a key drawback to waterbased adhesives.

If waterbased adhesives can meet the performance requirements of a manufacturer, a conversion can yield significant environmental benefits. Full conversion to waterbased adhesives virtually eliminates solvent emissions and hazardous waste production at a facility, unless solvents are still used for cleaning purposes. These environmental benefits can translate into economic benefits for a facility, as emissions control devices and hazardous waste disposal are both very costly and add no value to end products. However, waterbased adhesives do have some environmental impacts. Wastewater and adhesive waste sludge (*e.g.*, waste solids from waterbased adhesive coating) must be disposed of with varying costs, depending on local regulations.

When both technical and environmental issues have been addressed, a facility can determine if waterbased adhesive use will produce an economic benefit at the facility. Generally, low performance and dedicated-line coaters will find waterbased adhesives most attractive. Batch operations and high performance coaters generally find only limited use for waterbased adhesives, or may find them economically unsound for their operations. The reasons for this are explained in Sections 4.2 through 4.4, which discuss technical, environmental, and economic issues related to waterbased adhesive use in various segments of the industry.

4.1.2 Execution Stages of Retrofit

If a facility has determined that waterbased adhesives are applicable to some or all of its end products, it can begin to implement a retrofit. The first step in a retrofit is to identify waterbased adhesives which can meet or exceed the performance levels of currently used solvent-based adhesives. It is best to first replace lower performance solvent-based adhesives, since waterbased adhesives generally exhibit lower performance levels. To locate suitable adhesives, a number of adhesive manufacturers should be contacted. There may be several adhesive manufacturers with waterbased adhesives that meet the required criteria. Once several potentially suitable adhesives have been identified and purchased, small-scale performance testing can be conducted in-house. This process can narrow the potential waterbased adhesive formulations to a small number. These adhesives can be further tested and evaluated with the help of the clientele for which they are intended. With input from clientele, a final decision can be made as to the appropriateness of conversion, and which formulation will best meet customer needs.

Once both the facility and the customers are satisfied with a formulation for conversion, the facility can address equipment issues. For instance, equipment cleaning with waterbased adhesives is a more onerous task than with solvent-based adhesives. New pumps and piping will have to be purchased. Coating heads and ovens will require adjustments or additional equipment. To achieve maximum processing speed, these items may eventually need to be replaced.

To profitably retrofit its solvent-based lines with waterbased capability, a facility must allow a suitable amount of time. Attempting to perform a retrofit quickly is likely to disrupt operations and client relationships. A full conversion to waterbased adhesives should not be attempted immediately, but instead waterbased products should be phased in over time to the maximum extent possible. By slowly introducing waterbased adhesive technology to their plants and clients, adhesive coaters are much more likely to keep clients happy and remain profitable.

4.2 TECHNICAL RETROFIT BARRIERS TO PROCESS CONVERSION

4.2.1 Introduction

This section discusses the technical considerations associated with converting from solvent-based to waterbased adhesives. Technical barriers can be divided into three general categories: chemistry, equipment, and performance issues. Adhesive chemistry issues relate to chemical characteristics and composition of the adhesive. Equipment issues involve coating supply and delivery systems, coating head and auxiliary equipment, oven, and cleaning requirements. Performance issues relate to waterbased adhesives' ability to conform to customer specifications. These issues are discussed for all industry segments with specific considerations identified for large versus small and dedicated versus batch facilities. Because performance issues are a separate topic, they are discussed from the standpoint of high and low performance product manufacturers. The facility requirements for coating both solvent-based and waterbased adhesives are summarized in Table 4-1.

TABLE 4-1. PROCESSING REQUIREMENTS FOR SOLVENT-BASED AND WATERBASED ADHESIVE COATING IN ALL INDUSTRY SEGMENTS

Item	Solvent-based Adhesives	Waterbased Adhesives
Storage Area	Must be explosion-proof	No requirements
Backing Materials	Relatively easy to coat on most types of backings	Primarily coated on paper and some plastic films
Chemical/Corona Pretreatment	Required for some low surface energy backing materials	May be required for many non-paper backing materials
Storage/Mixing/ Holding Tanks	Storage tanks (minimal cleaning requirements) Stainless steel construction	Above ground (to ease cleaning) Glass-fiber construction Agitation required to prevent settling of solids
Piping	Stainless steel Explosion-proof	PVC or other water-resistant materials
Pumps	High-shearing (diaphragm) explosion-proof	Low-shearing (air)
Adhesive Coating Properties	Uses solvent vehicle Solids content generally lower than waterbased Foaming is not a problem	Uses water vehicle Solids content generally higher than solvent-based Emulsion instability can cause coating problems (foaming)
Coating Viscosity	Relatively stable	Must be monitored and altered to ensure optimum coating viscosity
Heat Exchanger	Not usually required	Sometimes used to control coating viscosity
Coating Head	Most types are satisfactory (*e.g.*, reverse roll, air knife, gravure, slot die)	Can coat with most types; however, gravure, slot die, and Mayer rod may offer fastest line speeds
Static Grounding	Required to prevent explosive potential	Not usually required
Drying/Curing Oven	Low initial temperature, rising through oven Volatile solvents evaporate quickly Requires VOC level monitoring Sufficient airflow required to maintain solvent concentrations below LEL	High initial temperature, sometimes dropping through oven No VOC monitoring required May require more energy to evaporate water Sufficient airflow required to increase heat transfer (*i.e.*, water evaporation)
Misting System	Not required due to low oven temperature	May be required to replace natural moisture content in paper substrates
Emissions Control	Carbon adsorption, thermal or catalytic oxidation	No emissions control required
Cleaning	Flushing with solvents No adhesive particle settling	Required more often More scraping and peeling of settled solids required (if solvents are not used in cleaning)

4.2.2 Chemistry

4.2.2.1 Solvent-based and Waterbased Adhesive Chemistries

Solvent-based adhesives are solutions, in which adhesive resins are completely dissolved by the solvent (*e.g.*, toluene or MEK). Waterbased adhesives are emulsions, in which adhesive particles are suspended in water. Waterbased adhesives typically have larger particle sizes than solvent-based adhesives.[1] Due to the emulsion state and larger particle size, settling of waterbased adhesive particles poses adhesive transfer problems. Settled particles will not readily re-enter the emulsion state as they would in solution adhesives.[1] Settled particles that may become re-entrained during the coating of waterbased adhesives will cause defects in the adhesive-coated product.[2]

Foaming is another critical factor in waterbased adhesive use. Excessive agitation in the storage tanks or excessive pumping rates can trap air bubbles in a waterbased adhesive. These trapped air bubbles can create foaming in the storage or mixing tanks, foaming at the coating head, or can cause unevenness or gaps in the adhesive coating on the web. Foaming is not a problem with solvent-based adhesives, since these formulations are in solution and tend not to trap air bubbles.

Viscosity control is also critical for waterbased adhesives to attain good wetout (*i.e.*, coating smoothness and evenness) and coating thickness control. Viscosity control is difficult because waterbased adhesives are an emulsion, rather than a solution. The desirable waterbased adhesive coating viscosity must be thoroughly examined before pumps, transfer lines, and coating configurations are designed and installed.[3] Facilities may have to employ viscometers at the storage, mixing, or delivery tanks to monitor and maintain coatable viscosities. Since viscosity is related to temperature and humidity, some waterbased adhesives require temperature controls to maintain optimum coating viscosity. Ingredients may also be added periodically to the mixing tank to adjust viscosity.[1,4] Solvent-based adhesive viscosities tend to be lower than waterbased adhesive viscosities and are less susceptible to temperature fluctuations.[1]

Nashua found that for its process, waterbased coating viscosities in the range of 500 to 2,000 centipoise are best. For other manufacturers, the optimal coating viscosity will vary depending on the coating technique used. Sometimes Nashua uses a heat exchanger prior to adhesive delivery to the coating head to ensure optimal coating temperature.[1]

Coating application thickness is another element of waterbased adhesives requiring strict control. In general, waterbased adhesives have a higher solids content than solvent-based adhesives. Proper coating thickness requires adhesive metering control adjustment. To adjust thicknesses on a reverse roll coater, the nip gap distance and reverse roll speed must be adjusted. In direct coating operations, the doctor blade or similar device used for metering would require adjustment.

At Nashua, the waterbased coating thickness is generally similar to comparable solvent-based coatings. This is because Nashua's waterbased coatings have the same solids content range as its old solvent-based coatings (waterbased 30 to 60 percent, solvent-based 30 to 70 percent solids).[1] At FLEXcon, the solids content of waterbased adhesives is higher than solvent-based adhesives, allowing lower coating thicknesses.[4] Nashua's coating thicknesses range from 0.001 to 0.003 inches (0.025 to 0.076 millimeters) for both types of adhesives.[1] FLEXcon's solvent-based adhesive coating thicknesses range from 0.001 to 0.003 inches (0.025 to 0.076 millimeters) while their waterbased adhesive coating thicknesses range from 0.001 to 0.002 inches (0.025 to 0.051 millimeters).[4]

When considering retrofitting, a manufacturer must determine whether to purchase pre-formulated adhesives, or formulate adhesives onsite. Manufacturers who currently formulate their own solvent-based adhesives may see advantages and disadvantages to formulating waterbased adhesives. Advantages include reduced solvent usage, disposal, and emissions; elimination of solvent-containing storage tanks; elimination of explosion-proof storage areas, pumps, and motors; and the potential to reduce raw material costs, as solvents are invariably more expensive than deionized water. Disadvantages may include difficultly in controlling coating viscosity, generation of wastewater during the deionized water manufacturing process, and additional wastewater streams generated from the waterbased coating process.

Nashua noted that the same amount of time (three to four hours) is typically required for formulating its solvent-based adhesives or making additions to their preformulated waterbased adhesives. However, some of its waterbased adhesives require agitation between additive additions, increasing the total mix time to a maximum of eight hours.[1] No other information was available on the time, labor, or material requirements of formulating waterbased versus solvent-based adhesives.

4.2.2.2 Solvent Retention

When an adhesive is dried in an oven, a small amount of solvent must be left in the adhesive in order to allow for adhesive flexibility and proper tack. The term solvent retention describes the amount of solvent that remains in the adhesive after it has left the oven. This amount varies, but is generally less than one percent of the solvent that was initially in the adhesive. Proper solvent retention is critical in ensuring that the adhesive functions appropriately. A discussion of solvent retention is included here to facilitate the reader's understanding of solvent-based adhesive coating and the potential emissions from different solvents and coating practices.

The most important factor in determining solvent retention is the choice of solvent used in the adhesive formulation. Different solvents have markedly different vaporization temperatures and evaporation rates, as well as other properties that affect solvent retention. Oven configuration (*e.g.*, temperature, air flow, and drying time) is the second most important factor in determining solvent retention. Since coating head type has little to do with solvent retention, no correlation was attempted between these two parameters.

An attempt was made to evaluate solvent retention times for adhesives. A solvent's retention time can be defined as the amount of time that it requires to evaporate in comparison to other solvents under similar drying conditions with other variables (*e.g.*, coating makeup and resin hardness) kept constant. Solvent retention time is a critical factor in determining the necessary process line setup to allow for proper solvent retention.

Unfortunately, few data were found during the research for this report on solvent retention times for adhesives. There are information sources on solvent retention times for paints; however, these sources are dated (*i.e.*, 1975 and before), and the dissimilarities between paints and adhesives might lead to variations in retention times. However, some characteristics of solvents and resins affecting retention times can be evaluated. These characteristics include molar volume, solvent volatility, polymer-solvent interactions, size and shape of the solvent molecule, and resin hardness.

Molar volume is the volume that a gram mole (*i.e.*, formula weight in grams) of liquid at standard temperature and pressure (*i.e.*, 0° Celsius and 1 atmosphere). Molar volume depends on a number of factors, including molecule size, polarity, and other molecular attributes and interactions. It is the most significant solvent or resin characteristic effecting solvent retention. Smaller molecules can be expected to occupy smaller molar volumes, and differences in molecular polarity can cause either smaller or larger molar volumes. Generally, as the molar volume decreases, less solvent retention can be expected.

Solvent volatility (*i.e.*, evaporation rate) also depends on molecule size, polarity, and other molecular attributes. As with molar volume, smaller molecules can be expected to have higher volatility. Also, decreasing polarity is coupled to increasing volatility. Generally, as solvent volatility increases, less solvent retention can be expected.

The final three characteristics affecting solvent retention are generally less important than the first two (*i.e.*, molar volume and solvent volatility). Polymer-solvent interactions are generally complex and depend on solvent and polymer characteristics. These interactions may increase or decrease molecular attraction between the solvent and polymer. Larger and more complex shapes of solvent molecules have greater retention. Increasing resin hardness causes increased retention.

Evaluation of the above characteristics should be an excellent indicator of solvent retention times from a solvent/adhesive system. An evaluation of these variables, along with actual coating experiences with the system, should allow oven configurations to be altered to ensure proper drying of the adhesive. The most logical way to evaluate solvent retention is to examine each solvent/adhesive combination individually. However, no studies could be found that have performed such examinations for adhesives. Table 4-2 lists 27 common solvents in increasing order of retention from one such study for paints.[5]

4.2.3 Equipment

As stated in Section 4.2.1, the equipment barriers associated with waterbased adhesives are common to all adhesive coating industry segments because the processing equipment used to manufacture adhesive-coated and laminated substrates is quite similar for solvent-based and

TABLE 4-2. TYPICAL SOLVENTS IN INCREASING ORDER OF RETENTION IN PAINTS

Solvent	Molar Volume (cm^3)	Evaporation Rate (*n*-butyl acetate = 1.0)
Methanol	40	4.1
Acetone	73	10.2
2-Methoxyethanol	79	0.51
Methyl ethyl ketone	90	4.5
Ethyl acetate	97	4.8
2-Ethoxyethanol	97	0.35
n-Heptane	146	3.3
2-Butoxyethanol	130	0.076
n-Butyl acetate	132	1.0
Benzene	88	5.4
2-Methoxyethyl acetate	117	0.35
2-Ethyloxyethyl acetate	135	0.23
Dioxan	85	NA
Toluene	106	2.3
Chlorobenzene	101	NA
2-Nitropropane	90	1.5
m-Xylene	122	0.75
Methyl isobutyl ketone	124	1.4
Isobutyl acetate	133	1.7
2,4-Dimethyl pentane	148	5.6
Cyclohexane	108	5.9
Diacetone alcohol	123	0.095
Pent-oxone	143	0.26
Methyl cyclohexane	126	3.5
Cyclohexanone	103	0.25
Methyl cyclohexanone	122	0.18
Cyclohexyl chloride	118	NA

NA- Not available

waterbased adhesives. The number of coating lines may vary from a small facility to a large facility, but, in most cases, the equipment is only slightly different.

4.2.3.1 Adhesive Storage/Delivery

In most instances, above-ground glass-fiber lined storage tanks are used for waterbased adhesives. These tanks usually contain agitation blades to minimize the amount of solids that settle in the tank and to maintain coatable viscosities.[1,3,6] As stated in Section 4.2.2, waterbased adhesive storage tanks normally require continuous viscosity measurement to ensure proper coating viscosity.[1]

An advantage of waterbased adhesives is that pumps and piping are not required to be explosion-proof like solvent-based pumps and piping.[1] However, pumps and piping used with waterbased adhesives must be water-resistant and easily cleanable. Nashua uses PVC piping to transfer its waterbased adhesives and replaces them when they become fouled.[1] Stainless steel piping may also be used; however, waterbased adhesives may eventually clog this piping, thus prohibiting the sale of replaced piping as scrap metal.[7] High-shearing pumps are typically used with solvent-based adhesives; however, waterbased adhesives require lower shearing pumps, such as the air cylinder type.[1,4]

As discussed in Section 4.2.2, waterbased adhesives have larger particle sizes than solvent-based adhesives. Therefore, a conversion to waterbased adhesives would require new filters with larger mesh sizes to allow filtering of waterbased adhesives.[1]

Due to the difficulties in formulating adhesives, many adhesive coaters buy pre-mixed adhesives, store them in their shipping containers, and then directly transfer the adhesive via pumps to the coating head.[4] Any additional mixing required of the supplied adhesive occurs in the shipping container. This direct delivery eliminates the need for lengthy piping systems and allows waterbased coating viscosity to be monitored directly as the coating is delivered to the coating head. Cleanup time is also reduced by direct delivery. The only required cleaning would take place in the coating trough and coating head. Some manufacturers line their coating troughs with plastic or another thin liner to reduce the cleanup requirement between batch jobs.[4]

4.2.3.2 Coating Head

One of the most important equipment retrofitting requirements for waterbased adhesives is the coating head. In many instances, the coating head used for solvent-based adhesives may be used to adequately apply waterbased adhesives with little or no modification.[8,9] However, in order to achieve optimal coating speed of waterbased adhesives, the coating head may have to be altered or replaced.

For example, prior to conversion Nashua used direct and direct reverse gravure coating heads to apply solvent-based adhesives. After conversion, Nashua used the same reverse-roll gravure coating technology, with some adjustments to maintain the process line speeds at their solvent-based levels [ranging from 300 to 1,200 feet (91 to 366 meters) per minute].[1] The coating of waterbased adhesives can, however, be faster than coating solvent-based adhesives for two reasons: (1) the generally higher solids content and lower coating weights required of waterbased adhesives allows less coating to be applied (less coating applied results in faster line speeds), and (2) the lower speeds at which solvent-based lines may be required to operate at to limit the potential for VOC emissions from the coating process.[1,4]

Many conventional facilities that coat solvent-based adhesives with reverse roll coating heads may be required to convert to other technologies to achieve faster line speeds with waterbased formulations. Two manufacturers noted that they were currently at maximum speeds with waterbased coating using reverse roll, and that increasing their line speeds will require switching to another coating technology such as gravure or slot die.[1,4]

While researching this report, ten general coating head types were identified as currently in use in the adhesive coating industry. These coating head types are described in Table 4-3 along with their respective adhesives, backings, and waterbased adhesive experiences. As indicated in Table 4-3, several coating heads are capable of producing waterbased adhesive-coated product.

As previously discussed, waterbased adhesive coatings are generally used in products aimed at the commodity sector of the adhesive coated product marketplace. Since these products are usually not subject to the rigorous performance requirements of specialty or high-performance products, end product characteristics are not as critical in most waterbased adhesive-coated products. However, as performance levels of waterbased coatings increase with advances in research, several of the coating methods will likely prove to be preferable in waterbased coating

TABLE 4-3. GENERAL INFORMATION ON COATING HEAD TYPES CURRENTLY USED IN THE ADHESIVE COATING INDUSTRY

Coating Head Type	Description	Applicable Adhesives	Applicable Backings[1]	Use Level in Industry	Description of Potential or Actual Use with Waterbased Adhesives
Blade/Knife over Roll, Floating or Trailing Blade/Knife Coaters[2]	Blade/knife removes excess adhesive from backing	Knife: solvent-based Blade: solvent-based and waterbased	Paper, plastic, fabric	Extensive but decreasing use	Knife results in uneven coating; blade produces acceptable product
Dip and Squeeze Coater	Backing is immersed in adhesive and then squeezed between two rollers to remove excess adhesive	Solvent-based	Paper, fabric	Limited use	Might be applicable for products requiring an adhesive-soaked backing
Air Knife Coater	Similar to blade/knife coaters, except high speed air is used to remove excess adhesive, which is captured in a blow-off hood	Solvent-based, low weight waterbased	Paper, plastic, fabric	Limited use	Applies adhesive well, but can cause foaming problems at application line
Offset Application Roll	One roller picks up adhesive and transfers it two a second roller, which applies the adhesive to the backing[3]	Silicone, low weight waterbased and solvent-based	Fabrics and plastics, some high performance paper	Limited but increasing use	Applicable for rough substrates and viscous adhesives
Slot-Die Coaters	Adhesive coated on backing in tank; slot in tank removes excess	Mostly hot melt adhesives, some waterbased and solvent-based use	Plastics, some high performance paper	Limited but increasing use	Applicable; limited use with waterbased adhesives
Direct Application Roll Coater	Adhesive applied by roller travelling in direction of backing	Solvent-based and waterbased	Paper, plastic	Widely used	Applicable; waterbased adhesives used frequently
Reverse Roll Coater	Adhesive applied by roller traveling in reverse direction of backing	Solvent-based and waterbased	Paper, plastic	Widely used	Applicable; waterbased adhesives used frequently

(continued)

TABLE 4-3. GENERAL INFORMATION ON COATING HEAD TYPES CURRENTLY USED IN THE ADHESIVE COATING INDUSTRY (continued)

Coating Head Type	Description	Applicable Adhesives	Applicable Backings[1]	Use Level in Industry	Description of Potential or Actual Use with Waterbased Adhesives
Metering Roll Coater[4]	Metering roll traveling in opposite direction to applicator roll removes excess adhesive	Solvent-based and waterbased	Paper, plastic	Widely used	Applicable; waterbased adhesives used frequently
Metering Rod Coater[5]	Similar to a metering roll, except the metering roll has a wire wound around its length	Low weight solvent-based and waterbased	Paper, plastic, fabric	Widely used	Applicable; waterbased adhesives used frequently
Direct or Reverse Roll Gravure Coater	Adhesive applied by etched or engraved roller; roller may be forward or reverse roll	Solvent-based and waterbased	Paper, plastic	Widely used	Applicable; gravure density must be smaller than for solvent-based application

[1]Many backing materials (especially plastics and fabrics) are not compatible with waterbased adhesives because of the high surface tension of the emulsions.

[2]These are all similar coating methods, in which a flexible blade or rigid knife is used to remove excess adhesive and smooth the surface adhesive after coating in an adhesive trough or by a direct or reverse roll coating roller.

[3]Usually, the first roller is an etched or engraved (*i.e.*, gravure) roller. In this case, this coating method may be known as offset gravure coating.

[4]Metering rolls are often used in combination with a direct or reverse roll coater.

[5]This is also known as a bar coater or Mayer rod coater. Metering rods are often used in combination with a direct or reverse roll coater.

application. Currently, the adhesive application industry is dominated by gravure, metering rod, metering roll, blade, and knife coating.[10,11] The coating methods with proven industrial experience with waterbased adhesives include direct or reverse roll gravure, metering rod, and metering roll coating.

Although most amenable to retrofitting from solvent-based to waterbased application, the gravure density of the application roller must be increased to allow for an even coating of high surface-tension waterbased adhesives. Metering rod and metering roll coating can be retrofitted as well, although the metering device must be kept clean to reduce fouling. Fouling is prevalent in metering rolls, which contain crevices that can trap adhesive solids. Knife coating is generally not used in waterbased adhesive application, as fouling of the knife eventually results in uneven coating and an unacceptable product. Blade coating can also be subject to fouling problems, but blade coating production lines have been successfully adapted to waterbased adhesive application. Since each coating line and product have different characteristics and requirements, retrofitting capabilities must be examined on an individual basis.[11]

Coating thicknesses can be controlled by altering various parameters in the coating head configuration. Since coating heads differ markedly in design, these parameters vary widely as well. For instance, for a gravure coater, gravure density is the most important variable in determining coating thickness. For a blade or knife coater, blade or knife pressure on the substrate is the most important variable.[10,11] Table 4-4 displays important coating thickness variables for different coating heads.

Although the parameters listed in Table 4-4 markedly affect coating thickness, they must be adjusted to achieve the desired qualities of the adhesive. For example, a typical high surface tension waterbased adhesive will have a thicker application than a typically lower surface tension solvent-based adhesive using the same coating head configuration.Adhesive coating thicknesses on the backing are typically described in thousandths of an inch, or "mils".

Adhesives are usually described in terms of their solids content. For example, a solvent-based or waterbased adhesive may be 33 percent solids, with the remaining 67 percent composed of the carrier (*i.e.*, solvent and/or water). In this instance, the thickness of the final coating, which will be primarily composed of adhesive solids with a small percentage of residual carrier, will be approximately 33 percent of the wet application thickness. In this case, a three mil

TABLE 4-4. IMPORTANT COATING THICKNESS PARAMETERS FOR VARIOUS COATING HEAD TYPES

Coating Head Type	Important Coating Thickness Parameters
Blade/Knife over Roll, Floating or Trailing Blade/Knife Coaters	Blade or knife pressure on the substrate
Dip and Squeeze Coater	Squeeze roller pressure on the substrate
Air Knife Coater	Air pressure from the blowers on the substrate
Offset Application Roll	Pressure between pickup and application rollers, application roller pressure on backing
Slot-Die Coaters	Slot/die width
Direct Application Roll Coater	Application roller pressure on backing
Reverse Roll Coater	Pressure between pickup and application rollers, application roller pressure on backing
Metering Roll Coater	Metering roll pressure on substrate
Metering Rod Coater	Wire gauge used on metering rod, metering rod pressure on substrate
Direct or Reverse Roll Gravure Coater	Gravure density, application roller pressure on backing, pressure between pickup and application rollers (reverse roll gravure coating only)

adhesive application at the coating head would translate to a one mil coating thickness at the end of the oven. Table 4-5 displays typical ranges of dry coating thicknesses in some commonly used adhesive coated products.

4.2.3.3 Oven

Another major equipment consideration for waterbased adhesive retrofit is the oven. A retrofit to waterbased adhesives involves oven temperature and airflow reconfiguration. Water has a heat capacity of 972 British thermal units (Btu) per pound (540 calories per gram) and

TABLE 4-5. FINAL DRY ADHESIVE COATING THICKNESSES OF COMMONLY USED PRODUCTS IN THE ADHESIVE COATING INDUSTRY

Product Type	Range of Coating Thickness (mils)
Paper labels	1.0
Paper transfer tape	1.0
Plastic labels and decals	1.0 to 1.5
PVC finger bandage	1.5 to 2.0
Silicone electrical tape	1.5 to 2.0
Diaper tape	1.5 to 2.0
Polyester packaging tape	2.0 to 3.5
Polypropylene strapping base	2.5 to 4.0
Acetate office tape	2.5 to 3.0
Aluminum foil duct tape	2.5 to 3.5
Printable computer tape	3.0
Porous hospital tape	3.0 to 4.0
Trainer's tape	4.0 to 5.0
Velcro strip	5.0 to 7.0
Glass-reinforced polyester tape	5.0 to 7.5
Film labels and decals	6.0
Paper masking tape	6.0 to 7.0
Coated cloth packaging tape	12.0
Corrosion protection tape	12.0 to 15.0

requires heating above 212°F (100°C) to achieve rapid evaporation. Typical solvents, such as toluene or MEK, have heat capacities in the range of 180 to 360 Btu per pound (100 to 200 calories per gram) and may only require oven temperatures as high as 180°F (82°C). At both FLEXcon and Nashua, the temperature settings through the oven for waterbased coatings are generally around 250°F (121°C), although Nashua stated that the last oven zone temperatures are generally cooler than 250°F (121°C). Both facilities also used approximately the same oven temperature configuration for solvent-based adhesives with initial zone temperatures around 200°F (93°C) and final zone temperatures nearing 100°F (38°C). Also, FLEXcon and Nashua employ IR heaters in the oven zones to assist in evaporating the water from waterbased adhesives thus reducing drying time and oven heating requirements.[1,4] The IR heaters were not required for solvent-based adhesives.[1,4]

The higher heat capacity of waterbased adhesives may necessitate an increase in oven capacity. However, the exact amount of oven capacity required is plant-specific and process-specific. For example, Nashua had enough oven capacity to convert from solvent-based to waterbased adhesives without increasing oven length or reducing process speeds. The limiting factor for process coating speed at Nashua is the coating head. Nashua noted that its overall energy requirements and total airflow in its ovens have remained approximately the same after conversion, although temperature and airflow configurations have changed.[1] However, a manufacturer with significantly smaller ovens may be required to either decrease process line speed or increase oven capacity. Oven capacity increases may be hampered by space limitations within a facility.

Airflow is an important variable to consider in oven design and retrofitting, and significantly effects the maximum temperature (*i.e.*, heat transfer rate) at which the oven can operate. The type of airflow nozzles used, the distance of nozzles from the adhesive surface, spacing between the nozzles, and other variables of nozzle design and arrangement are not amenable to frequent change or adjustment. This is because proper airflow arrangement is very important to uniform drying (heat transfer) across the web width, especially as oven temperatures increase.[11] Proper airflow for waterbased adhesives is more easily attained in ovens with high heat transfer capacities. For example, Nashua's ovens had tremendous excess capacity for processing solvent-based adhesives. This allowed the transfer to waterbased adhesives to proceed without great effects on oven airflow configuration.[1]

The maximum oven temperature increase to accommodate the higher heat capacity of waterbased adhesives is also limited by the properties of the backing. Some backings, such as metal foils, are unaffected by high oven temperatures, but other backings, like papers and plastic films, must be carefully monitored to ensure that backing deformation does not occur. For example, the high temperatures required to dry and cure waterbased adhesives tend to remove the natural moisture content from paper backings. This causes the paper to curl, which is detrimental to subsequent lamination and finishing processes. Facilities applying waterbased adhesives to paper backings may employ a re-moisturizing system either at the oven exit or in the last zone(s) of the oven. FLEXcon and Nashua both employ systems designed to re-moisturize the waterbased-coated paper backings to reduce curl and ease laminating, topcoat, and other finishing operations.[1,4]

A benefit of waterbased adhesives is that lower explosive limit (LEL) meters are not required in the ovens to measure VOC concentration levels. These meters can be expensive to maintain.

4.2.3.4 Cleaning

Cleaning requirements are generally increased with waterbased adhesives. Once a waterbased formulation has dried, the solid particles do not readily re-emulsify. These solids form a hard layer which water will not penetrate. Generally, increased scraping and peeling, combined with cleaning solutions consisting of soap and water or low volatility solvents, are required to effectively clean dried adhesive residue.[1]

4.2.3.5 Emissions Control

Other equipment considerations include the emissions control equipment and solvent recycling system. Obviously the elimination of solvent-based adhesives would eliminate the need for emissions control equipment. This equipment would have to be decommissioned, and probably removed and disposed of or sold. However, for an existing facility which converts only some of its end products to waterbased adhesives, the system would have to remain functional. A bypass would have to be installed so that when operating with waterbased adhesives, the captured water vapor is directed to the atmosphere instead of the control equipment. Water vapor can severely foul a carbon adsorption system and is very costly to incinerate.

4.2.4 Personnel Issues

Both solvent-based and waterbased adhesive-coating facilities have a similar number of production employees in proportion to the number of coating lines at the facility. This is because coating line processes and equipment are very similar for high or low performance and batch or dedicated facilities.

Nashua noted that maintenance requirements have remained approximately the same as before their conversion. This is because the new maintenance requirements associated with waterbased adhesives have absorbed maintenance capacity previously associated with solvent-based adhesives (*e.g.*, maintenance on the carbon adsorption system).[1]

Depending on the level of operator and engineer expertise with waterbased adhesives, some additional training time will be required during conversion to waterbased adhesives. Due to the differences in coating techniques for waterbased adhesives, a facility generally undergoes a learning period during the retrofitting process. This learning period involves adjusting equipment, raw materials, and expertise to match the characteristics of waterbased adhesives. As operators become more experienced with waterbased adhesives, problems such as foaming and improper coating will become less frequent.

In addition, personnel safety issues are generally reduced with the use of waterbased adhesives. For example, electrical grounding of coating and finishing equipment and/or humidifier use in manufacturing areas are normally required to run solvent-based adhesives.[1,13] These actions reduce the explosive potential that an inadvertent spark could cause if generated in the vicinity of a solvent. Solvent-free waterbased adhesives exhibit no such explosive potential. Also, elimination of solvent usage reduces Occupational Safety and Health Administration (OSHA) requirements for monitoring VOC concentration levels in and around the work area to protect production workers.

4.2.5 End Product Performance

The primary retrofit barrier associated with waterbased adhesives in any industry segment is their limited end use applications due to end product performance restrictions. Many high performance end product manufacturers stated that waterbased adhesives do not exhibit the high performance levels of solvent-based adhesives. The differences between retrofit requirements for high or low performance facilities, as well as large or small and batch or dedicated facilities, are summarized in Table 4-6.

TABLE 4-6. TECHNICAL BARRIERS ASSOCIATED WITH PROCESS RETROFIT BY INDUSTRY SEGMENT

Industry Segment	Barriers
Large or Small	Larger facilities may have difficulty redesigning their floor space to accommodate longer ovens, wastewater treatment operations, and new waterbased adhesive storage and transfer equipment.
	Small facilities may be in a better position to incorporate new equipment and grow.
High Performance or Low Performance	Waterbased adhesives do not yet exhibit all of the high performance characteristics of solvent-based adhesives.
	Many backing materials are not compatible with waterbased adhesives because of the high surface tension of the emulsion.
Dedicated or Batch	Waterbased adhesives perform better in dedicated facilities or long batch operations due to the longer time required for them to equilibrate on the coating web and the increased cleaning time between jobs.
	Dual coating facilities that convert some of their solvent-based products to waterbased will have to maintain separate adhesive storage, transfer, and waste handling systems; require adjustment of the coating head, oven temperature profile, and oven airflow configuration, and an emissions control equipment bypass.

Waterbased adhesives are not compatible with many backings. For some high performance products, backings include low surface energy materials such as plastic films, metal foils, vinyls, and foams. Water is a relatively high surface tension material and has difficulty achieving proper coating dispersion, or wetout, on these backings. Additional process steps such as chemical or corona pretreatment of the backing may be required to increase the backing's surface energy. However, solvents exhibit low surface tensions and will readily wetout most backings. Paper is a relatively high surface energy material on which waterbased adhesives can generally be coated with no pretreatment. Many transfer coating processes use a silicone-coated paper release liner to transfer the waterbased adhesive to its backing material.

Many low performance applications, such as paper labels and masking tapes for low to moderate end use environments, have been readily converted from solvent-based to waterbased adhesives. This is due to the low end product performance requirements and ease of coating waterbased adhesives on those particular backings.

Many facilities coat both commodity and specialty products for their customers. These facilities may have the potential to convert some of these products to waterbased adhesives. However, conversion of a few products rather than an entire end product line requires additional equipment for the coating line and additional waste separation and disposal activities. The two facilities noted that it is possible that some of their lower performance solvent-based adhesives could be replaced with a combination of waterbased adhesives.[4] However, the conversions are not currently economically feasible for the particular products that could be converted.

FLEXcon officials noted that while there are process difficulties associated with coating waterbased adhesives, the primary limiting factor for waterbased coatings are their lower performance characteristics.[4] The chemistry of waterbased adhesives has not evolved to rival solvent-based adhesives in most applications. The main limitations of current waterbased adhesives for use at FLEXcon are listed below:

- Lower peel strength at room temperature
- Lower sheer strength at high temperatures
- Less flexibility in adhesion to a broad range of backings
- Lower humidity resistance
- Limited products that can be used for direct skin contact

An important aspect of adhesive performance was discussed during all of the site visits conducted for this comparative analysis report. The performance of any given waterbased adhesive cannot exactly overlap the performance of a particular solvent-based adhesive. This is illustrated in Figure 4-1. The figure shows that a given solvent-based adhesive will cover an area of applicability for a certain range of backing surface energies and temperatures. Although a particular waterbased adhesive may overlap this area and cover additional temperature ranges and backing surface energies, no waterbased adhesive can completely fill the area of the conventional solvent-based adhesive. To make a complete conversion to waterbased adhesives, a manufacturing firm would have to change the configuration of its end product line to accommodate the different range of performance among its products. This re-configuration can disturb its customers, who may not be willing to alter their purchasing arrangements. Conversions to waterbased adhesives must nearly always involve customer input during the development of the new product to make sure that the new product can achieve or exceed the end product performance of the old solvent-based product.

4.2.6 Considerations for Dedicated and Batch Operations

The technical retrofit considerations for dedicated versus batch segments of the adhesive coating industry are primarily related to coating equipment and cleaning operations. The differences between retrofit requirements for dedicated or batch facilities, as well as large or small and high or low performance facilities, are summarized in Table 4-6.

One limitation identified with waterbased coatings is that they perform better in dedicated facilities or those that perform long (*i.e.*, greater than eight hours) batch operations. Waterbased adhesives typically require longer production runs than solvent-based adhesives in order to get usable end product. Waterbased adhesives require stricter process controls than solvent-based adhesives, as coater conditions must be optimum before process speeds can be increased. Solvent-based adhesives are well-suited for short production runs (*i.e.*, batches) due to their excellent wetout properties. FLEXcon officials noted that their waterbased product must be run at least approximately 2,500 yards (2,300 meters) in backing length to ensure a profit on the production run. For solvent-based products, production runs of approximately 250 yards (230 meters) may be performed profitably and without coating complications.[4]

One factor causing longer production runs is that waterbased adhesives require additional equipment cleaning time. Extensive cleaning is necessary when alternating between solvent-based and waterbased adhesives. One manufacturer noted than when alternating between solvent-based to solvent-based or waterbased to waterbased coatings, the cleaning time is normally less than one

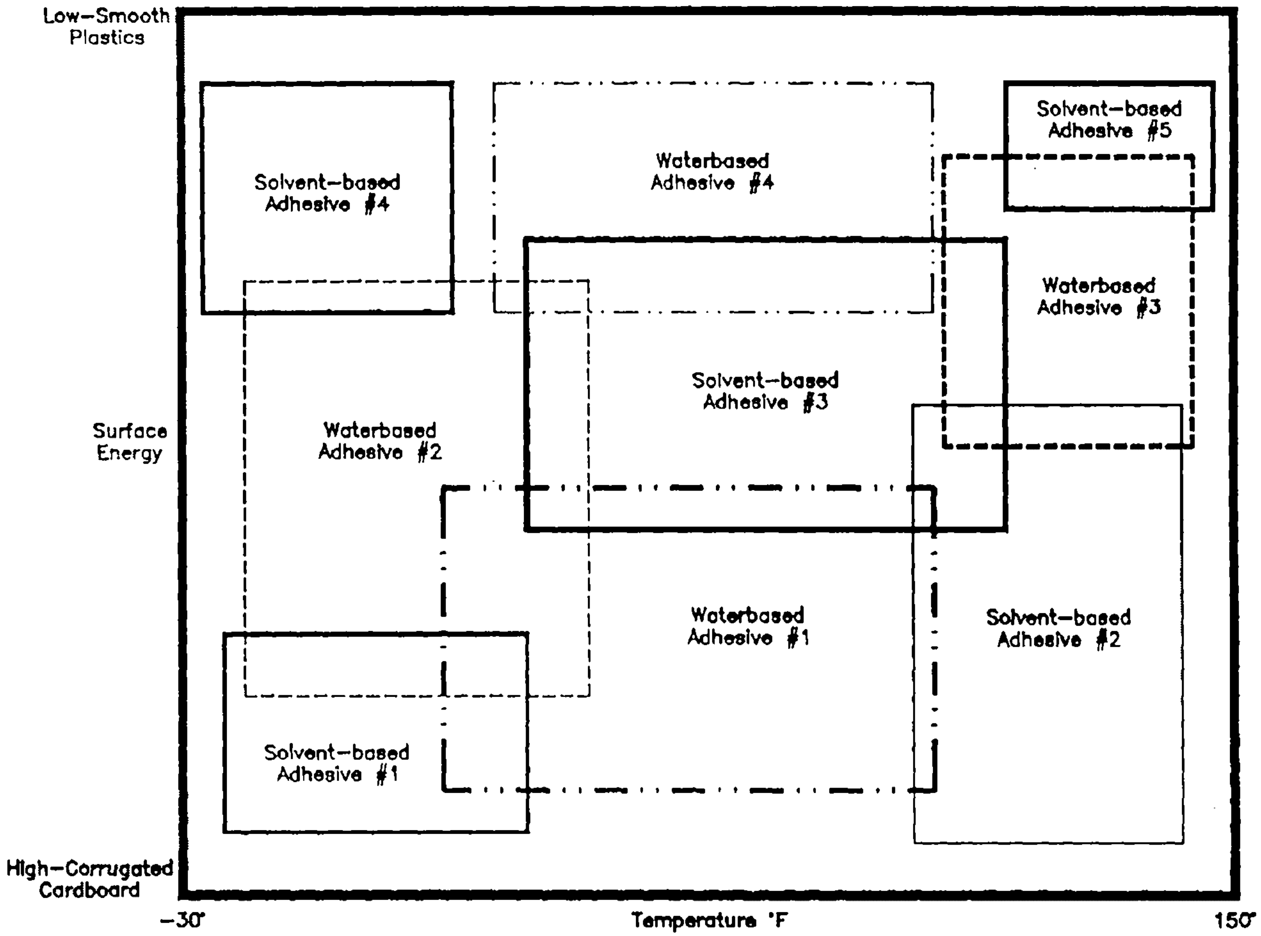

Figure 4-1. Applicability range of solvent-based and waterbased adhesives.

hour. However, when alternating between solvent-based and waterbased coatings, cleaning time is one to two hours.[1]

A second factor causing longer production times is that waterbased adhesives take some time to equilibrate on the backing during a production run. This causes excess coated paper waste before the coating head begins producing marketable product. For solvent-based coated products, a 50-yard (46-meter) production run is possible without coating problems.[4] For waterbased adhesives, minimum production runs are longer, although the increase varies depends on a number of factors, including the compatibility of the adhesive with the backing. However, waterbased adhesive runs are almost always in the hundreds of yards (meters), since cleaning requirements between runs are extensive.

In addition, for batch or dedicated operations which convert a process line to dual coating capability, the technical retrofit requirements are more complicated. Solvent-based coating lines which convert to dual coating capability will require new storage tanks, mixing/holding tanks, adhesive delivery systems, and coating heads compatible with waterbased adhesives, in addition to their existing solvent-based equipment. Separate equipment for solvent-based and waterbased adhesives is a necessity, since the cleaning requirements for both are very different. Normal solvent-based cleaning operations involve solvent flushing between batches, with the residual solvent and adhesive mixture collected for disposal or reuse in the next adhesive batch. Waterbased operations require flushing with water, and sometimes detergent, which can be very detrimental if mixed with a subsequent batch of either waterbased or solvent-based adhesive. In the operating environment of a coating line, in which cleaning operations and waste disposal are both costly procedures, it is not practical to consider using one delivery system for both waterbased and solvent-based adhesives.

4.3 ENVIRONMENTAL BARRIERS TO PROCESS CONVERSION

4.3.1 Introduction

The environmental impacts associated with converting to waterbased adhesives may be summarized as reducing solvent air emissions and hazardous waste streams while increasing

TABLE 4-8. ENVIRONMENTAL MEDIA IMPACTS FOR SOLVENT-BASED AND WATERBASED ADHESIVES IN ALL INDUSTRY SEGMENTS

Environmental Media	Solvent-based Adhesives	Waterbased Adhesives
Air	Stack and fugitive emissions from: Emissions control exhaust Equipment leaks Adhesive storage and transfer Cleaning operations Coating application	Solvent-free waterbased adhesives generate no stack or fugitive air emissions.
Wastewater	Most liquid waste from solvent-based operations contains some amount of solvent and must be disposed of as hazardous waste.	Wastewater generated from: Cleaning operations Waste adhesive Deionized water
Hazardous Waste	Hazardous waste generated from: Spent adhesive Spent cleaning solvents Recovered solvents (via emissions control equipment)	Hazardous waste may continue to be generated if solvents are used in waterbased cleaning operations.
Non-hazardous Waste	Non-hazardous waste generated from: Line start-up Finishing operations	Non-hazardous waste generated from: Line start-up Cleaning operations Finishing operations Wastewater sludge

The two primary environmental benefits of converting to waterbased adhesives are reduction or elimination of VOC and HAP air emissions and reduction in hazardous waste generation.[1,4] VOC and HAP emissions are virtually eliminated with waterbased adhesives because solvents are not used or are used in much smaller quantities than in solvent-based adhesives. Fugitive solvent air emissions from storage and transfer, equipment leaks, and cleaning operations are also eliminated. Hazardous waste generation will also decline dramatically because spent adhesive and cleaning wastes containing solvents are eliminated. Some hazardous waste may continue to be generated if solvents are used in waterbased cleaning operations.

The status of emissions control equipment is an important issue for a facility when considering a waterbased adhesive retrofit. If they do not already have a sufficient control device in place, facilities may choose to invest in state-of-the-art VOC emissions control equipment rather than convert to waterbased adhesives. Using emissions control devices, however, may present additional environmental concerns such as disposal or treatment of contaminated steam from carbon adsorption stripping. Some of these control devices can capture, destroy, or recover 98 percent of solvent emissions if used with enclosed coating heads that are ventilated to the emissions control device.[4] If facilities spend their capital on emissions control equipment for solvent based adhesives, they may limit the resources available to use waterbased adhesives.

The primary environmental disadvantages of converting to waterbased adhesives for all industry segments is the associated increase in both wastewater and solid waste generation. This increased generation results from two factors: waste adhesive which was formerly hazardous may now be considered non-hazardous and disposed of as such, and the water used on waterbased adhesive equipment most likely must be disposed of as wastewater. A third waste stream would be generated from the deionization of water if a facility manufactured its own waterbased adhesives. This waste could either be disposed of as a solid waste or in wastewater depending on facility operations and preferences.

Depending on both the amount of wastewater generated and state and local regulations concerning wastewater, a facility may find it necessary to treat its wastewater onsite. To perform wastewater treatment, the plant must operate and maintain a wastewater treatment plant. Non-hazardous solids (*e.g.*, sludge) collected by the wastewater plant may then be disposed of in a landfill, resulting in generation of solid waste. If these solids are found to be hazardous through testing, disposal costs increase exponentially. Treated wastewater can either be transported to the local POTW or recycled for use in cleaning operations. FLEXcon treats wastewater on-site and uses recovered water for equipment cleaning.[4] Facilities which formulate waterbased adhesives may be able to reuse this treated water in their formulations; however, no facilities were identified in this study which accomplish this type of recycling.

Wastewater from waterbased adhesives is generally an ideal medium for the growth of microbes because bacteria thrive on the adhesive solids found in the wastewater. Microbe growth can be controlled by the use of biocides. However, this will preclude the recycling of the water into an adhesive formulation, as biocides adversely affect adhesive properties. Some POTWs may find microbe-containing wastewater desirable, as the bacteria help to digest other wastes during wastewater treatment.

Several facilities noted that formulating and processing waterbased adhesives require more labor than solvent-based adhesives. Waterbased adhesives generally require more water flushing, scraping, and peeling during equipment cleaning operations. One manufacturer noted that while solvent-based storage systems require essentially no cleaning maintenance, a waterbased storage tank of approximately 8,000 to 10,000 gallon (2,114 to 2,642 liter) capacity required cleaning with a jet spray of water approximately two times per year. This cleaning requires 16 man-hours or more and generates approximately 3,000 gallons (11,355 liters) of wastewater.[1]

Excess coated paper generated during setup of waterbased adhesive-coated product runs and wastewater sludge add to the solid wastes requiring disposal associated with waterbased adhesives.[4]

Large solvent-based operations located in ozone nonattainment areas may enjoy many environmental benefits if converting their operations to waterbased adhesives is technologically and economically feasible. Ozone nonattainment areas generally have stiff restrictions on VOC levels emitted by a facility. Larger facilities with greater emissions are more likely to be required to install and operate emission control systems to reduce their solvent air emissions. Hazardous waste generation at larger facilities, and resulting disposal costs, may be considerably greater than for smaller facilities. Waterbased adhesives use does not require either of these expensive controls.

A disadvantage of waterbased adhesives for large facilities is the large volume of wastewater generated, which may require on-site treatment before disposal. POTWs located near large municipalities may not accept large amounts of untreated wastewater from an adhesive coater. However, Nashua's local POTW is generally receptive to its waterbased adhesive wastewater because its high biological oxygen demand (BOD) content aids in treating the local wastewater.[1] However, most facilities have BOD limits on their discharges. Those facilities which have difficulty disposing of their wastewater may require the addition of an on-site wastewater treatment facility. FLEXcon uses an on-site wastewater treatment facility to recycle its water for cleaning operations.[4]

Facilities operating dual coating lines generally separate their solvent and wastewater releases to all media at the coating line to reduce the volume of hazardous wastes requiring off-site disposal. In many instances, off-site energy recovery facilities will not accept or will charge high rates to dispose of mixed wastes due to the lower energy content, so separating waste streams for dual coaters is critical.

As stated in Section 4.2.2, many facilities which perform dual coating operations simplify their waste handling procedures by delivering adhesives directly to the coating line where they are pumped to the adhesive trough. This eliminates much of the flushing wastes from pipes and pumping equipment used to transfer adhesive from the storage tanks to the coating line.

Facilities operating dual coating lines may install ductwork to bypass emissions control equipment when coating waterbased adhesives. Commonly used controls for solvent-based adhesives, such as thermal oxidation and carbon adsorption beds, are not designed for waterbased adhesive use. Thermal oxidation of emission streams with high moisture content is extremely cost prohibitive and unnecessary. Also, carbon adsorption beds experience reduced solvent control potential when fouled with water. Therefore, when dual coating capabilities are essential, a facility will need to install ductwork to bypass emissions control equipment and vent oven exhaust (from waterbased adhesives) directly to the atmosphere.

Batch operations generate considerably more wastes with short-run waterbased adhesive batches than dedicated operations. This increased waste is generated during the start of a run (primarily composed of make-ready substrate) and from increased cleaning wastes.

4.4 ECONOMIC BARRIERS TO PROCESS CONVERSION

4.4.1 Introduction

The economic impacts associated with a process retrofit to waterbased adhesives are highly plant-specific. The possibility of retrofitting depends on many variables including technical feasibility of retrofit, end product performance, state and local environmental costs, and profitability/competitiveness of the company. These issues and how they relate to a manufacturer's decision to retrofit its process to waterbased adhesives are discussed in this section. The complexity of these issues reflect the highly competitive nature of the adhesive-coated and laminated substrate industry and its concerns about divulging proprietary information.

4.4.2 Segment-Specific Economic Impact

In most instances, the economic impacts of process retrofit to waterbased adhesives are plant-specific rather than segment-specific. However, some economic impact generalizations can be drawn for the different industry segments defined in this report. One factor of equal importance to all industry segments is the geographic location of the facility. Facility location will determine how state and local regulations or federal nonattainment status affect a firm's decision to retrofit. State and local regulations can influence the decision of a plant which may technologically be able to convert some or all of their end products to waterbased adhesives. Facilities must weigh the economic impact of capital investment for new equipment versus the costs of current and/or potential future environmental regulations. Geographic cost impacts include local rates for water and sewer, hazardous waste disposal, solid waste disposal, air permitting, and insurance. For example, those facilities designated large quantity generators (LQGs) of hazardous waste may realize more economic benefits from conversion to waterbased adhesives than small quantity generators (SQGs).

Generally, large companies have more capital and personnel available to dedicate to the study of waterbased adhesives. For smaller, profitable firms, capital may not hinder a retrofit to waterbased adhesives; however, the smaller number of personnel may hinder research and development efforts on waterbased adhesive replacement.

Waterbased adhesives are not well-suited for short (*i.e.*, eight hours or less) batch operations. They work more effectively and are more profitable in dedicated operations or long batches (*i.e.*, more than eight hours). One batch manufacturer noted that waterbased adhesives have to run approximately 2,500 yards (2,300 meters) of product to be profitable while solvent-based need only run 250 yards (230 meters).[4]

TABLE 4-9. ECONOMIC IMPACTS ASSOCIATED WITH PROCESS RETROFIT TO WATERBASED ADHESIVES[a]

Item	Existing Solvent-based Adhesive System	Retrofitted Waterbased Adhesive System
Capital Costs		
Storage/Mix/Hold Tanks	N/A[b]	$7,000 - 60,000 each[c]
Piping	N/A	$0.50/linear foot for PVC
Pumps	N/A	$500 - $1,200 each (air pump)
Adhesive Filter	N/A	$2,000 each
Heat Exchanger	Not Required	$7,500 each[c]
Coating Head	N/A	$0 - $600,000 each
IR Heater	Not Required	$20,000 each[c]
Control Panel for IR Heaters (maximum of 4)	Not Required	$60,000
Oven	N/A	$0 - $1,000,000[d]
Pretreatment	Usually Not Required	Costs not available
Annual Costs		
Environmental		
Air	$25/ton (Title V permitting)	None
Water	Minimal	Site specific, but generally higher than solvent-based
Hazardous	$100 - $600/55-gallon drum	None (except solvent cleaning)
Solid	$40/ton tipping fee	Increased volume generated
Energy		
Oven	Solvents evaporated readily	Higher heat capacity for water
Emissions Control	$60,000 (carbon adsorber)	None
Adhesive Cost	Varies with price of solvents	Generally lower than solvent-based
Emissions Control		Not required
Thermal oxidizer	Natural gas	
Catalytic oxidizer	Catalyst replacement	
Carbon adsorber	Carbon bed replacement	

[a] Costs are in 1993 dollars and were compiled from several industry sources; average costs will vary depending on facility size, product lines, performance requirements, etc.
[b] N/A - Not Applicable. Capital equipment costs are not incurred for existing solvent-based system.
[c] Price includes installation.
[d] Cost range reflects the level of oven modification required to retrofit to waterbased adhesives, from no modification ($0) to new purchased ovens ($1,000,000).

4.4.3 Costs Incurred Due to Process Retrofit

The costs incurred as a result of process retrofit consist of both easily quantifiable and difficult to quantify items. Difficult-to-quantify items are extremely site-specific and are discussed qualitatively later in this section. The easily quantifiable economic impacts are summarized in Table 4-9 and include the capital and annual operating costs associated with retrofitting an existing solvent-based adhesive coating line to waterbased adhesives. Therefore, there are no capital equipment costs incurred for the solvent-based adhesive coating system. These average costs were derived from numerous industry sources including coating facilities, equipment manufacturers, and raw material suppliers. Appendix B contains a detailed example cost comparison for a masking tape coating line which converts operations from solvent-based to waterbased adhesives.

The equipment items specified in Table 4-9 do not necessarily require retrofit in each facility attempting a conversion to waterbased adhesives. Each item listed depends on site-specific factors to determine whether or not retrofit is required. For example, facilities which formulate their own solvent-based adhesives and deliver them to the coating head via an extensive configuration of piping and pumps may require new or additional piping and pumps for waterbased adhesives. However, those facilities that purchase pre-mixed adhesives and locate them directly beside the coating head to be delivered via a small pump and minimal piping will not incur these costs.

Two of the most important cost issues associated with waterbased adhesives are related to the drying ovens. One is the potential for increased energy requirements and the other involves speeds). As stated in Section 4.2.1, water has a much higher heat capacity than most solvents andtherefore requires more energy to evaporate in the oven. However, since waterbased adhesives eliminate the potential for LEL exceedance and airflow volumes may be decreased, energy consumption may be reduced.[10] Energy consumption for drying both solvent-based and waterbased adhesive coatings appears to be site-specific criteria.

Some manufacturers have excess capacity ovens for which the conversion to waterbased adhesives may require only an oven temperature and airflow configuration adjustment. Nashua is one example of a coater with excess oven capacity. Nashua was able to dry its waterbased adhesives at approximately the same coating line speeds using the same ovens used for solvent-based adhesives with the addition of IR heaters.[1] Installation of IR heaters adds another waterbased conversion cost. Other manufacturers, however, may use smaller ovens on their solvent-based adhesives and would require either increased oven capacity or slower line speeds to coat waterbased adhesives. Slower line speeds are almost never an option for adhesive coating manufacturers, as less product would be produced and profitability would be jeopardized. When considering the conversion to waterbased adhesives, a balance must be weighed among energy requirements, oven size, additional equipment (*e.g.*, IR heaters), and production line speeds.

Another factor to consider when oven temperatures and airflows must be adjusted is the backings which will be coated with waterbased adhesives. Because of the higher temperatures used in drying ovens with waterbased adhesives, some backings may not be suitable for use with waterbased adhesives. For instance, some plastic film backings may become soft or disfigured when heated excessively. The most practical backing to coat with waterbased adhesive is paper due to its high surface energy. However, the relatively high oven temperatures may cause the natural moisture content in the paper to evaporate during drying. This causes paper curl which is detrimental to lamination, rewind, and finishing operations. Some paper coating facilities add a misting system at the oven exit to re-moisturize the paper before it is laminated and/or rewound. This results in an additional cost and maintenance item for the coating of waterbased adhesives.

Another backing-dependent cost incurred due to retrofit relates to the surface energy of the backing used in the end product. Many non-paper substrates require chemical or corona pretreatment to promote the adherence of waterbased adhesives. This requires an additional expense to a process line which may add little or no value to the end product.

Some of the equipment costs incurred from retrofitting result from the installation costs of process equipment. Table 4-9 includes easily quantifiable installation costs. In some instances, these costs can be reduced by performing installation with in-house personnel. Equipment such as pumps, valves, and piping may be changed by plant personnel to avoid excessive costs.

Costs incurred during retrofitting which are either too site-specific to quantify or not readily quantifiable include those costs of reduced production levels (*e.g.*, increased cleaning downtime and increased start-up wastes with waterbased adhesives), new or increased wastewater and solid waste generation, increased energy requirements in the oven (if applicable), and research and development costs (*e.g.*, operator and engineer training, internal research and development for new adhesive development, customer support during development of new waterbased adhesives, etc.). Research and development efforts involving both product and equipment may cause production delays and result in engineering expenses as well as lost production.[2]

Increased cleaning requirements for both the adhesive coating line and auxiliary equipment result in reduced operating time of the coating line. Many facilities noted that the hard polymeric coating that forms when waterbased acrylics have dried is difficult to clean and requires more operator labor time and cleaning supplies. In some instances, these increases may be offset by reduced maintenance requirements on solvent-based equipment such as emissions control equipment and storage areas.

Waterbased adhesives generally require more raw materials (backing and adhesive) for start-up on a coating line. This increases raw material and production time necessary to obtain a marketable end product.[4]

Increases in wastewater generation (from waste adhesive, cleaning operations, and potentially deionized water production) and the potential increase in solid waste (from treated wastewater and excess start-up adhesive-coated backing) may increase waste disposal costs for the facility. These potential costs are extremely site-specific and depend on the increased volume of waste generated as well as local POTW and landfill practices and costs. Nashua noted that its wastewater disposal costs are approximately $350 per week (volume and shipping cost) higher than before conversion.[1] In some instances, the increased wastewater generation may require the addition of an on-site wastewater treatment facility either to filter the wastewater (landfilling recovered solids) or recover some of the increased water and sewer costs.

Another unquantifiable cost involves the facility learning curve when converting to waterbased adhesives. In most instances, facilities must conduct either internal research and development or work closely with adhesive suppliers to develop a waterbased adhesive best suited for replacing their solvent-based adhesives. In addition, many facilities work closely with their customers to assure them that the new adhesive technology will, at a minimum, equal the performance of the conventional solvent-based product. Also, coating line operators will be required to adapt to the new coating application. Nashua operators indicated that they spent more time adjusting the nip gap (for coating thickness) and reverse roll speed during the coating of waterbased adhesives than while coating solvent-based adhesives. Nashua management indicates that this is an expected implication of the learning curve with waterbased adhesives.[1] One manufacturer noted that foaming was a problem upon initial conversion; however, with experience, operators were able to develop effective responses.[12]

4.4.4 Costs Saved Due to Process Retrofit

The costs saved as a result of process retrofit also consist of many quantifiable and unquantifiable items. The quantifiable economic impacts are summarized in Table 4-9 and include primarily solvent disposal costs, air permitting costs, and emissions control equipment costs associated with the process retrofit. Unquantifiable items are extremely site-specific and are discussed qualitatively in this section.

Solvent disposal costs saved due to retrofit include solvent collected from emissions control systems (*e.g.*, carbon adsorber) for energy recovery purposes, solvent cleaning wastes, and waste solvent adhesive. For example, Nashua estimates that its annual shipment of solvent waste to a local energy recovery facility has dropped from 30 55-gallon (208-liter) drums to one 55-gallon (208-liter) drum per month during its conversion. Shipping costs average $25 to $50 and disposal costs range from $100 to $600 per 55-gallon (208-liter) drum. Assuming an average cost of $180 per drum for shipping and disposal, the savings amount to $60,000 per year.[1] However, Nashua has experienced an increase in wastewater disposal costs of approximately $18,000 per year. Nashua hoped to eliminate hazardous waste shipments after the conversion, but complete elimination of hazardous waste production could not be confirmed prior to publishing this report.

Another cost savings from complete conversion is realized when emissions control systems (*e.g.*, carbon adsorber, thermal or catalytic oxidizer) used to collect or destroy solvent emissions are eliminated. Facilities with dual coating lines may experience a drop in costs relative to the amount of solvent-based adhesives converted to waterbased. Energy cost savings depend on the amount of solvent-based adhesives converted to waterbased and the type of emissions control system used at a facility. The cost savings depend on reductions in steam production for carbon adsorption stripping, fuel costs for thermal oxidation, and catalyst costs for catalytic oxidation. Maintenance costs are important because emissions control system problems can lead to lost production time and profits if the coating line must be shut down until the problem is fixed.

FLEXcon noted that the cost of the natural gas used in its thermal oxidizers is the primary operating cost for its emissions control system. FLEXcon is required to monitor and report the performance of its oxidizers to the state. While the cost of this monitoring is not readily quantifiable, FLEXcon considers it to be a significant operating cost of producing solvent-based adhesive-coated product.[4]

Nashua noted that before conversion, it experienced a maintenance problem approximately once a week with its carbon adsorption system resulting in significant coating line downtime. The charcoal bed used in Nashua's carbon adsorption system requires replacement about every five years at a cost of $75,000. The spent charcoal must also be disposed of, adding another cost.[1]

Depending on the state and local regulations pertinent to a facility, Title V CAAA permitting costs may be approximately $25 per ton ($22.70 per megagram) of regulated pollutant. Also, future regulations [*e.g.*, maximum achievable control technology (MACT) and lowest achievable emission rate (LAER)] may require additional emissions control systems. The effect of these emissions fees and emission control device costs may offset certain cost disadvantages associated with a transition to waterbased adhesives. In addition, the costs of converting to waterbased adhesives may be offset in future expansion efforts because the permitting requirements for increasing facility emissions would require reducing emissions elsewhere in the plant.[2]

Another potential cost savings of a conversion is a reduction in waterbased adhesive cost. Prices for the solvents used in solvent-based adhesives vary with the cost of oil.[4] The cost of producing deionized water will invariably be less than purchasing equivalent volumes of solvent, although water-deionization equipment prices were not determined for this report.

Complete conversion to waterbased adhesives would eliminate the requirement that the storage area, tanks, piping, and pumps for adhesives be explosion-proof. For dual coating facilities, this equipment would still be required to use solvent-based systems. Another savings would result from the elimination of systems used to discharge static electricity in solvent-based operations, such as tinsel and humidifiers.

4.4.5 End Product Cost and Profitability/Competitiveness Impacts Associated with Process Retrofit

All of the cost impacts discussed in Sections 4.4.1 through 4.4.3 will have some impact on the operating cost and thus the end product cost for a facility. Manufacturers must determine the economic feasibility of process retrofit based on current technology and consider current and future environmental regulations when deciding whether to proceed with process retrofit.

The capital investment required to convert almost certainly will increase the operating costs of a facility. A manufacturer's first instinct might be to offset these operating costs by increasing product costs, however, this action might result in lost market share. Therefore, manufacturers are likely to maintain current price levels if feasible.

Some manufacturers who find it advantageous to convert their entire process to waterbased adhesives may be forced to drop a number of product lines in order to be completely solvent-free. If these dropped product lines were minor volume products, increased sales of waterbased products could make up for their loss. However, many manufacturers may decide not to convert large sales-volume products if profits would be jeopardized by a conversion to waterbased adhesives.

Some facilities may re-direct their investment capital to pay for the costs of retrofit. These increased capital expenditures are normally viewed as capital improvements (investment) for new technologies which in the long term will reduce operating costs and open up new markets for end products produced with the new technology. Nashua is an example of one facility which has successfully spread retrofit costs over many years.

If a facility decides that it is technically infeasible to convert to waterbased adhesives, they may choose to spend investment capital on improved emissions control technologies to comply with current and future potential regulations. In fact, some companies are installing new control equipment that will allow them to enter markets lost to waterbased converters while remaining in compliance with the regulations.[13]

In general, waterbased adhesives cost less to apply than solvent-based adhesives. Solvents typically cost $1 to $4 per gallon ($0.26 to $1.06 per liter), while deionized water costs approximately $0.05 per gallon ($0.01 per liter).[7] With the inclusion of surfactants, defoamers, fillers, and a higher solids content, waterbased adhesives may cost more per volume than comparable solvent-based adhesives. However, because of the higher solids content, the coating coverage per unit volume of adhesive is higher for waterbased adhesives.[2] This reduces the waterbased adhesive's applied cost as compared to solvent-based adhesives. Nashua personnel indicated that the cost of pre-mixed waterbased adhesives is approximately the same per unit volume as the cost was for formulating their own solvent-based adhesives, but coverage per volume is higher. However, Nashua noted that by far the largest contributing cost in the end products is the raw paper cost.[1]

One of the main cost impacts of conversion is the effect on competitiveness. As stated earlier, waterbased adhesives cannot replace solvent-based adhesives one to one due to their differing performance levels. To convert to waterbased adhesives, some changes in end product lines to meet both customer needs and waterbased capability are necessary.[4] Only by changing the end product lines can a facility successfully convert to waterbased adhesives and remain competitive in the industry. As shown in Figure 4-1 and discussed in Section 4.2.3, this results in an end market product reconfiguration for a facility.

The long term cost impacts of process conversion appear to be an overall reduction in operating costs. Costs for emissions control equipment maintenance and operation are reduced by the level of solvent-based adhesive conversion to waterbased. Learning curve cost impacts diminish with time as engineers and operators become more familiar with the waterbased process and can operate more efficiently. Hazardous waste disposal costs and air permitting costs are eliminated for the long term. Also, the potential for new markets increases as waterbased adhesive product lines are developed.

In some instances, competing manufacturers of an end product may have already converted their product from solvent-based to waterbased adhesive. In this situation, the adhesive technology is obviously available to facilitate conversion. Some facility contacts have identified that the lower costs associated with producing waterbased product have resulted in both lower prices and lower profit margins for their end products. Companies manufacturing products in market areas where waterbased adhesives can be used may be forced to convert from a solvent-based to a waterbased process in order to remain competitive.

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APPENDIX A

QUESTIONS FOR FACILITY VISITS

QUESTIONS FOR FACILITY VISITS

GENERAL

1. When was this facility built?

2. What products are produced here (by name and SIC)?

3. Which of your products are produced using waterbased coatings?

4. How large is this facility?
   - number of employees
   - square footage
   - annual sales
   - annual production
   - capital investment
   - market share
   - number of production lines

5. How long has this facility been using waterborne coatings?

6. What prompted your conversion from solvent-based adhesive products to waterbased products?

7. When you identified the potential to make a conversion from solvent-based products to waterbased products, what were the major issues that you had to resolve in order to assess the feasibility of making the conversion?

COST

1. How did you project the cost of completing the conversion when examining the economic feasibility of the project?

2. How did you track the cost of effecting the conversion of your process?

3. What cost records do you have available for the materials used both before and after the conversion?

4. What cost records do you have available for the engineering costs of planning and executing the conversion?

5. What capital costs were incurred as a result of the conversion?

6. What other operating costs, besides inventory, changed as a result of the conversion?

PRODUCT PERFORMANCE AND QUALITY

1. What product characteristics are you required to control to meet customer specifications?

2. Of the product characteristics specified by your customers, which are most difficult to achieve using solvent-based coatings?

3. Which specified product characteristics are most difficult to achieve using waterbased coatings?

4. What difficulty, if any, did you experience in identifying satisfactory waterbased coating formulations to use as replacements for your solvent-based formulations?

5. How do you test a new coating to determine its conformance to specification (*i.e.*, what characteristics are commonly tested and what test methods are used)?

6. What assurances did your customers require before accepting any changed formulations?

7. What are the major causes of rejected product in your waterbased coating process?

8. What rejection rates did you experience when manufacturing solvent-based products?

9. What rejection rates did you experience when you first made the conversion to waterbased coatings?

10. What is your current rejection rate of waterbased product?

PROCESS

1. Do you coat waterbased and solvent-based coatings on the same equipment?

2. What type of coating apparatus do you use to coat waterbased products?

3. What type of coating apparatus do you use to coat solvent-based products?

4. Does the coating apparatus you use require special adjustment or modification to run waterbased coatings?

5. What type of oven configuration (*i.e.*, equipment, zone structure, and operating temperatures) do you employ when coating waterbased products?

6. How does this configuration differ from the one used when coating solvent-based products?

7. How does the process speed differ between waterbased and solvent-based coatings?

8. What is the difference in set-up of a solvent-based job and a waterbased job (*e.g.*, additional time, material, or requirements for machine adjustments)?

9. Is there a significant difference in the process robustness between waterbased and solvent-based products?

ENVIRONMENTAL IMPACTS

1. Have you measured or estimated the environmental impact (impact on air emissions, wastewater, solid waste, and hazardous waste generated) of the conversion from solvent-based to waterbased coatings?

2. Did the conversion introduce any new waste products, or eliminate any waste products, from your manufacturing process?

3. Did the conversion change your equipment and facility cleaning practices?

4. Has your use of water increased, and if so, is the increase greater than your expectations?

5. What control or disposal costs have you incurred or avoided as a result of the conversion?

LABOR

1. Did the conversion to waterbased products cause any changes in the composition of your labor force?

2. Did your workers require any specialized training to use waterbased products?

3. Were health and safety issues considered in evaluating the opportunity to convert to waterbased products?

4. Has the use of waterbased coatings caused any change in your measurements of labor efficiency?

APPENDIX B

COST COMPARISON FOR WATERBASED VERSUS SOLVENT-BASED ADHESIVE COATING SYSTEMS

B.1 INTRODUCTION

This appendix compares the capital and annual costs associated with using waterbased and solvent-based adhesive coating systems based on approximate costs provided by facility contacts and other industry sources. Section B.2 describes the costs associated with the purchase of a new waterbased and a new solvent-based adhesive coating system. Section B.3 provides the capital cost estimates for retrofitting an existing solvent-based coating line to operate with waterbased adhesives. Section B.4 compares the annual costs of operating solvent-based and waterbased adhesive coating lines.

In making these cost comparisons, certain industry segment and operational parameters were assumed. For each of the comparisons, the costs were derived for one adhesive coating line dedicated to producing a low performance masking tape. In addition, the following operational parameters were assumed to be the same for waterbased and solvent-based coating:

- Coating line designed to manufacture 239,000 yd^2 (200,000 m^2) of product per day
- Line speed of approximately 600 feet (180 meters) per minute
- Coating line operates 350 days per year
- An adhesive density of 69 lb/ft^3 (1,100 kg/m^3) of backing material
- Dry coating thickness of 0.001 inches (0.025 millimeters) on the backing

The capital and annual costs derived in this appendix for the example masking tape coating line should not be used to estimate the costs for other end product conversions.

B.2 CAPITAL COST COMPARISON OF NEW ADHESIVE COATING SYSTEMS

Table B-1 lists the capital costs associated with the purchase of a new waterbased and new solvent-based masking tape coating line. These costs were derived from an equipment suppliers' estimates and industry contacts. The results show that for a new system, the capital costs of both

TABLE B-1. CAPITAL COSTS FOR NEW WATERBASED AND SOLVENT-BASED COATING LINES[a]

	Waterbased System	Solvent-based System
Release Coater	$235,000	$235,000
Release Cure/Dryer System	$600,000	$700,000
Adhesive Coater	$400,000	$400,000
Adhesive Cure/Dryer System	$1,000,000	$1,100,000[b]
TOTAL	$2,235,000	$2,435,000
Installation (22% of purchase cost)	$492,00	$536,000
TOTAL CAPITAL COSTS	**$2,727,000**	**$2,971,000**

[a] Costs are in 1993 dollars.
[b] Dryer system for solvent-based adhesive coater is 120 feet long, with five temperature zones and a heat exchanger.

solvent-based and waterbased coating lines are approximately the same. However, the costs in Table B-1 do not include the purchase of an emissions control system for the solvent-based coating line, which would be required for coating solvent-based adhesives. The additional costs of an emissions control system would make the solvent-based system a much more expensive option.

B.3 RETROFIT CAPITAL COST OF WATERBASED SYSTEM

Table B-2 lists the capital costs associated with retrofitting an existing solvent-based masking tape line to a waterbased system. Since the solvent-based system exists, the table indicates where new equipment for waterbased adhesive coating are not required in operating the solvent-based system. One major assumption for this example is that the coating head would require alteration or changeout to maintain a waterbased coating line speed similar to the solvent-based system. Table B-2 indicates that it costs approximately $660,000 to retrofit an existing solvent-based masking tape line to operate with waterbased adhesives. These costs do not include research and development efforts or production losses during the retrofit.

TABLE B-2. CAPITAL COSTS TO RETROFIT A SOLVENT-BASED COATING LINE TO WATERBASED[a]

	Waterbased System	Solvent-based System
Adhesive Transfer		
Storage Tanks (2)[b]	$90,000	Existing
Mix Tanks (3)[b]	$90,000	Existing
Piping (500 feet)	$250	Existing
Air Pumps (3)	$3,600	Existing
Heat Exchangers (2)[b]	$15,000	Not Required
Coating Application		
Coating Head	$400,000	Existing
Drying/Curing Oven		
IR Heaters (2)	$60,000	Not Required
TOTAL RETROFIT COSTS	**$658,850**	

[a] Costs are in 1993 dollars.
[b] Price includes installation.

B.4 ANNUAL COST COMPARISON OF WATERBASED AND SOLVENT-BASED ADHESIVE COATING SYSTEMS

Table B-3 lists the annual operating costs for a solvent-based and waterbased system coating masking tape. In order to assess the operating costs, assumptions were made to simplify the calculations and are discussed in this section. As stated previously, this cost comparison is only for a dedicated masking tape line and should not be used to compare these costs with other industry segments or end products.

TABLE B-3. ANNUAL COSTS FOR WATERBASED AND SOLVENT-BASED ADHESIVE COATING LINES[a]

	Waterbased System	Solvent-based System
Environmental - Air		
Permitting Fees ($25/ton of HAP)	no permit required	$12,500 (assuming 500 tons emitted after control)
Environmental - Liquid		
Wastewater[b]	$18,200	minimal
Hazardous Waste ($450/55-gallon drum)	$5,400 (12 drums/yr)	$162,000 (360 drums/yr)
Environmental - Solid		
Start-up Wastes ($39.50/ton tipping fee)	$17,500	$3,500
Operating Costs		
Drying/Curing Oven[c]	$343,000	$228,700
Emissions Control	$0	$97,500
Adhesive Coating		
Cost/Wet Pound	$1.00	$1.50
Dry Pounds Used	8,657,775	8,657,775
Adhesive Coating Cost	$8,657,775	$12,986,663
TOTAL ANNUAL COSTS	**$9,041,875**	**$13,490,863**
ANNUAL COSTS SAVED WITH WATERBASED	**$4,448,988**	

[a] Costs are in 1993 dollars.
[b] Wastewater costs for the waterbased system represent the increased amount of wastewater generated relative to the solvent-based system.
[c] For estimating purposes, the oven energy costs for the waterbased system were assumed to be 1.5 times the cost for the solvent-based system.

To calculate the air permitting fees for a solvent-based system, the air emissions after carbon adsorption control were assumed to be 1,000,000 pounds (500 tons) [450,000 kilograms (450 Megagrams)] of solvent. A permitting cost of $25 per ton ($22.70 per Megagram) of HAP was used, based on CAAA Title V guidelines. The waterbased system was assumed to be solvent-free.

Wastewater generation and disposal costs were assumed to be minimal for the solvent-based system. The waterbased system was assumed to generate wastewater costing $350 per week for disposal.

The solvent-based system was assumed to generate 30 55-gallon (208-liter) drums per month at an average cost of $450/55-gallon (208-liter) drum for disposal. The waterbased system was assumed to generate one 55-gallon (208-liter) drum per month of hazardous waste from spent fluids such as hydraulic oil.

Solid waste disposal costs were assumed to increase in proportion to the increased amount of start-up substrate required for a waterbased adhesive coating system. For a masking tape production line, the amount of start-up waste was assumed to be five times that for a solvent-based system. The solvent-based system was assumed to generate 6,000 yd^2 (5,000 m^2) of solid waste per day at a cost of $3,500 per year for landfill disposal.

The operating costs for both oven systems were assumed to be the energy costs required to evaporate the adhesive vehicle. The following assumptions were made to calculate the oven energy costs:

- Natural gas oven
- Energy requirements of 83,000 Btu/1,000 ft^2 of 0.0015 inch (260 kW-hrs/1,000 m^2 of 0.038 millimeter) adhesive-coated substrate
- Natural gas cost of $5.49/MMBtu ($0.55/therm)

Using these parameters and the assumptions stated in section B.1, the energy costs for a solvent-based oven were calculated by:

$$(\textit{Energy required/unit of product}) \times (\textit{Amount of product generated annually}) \times (\textit{Cost of energy}) = \textit{Annual energy cost}$$

$$[(83{,}000\,Btu/1{,}000ft^2) \times (0.001\,inch/0.0015\,inch) \times (9ft^2/yd^2)] \times [(239{,}000\,yd^2/day) \times (350\,days/yr)] \times [(MMBtu/10^6\,Btu) \times (\$5.49/MMBtu)] = \$228{,}700$$

Therefore, the energy costs of operating a solvent-based oven are $228,700 per year. The energy costs for operating a waterbased oven were assumed to be 1.5 times the operating cost of a solvent-based oven. This factor takes into account the higher heat capacity of water versus solvents and the energy required to operate any IR heaters used in the waterbased oven.

The costs for operating a carbon adsorber used with the solvent-based system were derived from the following assumptions:

- Cost of $75,000 per carbon bed replacement
- Carbon bed replacement occurs every two years
- Electrical energy costs of $60,000 per year

These costs yield an annual operating cost of approximately $97,500 for the carbon adsorber. No emissions control system is required with a solvent-free waterbased adhesive system, therefore, the operating costs for emissions control are zero.

The annual costs for waterbased and solvent-based adhesive coatings were calculated using several assumptions:

- Solvent-based adhesive cost of $1.50 per wet pound ($0.68 per wet kilogram)
- Waterbased adhesive cost of $1.00 per wet pound ($0.45 per wet kilogram)
- 50 percent solids content for both solvent-based and waterbased adhesives

Using these adhesive parameters and the assumptions stated in section B.1, the waterbased adhesive costs were calculated from:

$$(Amount\ of\ product\ generated\ annually) \times (Adhesive\ coating\ density)$$
$$\times (Cost\ of\ adhesive) = Annual\ cost\ of\ adhesive\ coating$$

$$[(239{,}000\, yd^2/day) \times (350\, days/yr) \times (9\, ft^2/yd^2)] \times [(69\, lb\, adhesive/ft^3)$$
$$\times (0.001\, inch) \times (1\, ft/12\, inch)] \times [(\$1.00/lb\, coating)$$
$$\times (2\, lb\, coating/1\, lb\, adhesive)] = \$8{,}657{,}775/yr$$

Therefore, the waterbased adhesive costs approximately $8,657,775 per year. By substituting the cost of solvent-based adhesive [$1.50 per wet pound ($0.68 per wet kilogram)] into the above equation, the cost of solvent-based adhesive amounts to approximately $12,986,663 per year.

Summing the costs in Table B-3 results in an annual savings of $4,448,988 using a waterbased masking tape line.

APPENDIX C

1992 TRI DATA FOR ADHESIVE COATING INDUSTRY

TABLE C-1. 1992 TOXIC CHEMICALS RELEASE INVENTORY DATA FOR SICs 2641, 2671, AND 2672[a]

	SIC 2641			SIC 2671			SIC 2672		
Pollutant	**Fugitive**	**Point**	**Total**	**Fugitive**	**Point**	**Total**	**Fugitive**	**Point**	**Total**
Acetaldehyde							2,300	47,000	49,300
Acetone	5,360	1,004,043	1,009,403	60,695	204,105	264,800	697,496	1,356,320	2,053,816
Acrylamide							2	0	2
Acrylic acid							297	14,359	14,656
Acrylonitrile							6,300	22,500	28,800
Ammonia	250	500	750	52,000	0	52,000	1,683	123,082	124,765
Antimony							52	210	262
Benzene							14	4,800	4,814
Bis(2-ethylhexl) adipate				34	6,769	6,803			
Butyl acrylate	218	56	274				4,300	207	4,507
Chlorine	1	0	1				250	31,000	31,250
Chlorine dioxide	5	0	5						
Chloroform							3,300	3,700	7,000
Chromium compounds							0	10	10
Cobalt compounds							0	30	30
Cumene							340	1,500	1,840
Cyclohexane	5	21,000	21,005	6,244	157,732	163,976	23,805	865,472	889,277
Di(2-ethylhexyl) phthalate							0	1,485	1,485
Dichloromethane				0	680,000	680,000	21,000	57,000	78,000
Diethyl phthalate	5	5,700	5,705				0	25,000	25,000

(continued)

TABLE C-1. 1992 TOXIC CHEMICALS RELEASE INVENTORY DATA FOR SICs 2641, 2671, AND 2672[a] (continued)

	SIC 2641			SIC 2671			SIC 2672		
Pollutant	Fugitive	Point	Total	Fugitive	Point	Total	Fugitive	Point	Total
Ethyl acrylate							3,000	400	3,400
Ethylbenzene							880	28,870	29,750
Ethylene glycol				1,200	24,000	25,200	32,636	32,335	64,971
Formaldehyde							7,469	94,426	101,895
Freon 113							10,000	0	10,000
Glycol ethers	5	700	705	26,287	76,631	102,918	11,524	87,243	98,767
Hydrochloric acid	0	286,705	286,705				3	572,551	572,554
Isopropyl alcohol	52,225	5,729	57,954	6,200	9,600	15,800	11,399	4,886	16,285
Lead compounds							0	20	20
Maleic anhydride							5	500	505
Methanol	525	337,027	337,552	66,832	220,408	287,240	464,115	2,030,159	2,494,275
Methyl acrylate							4,291	7,000	11,291
Methyl ethyl ketone	55,760	386,533	442,293	332,366	776,865	1,109,231	731,217	4,448,321	5,179,538
Methyl isobutyl ketone	147	29,272	29,419	7,500	89,620	97,120	16,225	318,169	334,394
Methyl methacrylate							3,600	20,200	23,800
Methylenebis(phenyliso cyanate)							0	1	1
n-Butyl alcohol				500	23,667	24,167	7,079	62,087	69,166
Naphthalene							750	87,000	87,750
Nickel compounds	0	3	3						

(continued)

TABLE C-1. 1992 TOXIC CHEMICALS RELEASE INVENTORY DATA FOR SICs 2641, 2671, AND 2672[a] (continued)

	SIC 2641			SIC 2671			SIC 2672		
Pollutant	**Fugitive**	**Point**	**Total**	**Fugitive**	**Point**	**Total**	**Fugitive**	**Point**	**Total**
Nitric acid							500	0	500
Phenol							8,957	87,817	96,774
Phthalic anhydride	5	0	5						
sec-Butyl alcohol				0	13,232	13,232			
Styrene	8,714	2,260	10,974				6,800	37,597	44,397
Sulfuric acid	0	56,493	56,493				0	168,780	168,780
tert-Butyl alcohol				250	750	1,000	0	4,900	4,900
Tetrachloroethylene				4,260	0	4,260	0	3,000	3,000
Toluene	1,350,536	4,188,701	5,539,237	892,957	5,554,775	6,447,732	2,067,138	17,022,103	19,089,241
Toluene-2,4-diisocyanate							10	10	20
Toluene-2,6-diisocyanate							10	10	20
Toluenediisocyanate							15	7	22
Trichloroethylene				7,065	0	7,065			
Vinyl acetate	295	581	876	2	7,192	7,194	14,336	35,230	49,566
Vinylidene chloride							15,300	140,800	156,100
Xylenes	5,300	5,400	10,700	6,750	119,586	126,336	48,993	1,297,858	1,346,851
Zinc (fume or dust)							0	750	750
Zinc compounds	0	15,048	15,048	1,750	251	2,001	372	10	382
1,1,1-Trichloroethane				129,996	46,748	176,744	22,829	258,083	280,912
1,2,4-Trimethylbenzene							1,600	7,800	9,400

(continued)

TABLE C-1. 1992 TOXIC CHEMICALS RELEASE INVENTORY DATA FOR SICs 2641, 2671, AND 2672[a] (continued)

Pollutant	SIC 2641			SIC 2671			SIC 2672		
	Fugitive	Point	Total	Fugitive	Point	Total	Fugitive	Point	Total
1,3-Butadiene	36	36	72				18,500	115,300	133,800
1,4-Dioxane							90	12,000	12,090
2-Ethoxyethanol							18,000	19,000	37,000
2-Methoxyethanol							2,917	16,630	19,547
4,4'-Isopropylidene-diphenol							0	2,000	2,000
GRAND TOTAL	1,479,392	6,345,787	7,825,179	1,602,888	8,011,931	9,614,819	4,291,700	29,577,528	33,869,228

[a]SIC 2641 was discontinued in the late 1980s and subdivided into SICs 2671 and 2672. However, many facilities still report under this SIC.