Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment

Design for the Environment
U.S. EPA

Volume 1

Flexographic Ink Options:

A Cleaner Technologies Substitutes Assessment

VOLUME 1

Design for the Environment Program
Economics, Exposure, and Technology Division
Office of Pollution Prevention and Toxics (7404)
U.S. Environmental Protection Agency

February 2002
EPA 744-R-02-001A

Developed in Partnership with the Following Associations:

Flexible Packaging Association
napim
fta

CALIFORNIA FILM EXTRUDERS & CONVERTERS ASSOCIATION
RADTECH INTERNATIONAL NORTH AMERICA
FILM & BAG FEDERATION

For More Information

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This document presents the findings and analysis of a voluntary, cooperative effort between the flexographic printing industry and the U.S. EPA. This is not an official guidance document and should not be relied on by companies in the printing industry to determine regulatory requirements. Information on cost and product usage in this document was provided by individual product vendors and has not been corroborated by EPA. Mention of specific company names or products does not constitute an endorsement by EPA.

Acknowledgments

DfE would like to thank its many partners for their participation in the Flexography Project.

- Members of the Steering and Technical Committees provided valuable guidance and feedback throughout the project. The Technical Committee included volunteer printers and suppliers, who contributed much time, expertise, materials, and the use of their facilities; their cooperation was essential to the project. (The next two pages list the participants.)
- Lori Kincaid of the University of Tennessee Center for Clean Products and Clean Technologies analyzed the data on energy and resource conservation.
- John Serafano of Western Michigan University attended the performance demonstrations, supervised the laboratory runs, and analyzed the performance data.
- Laura Rubin, formerly of Industrial Technology Institute, contributed to the cost analysis.
- Members of the EPA Workgroup contributed significantly, especially to the risk, cost, and benefit-cost analyses. The Workgroup consisted of the following individuals: Susan Dillman, Conrad Flessner, Jr., Eric Jackson, Susan Krueger, David Lai, Fred Metz, and Jerry Smrchek.
- This document was prepared by Susan Altman, Dennis Chang, Cheryl Keenan, Harry (Trey) Kellett III, and Srabani Roy of Abt Associates, Inc. under EPA Contract 68-W6-0021, Work Assignments 3-07, 4-05, and 5-08, and EPA Contract 68-W-01-039, Work Assignment 1-2. EPA work assignment managers included Stephanie Bergman, Karen Chu, and James Rea.

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* These companies voluntarily supplied materials for the CTSA or participated in the performance demonstrations.

Contents

VOLUME 1

EXECUTIVE SUMMARY

Chapter 1: INTRODUCTION TO THE CLEANER TECHNOLOGIES SUBSTITUTES ASSESSMENT

Chapter 2: OVERVIEW OF FLEXOGRAPHIC PRINTING

Chapter 3: RISK

Chapter 4: PERFORMANCE

Chapter 5: COST

Chapter 6: RESOURCE AND ENERGY CONSERVATION

Chapter 7: ADDITIONAL IMPROVEMENT OPPORTUNITIES

Chapter 8: CHOOSING AMONG INK TECHNOLOGIES

VOLUME 2: APPENDICES

Appendices to Chapter 3: RISK

Appendices to Chapter 4: PERFORMANCE

Appendices to Chapter 5: COST

Appendices to Chapter 6: RESOURCE AND ENERGY CONSERVATION

Abbreviations

ADC	Average Daily Concentration
ADD	Average Daily Dose
BACT	Best Available Control Technology
BCM	Billion Cubic Microns per Square Inch
BOD	Biological Oxygen Demand
CAA	Clean Air Act
CAS	Chemical Abstracts Service Registry Number
CBI	Confidential Business Information
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CESQG	Conditionally Exempt Small Quantity Generator
CFR	Code of Federal Regulations
CTG	Control Technology Guidelines
CTSA	Cleaner Technology Substitutes Assessment
CWA	Clean Water Act
DfE	Design for the Environment
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FPA	Flexible Packaging Association
FTA	Flexographic Technical Association
FWPCA	Federal Water Pollution Control Act
HAP	Hazardous Air Pollutant
HQ	Hazard Quotient
HSWA	Hazardous and Solid Waste Amendments
IARC	International Agency for Research on Cancer
LDPE	Low-Density Polyethylene
LEPC	Local Emergency Planning Commission
LOAEL	Lowest Observed Adverse Effect Level
LQG	Large Quantity Generator
MACT	Maximum Achievable Control Technology
MEK	Methyl Ethyl Ketone
MIBK	Methyl Isobutyl Ketone
MOE	Margin of Exposure
MSDS	Material Safety Data Sheet

NAICS	North American Industry Classification System
NAPIM	National Association of Printing Ink Manufacturers
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NOAEL	No Observed Adverse Effect Level
NPDES	National Pollution Discharge Elimination System
OPP	Oriented Polypropylene
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
PE/EVA	Polyethylene/Ethylvinyl Acetate
POTW	Publicly Owned Treatment Works
PTE	Permanent Total Enclosure
RACT	Reasonably Achievable Control Technology
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SERC	State Emergency Response Commission
SIC	Standard Industrial Classification
SQG	Small Quantity Generator
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Ace
TSD	Treatment, Storage, and Disposal (facility)
TSS	Total Suspended Solids
UST	Underground Storage Tank
VOC	Volatile Organic Compound

Glossary

Acetate	a family of solvents also known as esters of acetic acid
Acrylate	a chemical functional group commonly used in UV curing
Acute exposure	one dose or multiple dose exposures occurring over a short time (24 hours)
Additive	a substance used in small quantities to modify the properties of an ink
Adhesion	state in which two surfaces are held together by molecular forces; measure of the strength with which one material sticks to another
Adhesive	any material that is applied to one or more surfaces to form a bond between the two
Adsorbent	material (e.g., carbon) that adsorbs (concentrates) a substance on its surface
Adsorption	accumulation of a gaseous, liquid, or dissolved substance on the surface of a solid
Ambient environment	the existing conditions in the environment or immediate vicinity
Amide	a nitrogen-containing compound that usually is basic (alkaline)
Anilox roll	engraved steel and chrome-coated metering roll to control the amount of ink sent from the fountain roller to the printing plates
Anilox volume	the volume of cells on an anilox roll in a standardized area, expressed as billion cubic microns per square inch (BCM)
Aquatic toxicity	capability of a substance to cause adverse effects in aquatic organisms
Benefit	the value to society of a good or service. From a firm's perspective, the benefit of a good or service can be measured by the revenue the firm receives from its sales as compared to the costs incurred when producing its products. From the consumer's perspective, the benefit can be measured by what the consumer would be willing to pay for the good or service. Some goods and services, such as environmental amenities and health risk reductions, are not generally for sale in a market economy. However, these goods and services do provide benefits to society which should be recognized. Economists attempt to estimate the value of these goods and services through various nonmarket valuation methods.
Best Available Control Technology (BACT)	an emission limitation based on the maximum degree of emission reduction (considering energy, environmental, and economic impacts) achievable through application of production processes and available methods, systems, and techniques; (EPA) the most stringent technology available for controlling emissions; major sources are required to use BACT, unless it can be demonstrated that it is not feasible for energy, environmental, or economic reasons.
Block resistance	a type of performance test that measures the bond between ink and substrate when heat and pressure are applied
Blocking	undesired adhesion between layers of material that may cause damage to at least one surface upon their separation

Caliper	the thickness of a sheet or material measured under specific conditions, expressed in thousandths of an inch
Carcinogen	cancer-causing chemical
Carcinogenic effect	malignant tumor or other manifestation of abnormal cell growth caused by cancer
Catalyst	a substance that accelerates the rate of a reaction between two or more substances without being consumed in the process
Catalytic oxidizer	type of oxidizer that contains a catalyst
Cationic ink	a type of UV-cured ink in which photoinitiators start the reaction by causing an electron deficiency in the monomers and oligomers
Central impression printing press	printing press in which the material being printed is in continuous contact with a single-large diameter impression cylinder; the color stations are arranged around the circumference of the cylinder and imprint the image on the substrate
Chill roller	metal roll or drum with internal cooling, used to cool the printed web prior to rewinding
Coating	the outer covering of a film or web; the film may be coated on one or both sides
Co-extruded polyethylene/ethyl vinyl acetate (PE/EVA)	a type of film substrate used in flexographic printing
Co-extrusion	a process used to produce a product, such as a film substrate, by forcing more than one extruder through a common die
Colorant	a substance that provides the color associated with ink; it can be a pigment or a dye
Control option	add-on technological system or device that removes pollutants from a flexographic facility's waste stream and thereby keeps them out of air, water, and landfills; pollutants may be captured for reuse, recycling, or disposal
Conventional pollutant	a pollutant chemical in wastewater effluent regulated under the Clean Water Act (CWA); includes biological oxygen demand (BOD), total suspended solids (TSS), fecal coliform bacteria, fat/oil/greases (FOG), and pH
Core	a tube on which paper, film, or foil is wound for shipment; the metal body of a roller which is rubber covered
Corona treater	equipment that electrically charges the substrate to improve ink adhesion by raising the surface tension of the substrate
Corrosivity	capability of corroding
Cross-linker	a component of UV-cured inks, such as a monomer or oligomer, that is capable of reacting to form a solid coating
Cure	process of treating inks with ultraviolet light which creates a bond between the monomers and oligomers in the ink; the reaction (or "drying") causes the ink to solidify and bind with the substrate

Curing agent	a chemical that participates in the reaction that results in the curing of UV inks
Dermal exposure	exposure through the skin
Developmental toxicity	adverse effects caused to a developing organism from exposure to a substance prior to conception, during prenatal development, or postnatally up to the time of sexual maturation
Die	any of various sharp cutting forms, used to cut desired shapes from papers, paperboard, plastics or other stocks
Diluent	a liquid with no solvent action, used to dilute or thin an ink or lacquer; a type of extender
Direct medical costs	costs associated specifically with the identification and treatment of a disease or illness (e.g., costs of visits to the doctor, hospital costs, costs of drugs).
Discounting	Economic analysis procedure by which monetary valuations of benefits and/or costs occurring at different times are converted into present values which can be directly compared to one another.
Dispersant	material that enables a uniform distribution of solid particles
Dispersion	a uniform distribution of solid particles in a vehicle by mixing or milling
Doctor blade	a thin flexible blade that grazes the anilox roll at an angle to remove excess ink from the roll before the ink is applied to the printing plate
Dose-response assessment	in a risk assessment, the relationship between the dose of the chemical received and the incidence and severity of the adverse health effects in an exposed population
Dot gain	the undesired increase in size of a printed "dot" of ink
Dye	coloring material which is soluble in an ink vehicle, as opposed to pigments, which are not soluble and must be dispersed
Electrolytic silver recovery	method of silver recovery whereby a current is passed between two electrodes in silver-laden water, plating the silver on the cathode in a virtually pure form
Exposed population	the estimated number of people from the general public or a specific population group who are exposed to a chemical, process, and/or technology. The general public could be exposed to a chemical through wide dispersion of a chemical in the environment (e.g., DDT). A specific population group could be exposed to a chemical due to its physical proximity to a manufacturing facility (e.g., residents who live near a facility using a chemical), through the use of the chemical or a product containing a chemical, or through other means.
Exposed worker population	the estimated number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be based on market share data as well as estimations of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration

Exposure assessment	in risk assessment, identification of the pathways of which toxicants may reach individuals, estimation of how much of a chemical an individual is likely to be exposed to, and estimation of the number of people likely to be exposed
Epoxy resin	plastic or resinous materials used for strong, fast-setting adhesives, as heat resistant coatings and binders
Extender	any material added to inks to reduce its color strength and/or viscosity
External benefits	a positive effect on a third party who is not part of a market transaction. For example, if an educational program (i.e., a smoking-cessation class) results in behavioral changes which reduce the exposure of a population group to a disease (i.e., lung cancer), then an external benefit is experienced by those members of the group who did not participate in the educational program (i.e., those inhaling second-hand smoke). External benefits also occur when environmental improvements enhance enjoyment of recreational activities (e.g., swimming, hiking, etc.).
External costs	a negative effect on a third party who is not part of a market transaction. For example, if a steel mill emits waste into a river which poisons the fish in a nearby fishery, the fishery experiences an external cost to restock as a consequence of the steel production. Other examples of external costs are the effects of second-hand smoke on nonsmokers, increasing the incidence of respiratory distress, and a smokestack which deposits soot on someone's laundry, thereby incurring costs of relaundering.
Externality	a cost or benefit that involves a third party who is not a part of a market transaction; "a direct effect on another's profit or welfare arising as an incidental by-product of some other person's or firm's legitimate activity" (Mishan, 1976). The term "externality" is a general term which can refer to either external benefits or external costs.
Extrusion	the production of a continuous product (e.g., a sheet of film) by forcing a material (e.g., thermoplastic) through a die or orifice
Flammability	the capability of burning
Flexible packaging	any package or part of packaging with a thickness of ten millimeters or less whose shape can be changed readily
Flexographic printing plate	a plate with a raised image that prints on the desired substrate
Formulation	a specific color (e.g., Reflex blue) within an ink product line used in the CTSA (e.g., solvent-based ink#1)
Fountain	a pan or trough on a press that serves as a reservoir for ink
Fountain roll	a press roll that picks up ink or coating material from the fountain and applies it to the transfer roll
Four-color process	printing with cyan, magenta, and yellow color inks plus black, and using combinations of these colors to create all other colors (see process printing)
Free radical	an unstable, reactive molecule that has a neutral charge (in comparison to an ion)

Free radical curing	a type of ultraviolet curing in which photoinitiators release reactive free radicals
Fugitive emissions	emissions that escape from the printing press and leave the facility through openings such as windows and doors
Hazard	potential for a chemical or other pollutant to cause human illness or injury; the inherent toxicity of a compound
Hazard identification	in a risk assessment, determining whether exposure to a chemical could cause adverse health effects in humans or in nature; an informed judgment based on verifiable toxicity data from animal models or human studies
Hazard quotient	the ratio of estimated site-specific exposure to a single chemical over a specified period to the estimated daily exposure level at which no adverse health effects are likely to occur
Hazardous	harmful to human health and the environment
Hazardous Air Pollutant (HAP)	air pollutants listed under the Clean Air Act (CAA) as being hazardous to human health and the environment
Hazardous waste	by-products of industrial activities that can pose a substantial or potential hazard to human health or the environment when improperly managed
Hazardous waste generator	a facility that produces hazardous waste
Human health benefits	reduced health risks to workers in an industry or business as well as to the general public as a result of switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile chemical or a new method of storing or using a volatile, hazardous chemical, to reduce the amount of volatilization, thereby lessening worker inhalation exposures as well as decreasing the formation of photochemical smog in the ambient air.
Human health costs	the cost of adverse human health effects associated with production, consumption and disposal of a firm's product. An example is the cost to individuals and society of the respiratory effects caused by stack emissions, which can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work.
Ignitability	capability of lighting on fire
Illness costs	a financial term referring to the liability and health care insurance costs a company must pay to protect itself against injury or disability to its workers or other affected individuals. These costs are known as illness benefits to the affected individual.
Incineration	the process of burning to ashes with the intent of reducing harmful substances to more benign ones
Indirect medical costs	costs associated with a disease or medical condition resulting from exposure to a chemical, product or technology, such as the costs of decreased productivity of patients suffering a disability or death, and the value of pain and suffering borne by the afflicted individual and/or family and friends.

Individual risk	an estimate of the probability of an exposed individual experiencing an adverse effect, such as "1 in 1,000" (or 10) risk of cancer.
Inhalation exposure	exposure through breathing
Ink pan	reservoir for ink
Ink splitter	a device that separates solids from fluids in waste ink and cleaning solutions, or removes pigments from water-based ink wastes using a porous cellulose material
In-line printing press	a multicolored press in which the color stations are mounted horizontally in a line; a press coupled to another operation such as bagmaking, sheeting, diecutting, creasing, etc.
Ion exchange	method of recovering silver from wash water or mixtures of wash waters, fixer and bleach fix, especially from dilute solutions
Laminate	to bond together two or more layers of material or materials
Line color printing	process of printing “line work” such as text, display type, and some types of graphics
Liquid ink	low-viscosity ink
Low-density polyethylene (LDPE)	type of film substrate used for printing on packaging such as frozen food bags
Lowest Observed Adverse Effect Level (LOAEL)	lowest exposure level at which adverse effects to human health and/or the environment have been shown to occur
Major Source	under Title V of the Clean Air Act, a facility that has the potential to emit 10 tons per year or more of any individual Hazardous Air Pollutant (HAP), 25 tons per year or more of any combination of HAPs, or 100 tons per year or more of any air pollutant. The 100 tons per year limit applies to facilities located in areas with relatively good air quality (“attainment areas”); the limit decreases in non-attainment areas.
Makeready	the preparation and correction of the printing plate before starting the print run, to insure uniformly clean impressions; all preparatory operations preceding production
Margin of exposure (MOE)	the ratio of the no-observed-adverse-effect-level (NOAEL) to the estimated exposure dose
Material Safety Data Sheet (MSDS)	a compilation of information required under the Occupational Safety and Health Administration (OSHA) Communication Standard on the identity of hazardous chemicals, health and physical hazards, exposure limits, and precautions of a product
Maximum Achievable Control Technology (MACT)	the emission standard for sources of air pollution requiring the maximum reduction of hazardous emissions, taking cost and feasibility into account
Metallic replacement	method of silver recovery whereby wastewater is passed through one or more steel wool filters in which silver in the wastewater is chemically replaced by iron from the filter
Monomer	an individual molecular unit that is capable of linking together to form polymers

Narrow web press	any printing press web that is less than 24 inches wide; narrow web presses are able to do multiple converting operations (e.g., diecutting) in the same pass with the printing
National Emission Standards for Hazardous Air Pollutants (NESHAP)	emissions standards set by EPA for air pollutants that may cause an increase in fatalities or in serious, irreversible, or incapacitating illness
Net benefit	the difference between the benefits and the costs. For a company this could be interpreted as revenue - costs, assuming that the revenue and the costs are fully determined.
No Observed Adverse Effect Level (NOAEL)	the highest exposure level that can occur without statistically or biologically significant adverse effects to human health and/or the environment
Non-conventional pollutant	any wastewater effluent pollutant regulated under the Clean Water Act (CWA) that is not identified as a conventional or priority pollutant
Oligomer	a low-weight polymer that is capable of further combination; the component of UV-cured inks that links together to form a solid coating
Opportunity cost	a hidden or implied cost incurred due to the use of limited resources such that they are not available for an alternative use. For example, the use of specific laborers in the production of one product precludes their use in the production of another product. The opportunity cost to the firm of producing the first product is the lost profit from not producing the second. Another example would be a case where in hiring legal representation to respond to a lawsuit, and due to limited financial resources, a firm must cancel a planned expansion. The opportunity cost of responding to the lawsuit is the lost gain from not expanding.
Oral exposure	exposure to contaminated substances through eating or drinking
Oral toxicity	ability of a chemcial to cause injury when ingested
Oriented polypropylene (OPP)	a film substrate noted for clarity, stiffness, and ability to form a strong barrier
Overprinting	the printing of one impression over another
Oxidation	the reaction of a chemical (such as VOCs) with oxygen; the process of combining with oxygen
Oxidizer	equipment that burns contaminated air to break down harmful substances (e.g., VOCs) into water, carbon dioxide, and other gases
Ozone	a gas containing three oxygen molecules; at ground level it is a pollutant formed in part by the reaction of volatile organic compounds (VOCs) released by solvent-based inks; contributes to smog formation
Paste ink	high-viscosity ink
Permanent total enclosure	a structure that completely surrounds a source of air emissions, captures all VOC emissions, and sends them to a control device
Photoinitiator	the component of UV-cured inks that reacts with ultraviolet light to begin the curing process
Photopolymer	any mixture of materials that can change its own physical properties on exposure to ultraviolet or visible light

Pigment	insoluble substance used to give color to inks, paints and plastics
Pinholing	failure of a printed ink to form a complete continuous film; visible in the form of small holes in the printed area
Plasticizer	material (usually in liquid form) that is added to ink to improve the flexibility of dried ink
Pollution prevention	identification of substances, processes, and activities that create excessive waste products or pollutants, followed by reductions in pollution generation by altering or eliminating a process or materials
Polyethylene	a synthetic resin of high molecular weight resulting from the polymerization of ethylene gas under pressure.
Polymer	a compound formed by the linking together of simple molecules
Polymerization	a chemical reaction in which the molecules of a monomer are linked together to form large molecules
Polypropylene	a synthetic resin of high molecular weight resulting from the polymerization of propylene gas
Population risk	an aggregate measure of the projected frequency of effects among all exposed people, such as "four cancer cases per year."
Present value	the value in today's terms of a sum of money received in the future. Present Value is a concept which specifically recognizes the time value of money, i.e., the fact that $1 received today is not the same as $1 received in ten years time. Even if there is no inflation, $1 received today can be invested at a positive interest rate (say 5 percent), and can yield $1.63 in ten years; $1 received today is the same as $1.63 received ten years in the future.
Press-side solvent or additive	a product added to ink during a press run to improve the printing performance (e.g., to decrease viscosity)
Primer	a first coat intended to enhance subsequent printing
Priority pollutant	a toxic chemical found in wastewater effluent and regulated under the Clean Water Act (CWA)
Private (internalized) benefits	the direct gain received by industry or consumers from their actions in the marketplace. One example includes the revenue a firm obtains in the sale of a good or service.
Private (internalized) costs	the direct negative effects incurred by industry or consumers from their actions in the marketplace. Examples include a firm's cost of raw materials and labor, a firm's costs of complying with environmental regulations, or the cost to a consumer of purchasing a product.
Process color printing	halftone color printing created by the color separation process; a piece of copy is broken down to the primary colors to produce individual halftones, which are then recombined at the press to replicate the full range of colors
Product line	a group of proprietary inks that are made by one manufacturer, share certain printing characteristics, include multiple colors, and are intended for use with a specific ink system (e.g., solvent-based)
Propylene	gas used in polymerization to form polypropylene

Publicly Owned Treatment Works (POTW)	a municipal or regional water treatment plant
Reactive diluent	material used in ultaviolet curing that reduces viscosity of ink
Reactivity	property of being able to decompose or react with other chemicals
Reasonably Available Control Technology (RACT)	technology required under the Clean Air Act to control the emissions of volatile organic compounds
Recycling	the practice of reducing environmental wastes by recovering and reprocessing waste materials, thereby reducing the use of virgin materials
Reducer	material used to alter the body, viscosity, or color strength of ink
Reference concentration	*lowest continuous human inhalation exposure* that does not have an appreciable risk of deleterious, non-cancerous effects during a lifetime
Reference dose	*lowest daily human exposure* that does not have an appreciable risk of deleterious, non-cancerous effects during a lifetime
Repeat length	printing length of a plate cylinder, determined by one complete revolution of the plate cylinder gear
Reportable quantity	substance-specific amount of hazardous material reportable under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
Reproductive toxicity	biologically adverse effects on the female or male reproductive organs, the related endocrine system, or offspring
Resin	natural or synthetic complex organic substance with no distinct melting point, which in a solvent solution forms the binder portion of the flexographic ink
Reverse printing	printing on the underside of a transparent film; or a design in which an image or type is "dropped-out" and the background is printed
Risk characterization	in risk assessment, the process of using hazard, dose-response, and exposure information to develop quantitative and qualitative expressions of risk
Scuffing	action of rubbing something against a printed surface
Silver recovery	process by which silver is recovered from printing wastewater
Smog-related emissions	gases, such as volatile organic compounds (VOCs), carbon monoxide, and nitrogen oxides (NO_x), that are released during printing or energy production operations and contribute to the formation of smog when exposed to sunlight
Social benefit	the total benefit of an activity that society receives, i.e., the sum of the private benefits and the external benefits. For example, if a new product prevents pollution (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the external benefit (benefit society receives from reduced waste).

Social cost	the total cost of an activity that is imposed on society. Social costs are the sum of the private costs and the external costs. Therefore, in the example of the steel mill, social costs of steel production are the sum of all private costs (e.g., raw material and labor costs) and the sum of all external costs (e.g., the costs associated with replacing the poisoned fish).
Solvent	medium used to dissolve a substance
Solvent-based ink	an ink containing more than 25% VOCs and formulated to dry via evaporation
Solvent recovery	process of recovering purified solvents from VOC emissions
Solvent resistance	the ability of a cured ink coating to resist removal during exposure to a solvent such as methyl ethyl ketone (MEK)
Stack emission	emissions that are collected from the printing press and are released through a roof vent or stack to the outside air, sometimes undergoing treatment to reduce the emissions
Stack printing press	press where the printing stations are placed one above the other, each with its own impression cylinder
Substrate	material upon which an image is printed
Systemic toxicity	adverse effects on any organ system following absorption and distribution of a chemical throughout the body
Thermal oxidizer	oxidizer that requires high operating temperatures (see Oxidizer)
Thinner	liquid, solvent, and/or diluent added to ink for dilution or thinning; a type of extender
Tone	color quality or value; a tint or shade of color
Toxic Chemical Release Inventory (TRI)	requirement under the Emergency Planning and Community Right-to-Know Act (EPCRA) requiring certain facilities to report release of specified chemicals
Toxicity	property of being harmful or poisonous
Trapping	printing of one color over another
Tropospheric Ozone	see Ozone
Turbidity	a condition in which the clarity of water is reduced because of the presence of sediment, pigment, or other suspended material
Ultraviolet light	electromagnetic radiation of shorter wavelength than visible light
UV-cured ink	ink that is cured by ultraviolet light rather than evaporation
Vehicle	liquid component of a printing ink; carries the ink from the ink pan to the substrate
Viscosity	resistance to flow
Volatile Organic Compound (VOC)	any organic (carbon-containing) compound that participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity
Volatilization	the process of passing from liquid to gaseous state; subject to rapid evaporation; having high vapor pressure at room temperature

Waste generator	a facility that generates wastes and is responsible for determining whether the waste is hazardous and what classification may apply to a waste stream
Water-based ink	an ink containing less than 25% VOCs and formulated to dry via evaporation
Wetting	process by which a liquid wets the surface of a dissimilar material by reducing the surface tension of the liquid
Wide-web press	a printing press with a web that is greater than 24 inches wide, usually in the range of 50-60 inches
Willingness-to-pay	estimates used in benefits valuation intended to encompass the full value of avoiding a health or environmental effect, which are often not observable in the marketplace. For human health effects, the components of willingness-to-pay include the value of avoided pain and suffering, impacts on the quality of life, costs of medical treatment, loss of income, and, in the case of mortality, the value of a statistical life.

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Executive Summary

Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment (the Flexographic Inks CTSA) presents the results of a technical study of the comparative environmental impacts, health risks, performance, and cost of the three primary flexographic printing ink systems: solvent-based inks, water-based inks, and ultra-violet (UV)-cured inks. The study was initiated through the Flexography Partnership of the Design for the Environment (DfE) Program at the U.S. Environmental Protection Agency (EPA).* The broad goal of the CTSA was to develop as complete and systematic a picture as possible of competing ink technologies, thereby helping industry incorporate environmental and health information into their ink decisions. It is hoped that the CTSA will serve as a resource to

- identify and inform industry about comparative chemical risks in inks, including unregulated ones that present opportunities for proactive, voluntary risk management,
- facilitate the use and formulation of cleaner inks, and
- encourage adoption of workplace practices that minimize health and environmental risks from exposure to chemicals of concern.

The study examined ink systems that are used on wide-web film substrates, a combination that presented special technical and environmental challenges for printers. Notably, at the time the study was initiated, use of UV-cured inks on wide-web film substrates was still in a developmental stage and was just beginning to emerge commercially. One of the benefits of the CTSA approach is its ability to provide unbiased insights into the environmental and health impacts and competitiveness of emerging technologies.

Interestingly, the CTSA found that each of the ink systems studied had different advantages, as well as health and environmental concerns. Considerable variation was noted even among different colors within a single ink product line. Thus, *selecting the best formulations is just as important for a printer as selecting an ink system.* The CTSA results can help printers and formulators familiarize themselves with the toxicities of chemicals they use on a daily basis, be more aware of their risk concerns, and identify cleaner ink systems, formulations, and chemicals.

The primary audiences for the Flexographic Inks CTSA are flexographic printers, ink manufacturers, environmental health and safety personnel, community groups, and other technically informed decision makers.

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* EPA's Design for the Environment Program is located within the Economics, Exposure and Technology Division, in the Office of Pollution Prevention and Toxics.

The Flexography Partnership is a voluntary, cooperative effort among EPA, industry, academia, public interest groups, and other stakeholders. Project partners participated in all stages of planning and implementing this CTSA. They helped define its scope and direction, provided technical information, reviewed data and text, and donated time, materials, and printing facilities for performance demonstrations. Critical information about ink formulations used in the analyses was provided by ink manufacturers.

In addition to the Flexographic Inks CTSA, the Flexography Partnership has developed a summary report, a pollution prevention video, and a number of other materials for printers. These may be obtained from the DfE website (www.epa.gov/dfe) or by contacting EPA's National Service Center for Environmental Publications (telephone 800-490-9198 or 513-489-8190; fax 513-489-8695; Internet address www.epa.gov/ncepihom/ordering.htm; e-mail ncepimal@one.net).

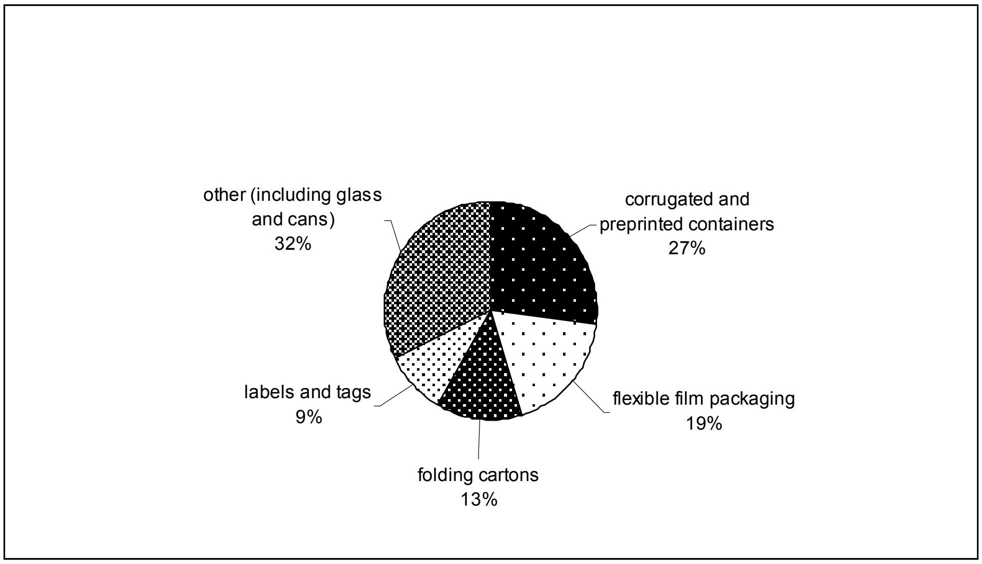
This Executive Summary first provides a brief background of the flexographic industry, the DfE Program, and the Flexographic Inks CTSA. It then presents key results on the main research areas: environmental impacts and health concerns, performance, and costs. It ends with some steps that flexographic professionals could take to minimize impacts on the environment and worker health.

BACKGROUND OF THE DFE FLEXOGRAPHY PROJECT

The Flexographic Printing Industry

Flexography is a process used primarily for printing on paper, corrugated paperboard, and flexible plastic materials. Especially well suited to printing on flexible and non-uniform surfaces (such as plastic films and corrugated board), flexography is used to print a wide range of products we all use, such as snack food and frozen food bags, labels for medicines and personal care products, newspapers, drink bottles, and cereal containers (Figure ES.1).

Figure ES.1 Primary Types of Packaging Manufactured in the United States, 2000
(by % of sales dollars)



Flexography is a highly visible, growing, national industry that is dominated by small businesses. Combined, these businesses have the potential to make a major environmental impact, especially on air quality, resource use (e.g., inks and substrates), and solid and hazardous waste.

- U.S. flexographic printing firms had annual sales of approximately $50 billion in 1999.[1]
- The sector employs about 30,000 people.[2]
- More than 80% of all flexography firms have fewer than 50 employees.
- It has an annual growth rate of about 6%.[3]
- Roughly 60% of flexographic businesses are concentrated in ten states: California, Florida, Illinois, Missouri, New Jersey, New York, North Carolina, Ohio, Texas, and Wisconsin.[4]
- Flexographic printing consumed more than 513 million pounds of ink in 2000.[5]

EPA's Design for the Environment Program

The Design for the Environment (DfE) Program is a voluntary partnership program that works directly with industries, usually through industry leaders and trade or technical associations, to integrate health and environmental considerations into their business decisions. The DfE approach compares the human health and environmental risks, performance, and costs associated with existing and alternative technologies or processes. DfE helps businesses design or redesign products, processes, and management systems that are cleaner, more cost-effective, and safer for workers and the public.

DfE partnerships may take several approaches to designing for the environment: technology assessments, formulator approaches, best practices approaches, greening the supply chain, integrated environmental management systems, and life-cycle assessments. DfE has established partnerships in commercial printing (flexography, lithography, and screen printing), garment and textile care, computer monitors, printing wiring boards (used for computers and other electronics), industrial and institutional cleaning formulations, automotive refinishing, adhesives used in foam furniture and sleep products, and automotive suppliers.

Background and General Methodology of the Flexographic Inks CTSA

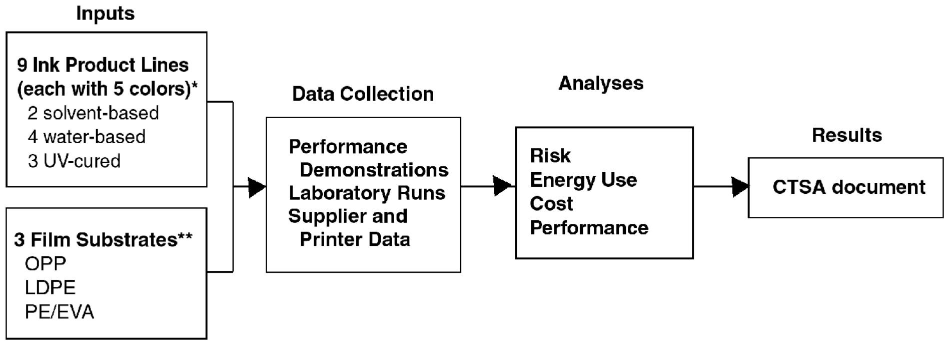
In the mid-1990s, DfE identified flexography as an important industry sector that could benefit from a DfE assessment:

- Historically, most flexographic inks had been solvent-based, had high levels of volatile organic compounds (VOCs), and contained many chemicals, some of which were quite toxic. Although the printing industry has addressed a number of environmental and health concerns of inks through reformulation of inks, add-on pollution control devices, and other improvements to operations and materials, these had not resolved all concerns about human health and ecological risks.
- Inks are a major use and cost category for printers.
- As small businesses, individual flexography firms might not have the resources or expertise to research the environmental implications of competing technologies.
- The industry had been growing rapidly for several years, which increases its impacts.

The Flexography Partnership decided to perform a cleaner technologies substitutes assessment or CTSA for flexographic inks. This methodology allowed the Partners to evaluate traditional and alternative technologies for the potential risks they pose to human health and the environment, as well as for performance and cost. The CTSA methodology is described in the DfE document, *Cleaner Technologies Substitutes Assessment: A Methodology and Resources Guide*.[**] Figure ES.2 graphically displays the methodology used for this CTSA.

[**] See the beginning of this volume (page ii) for ordering information.

Figure ES.2 Flexographic Inks CTSA Methodology



*** blue, white, cyan, magenta, green.**
**** OPP = oriented polypropylene. LDPE = low-density polyethylene.**
PE/EVA = polyethylene/ethyl vinyl acetate co-extruded film.

ENVIRONMENTAL IMPACTS AND HEALTH CONCERNS

This section describes the risk assessment methodology that was used to obtain and evaluate the health and environmental findings for flexographic inks. Findings related to workers and the general population are discussed first. Environmental findings follow, including (1) ambient air releases, (2) aquatic toxicity, and (3) resource use and energy conservation.

Over the past decade, ink manufacturers have made environmental improvements by developing inks with lower VOC content. The Flexography Partnership wanted to obtain an even deeper understanding of environmental and health implications of ink chemicals, to help the industry innovate and select cleaner inks, and to ensure that new formulations were not shifting risks from one medium to another (e.g., from ambient air quality to worker health).

The study examined 45 ink formulations, which contained approximately 100 chemical substances (Table ES.1). Ink suppliers voluntarily provided the inks, along with complete information about the chemical compositions of their formulations. To compare the environmental and health implications of the three ink systems, the study examined the toxicity, estimated releases and exposures, and risk concerns for the chemicals. To protect manufacturers' confidentiality, the formulation information they provided was treated as confidential business information.

Table ES.1 Categorization of Ink Chemicals

Category	Chemicals in category	CAS number
Acrylated polyols	Dipropylene glycol diacrylate	57472-68-1
	1,6-Hexanediol diacrylate	13048-33-4
	Hydroxypropyl acrylate	25584-83-2
	Trimethylolpropane triacrylate	15625-89-5
Acrylated polymers	Acrylated epoxy polymer[c]	NA[a]
	Acrylated oligoamine polymer[c]	NA
	Acrylated polyester polymer (#'s 1 and 2)[c]	NA
	Glycerol propoxylate triacrylate	52408-84-1
	Trimethylolpropane ethoxylate triacrylate	28961-43-5
	Trimethylolpropane propoxylate triacrylate	53879-54-2
Acrylic acid polymers	Acrylic acid-butyl acrylate-methyl methacrylate-styrene polymer	27306-39-4
	Acrylic acid polymer, acidic (#'s 1 and 2)[c]	NA
	Acrylic acid polymer, insoluble[c]	NA
	Butyl acrylate-methacrylic acid-methyl methacrylate polymer	25035-69-2
	Styrene acrylic acid polymer (#'s 1 and 2)[c]	NA
	Styrene acrylic acid resin[c]	NA
Alcohols	Ethanol	64-17-5
	Isobutanol	78-83-1
	Isopropanol	67-63-0
	Propanol	71-23-8
	Tetramethyldecyndiol	126-86-3
Alkyl acetates	Butyl acetate	123-86-4
	Ethyl acetate	141-78-6
	Propyl acetate	109-60-4
Amides or nitrogenous compounds	Amides, tallow, hydrogenated	61790-31-6
	Ammonia	7664-41-7
	Ammonium hydroxide	1336-21-6
	Erucamide	112-84-5
	Ethanolamine	141-43-5
	Hydroxylamine derivative	NA
	Urea	57-13-6
Aromatic esters	Dicyclohexyl phthalate	84-61-7
	Ethyl 4-dimethylaminobenzoate	10287-53-5
Aromatic ketones	2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone	119313-12-1
	1-Hydroxycyclohexyl phenyl ketone	947-19-3
	2-Hydroxy-2-methylpropiophenone	7473-98-5
	2-Isopropylthioxanthone	5495-84-1
	4-Isopropylthioxanthone	83846-86-0
	2-Methyl-4'-(methylthio)-2-morpholinopropiophenone	71868-10-5
	Thioxanthone derivative[c]	NA
Ethylene glycol ethers	Alcohols, C11-15-secondary, ethoxylated	68131-40-8
	Butyl carbitol	112-34-5
	Ethoxylated tetramethyldecyndiol	9014-85-1
	Ethyl carbitol	111-90-0
	Polyethylene glycol	25322-68-3

Category	Chemicals in category	CAS number
Hydrocarbons — high molecular weight	Distillates (petroleum), hydrotreated light Distillates (petroleum), solvent-refined light paraffinic Mineral oil Paraffin wax	64742-47-8 64741-89-5 8012-95-1 8002-74-2
Hydrocarbons — low molecular weight	n-Heptane Solvent naphtha (petroleum), light aliphatic Styrene	142-82-5 64742-89-8 100-42-5
Inorganics	Barium Kaolin Silica	7440-39-3 1332-58-7 7631-86-9
Olefin polymers	Polyethylene Polytetrafluoroethylene	9002-88-4 9002-84-0
Organic acids or salts	Citric acid Dioctyl sulfosuccinate, sodium salt Methylenedisalicylic acid	77-92-9 577-11-7 27496-82-8
Organophosphorus compounds	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 2-Ethylhexyl diphenyl phosphate Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	75980-60-8 1241-94-7 145052-34-2
Organotitanium compounds	Isopropoxyethoxytitanium bis(acetylacetonate) Titanium diisopropoxide bis(2,4-pentanedionate) Titanium isopropoxide	68586-02-7 17927-72-9 546-68-9
Pigments — inorganic	C.I. Pigment White 6 C.I. Pigment White 7	13463-67-7 1314-98-3
Pigments — organic	C.I. Pigment Blue 61 C.I. Pigment Red 23 C.I. Pigment Red 269 C.I. Pigment Violet 23 C.I. Pigment Yellow 14 C.I. Pigment Yellow 74	1324-76-1 6471-49-4 67990-05-0 6358-30-1 5468-75-7 6358-31-2
Pigments — organometallic	C.I. Basic Violet 1, molybdatephosphate C.I. Basic Violet 1, molybdate-tungstatephosphate C.I. Pigment Blue 15 C.I. Pigment Green 7 C.I. Pigment Red 48, barium salt (1:1) C.I. Pigment Red 48, calcium salt (1:1) C.I. Pigment Red 52, calcium salt (1:1) C.I. Pigment Violet 27 D&C Red No. 7	67989-22-4 1325-82-2 147-14-8 1328-53-6 7585-41-3 7023-61-2 17852-99-2 12237-62-6 5281-04-9
Polyol derivatives	Nitrocellulose Polyol derivative A[c]	9004-70-0 —[b]
Propylene glycol ethers	Dipropylene glycol methyl ether Propylene glycol methyl ether Propylene glycol propyl ether	34590-94-8 107-98-2 1569-01-3

Category	Chemicals in category	CAS number
Resins	Fatty acid, dimer-based polyamide[c]	NA
	Fatty acids, C18-unsatd., dimers, polymers with ethylenediamine, hexamethylenediamine, and propionic acid	67989-30-4
	Resin acids, hydrogenated, methyl esters	8050-15-5
	Resin, acrylic[c]	NA
	Resin, miscellaneous[c]	NA
	Rosin, fumarated, polymer with diethylene glycol and pentaerythritol	68152-50-1
	Rosin, fumarated, polymer with pentaerythritol, 2-propenoic acid, ethenylbenzene, and (1-methylethylenyl)benzene[c]	NA
	Rosin, polymerized	65997-05-9
Siloxanes	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-, hydrolysis products with silica	68909-20-6
	Silicone oil	63148-62-9
	Siloxanes and silicones, di-Me, 3-hydroxypropyl Me, ethers with polyethylene glycol acetate	70914-12-4

[a] No data or information available.

[b] Actual chemical name is confidential business information.

[c] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.

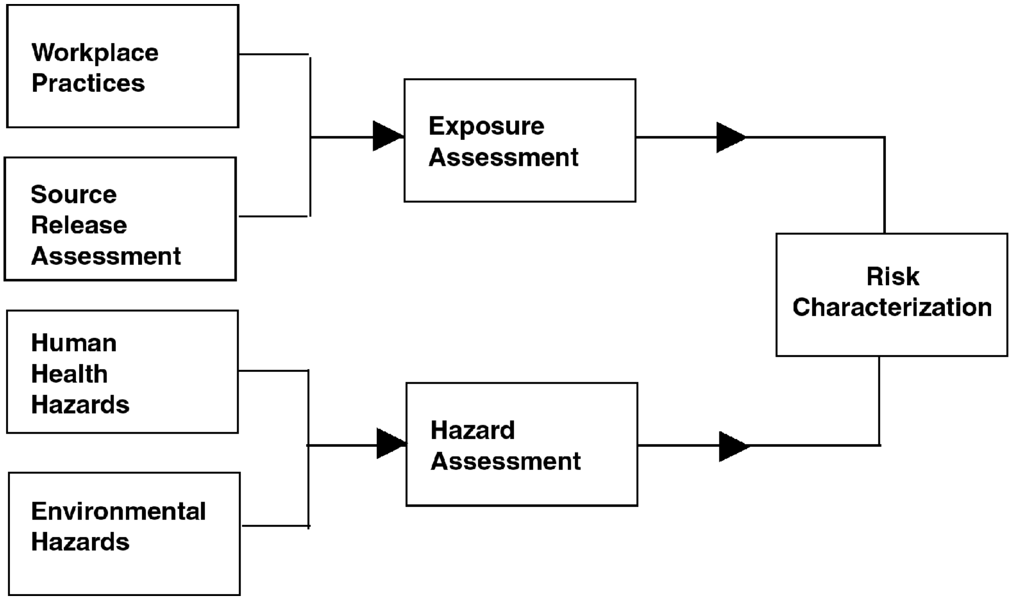
The CTSA Risk Assessment Methodology

A risk assessment has several phases: hazard identification, dose-response assessment, exposure assessment, and risk characterization. The CTSA risk assessment (Figure ES.3) focused on two areas of interest regarding the chemicals:

- possible health concerns to industry workers and the general population, and
- environmental concerns, including ambient air releases and aquatic toxicity.

For flexographic workers, exposures were analyzed for prep room workers and press workers, since both of these groups handle inks regularly in the course of their jobs. The assessment included exposure to VOCs and hazardous air pollutants (HAPs) through fugitive releases, which escape from the printing process into the ambient internal air and eventually exit the facility through windows and doors. Workers therefore can be exposed to fugitive emissions in the facility.

Figure ES.3 The Flexographic Inks CTSA Risk Assessment Process



Exposure was "modeled" — that is, it was not based on actual measurements of releases. A number of assumptions were made about a hypothetical "model facility" in developing the risk assessment. Most of the assumptions reflect typical operating conditions, and some facilitated identification of cleaner technologies or comparative analysis. Facilities with different operating characteristics would have different findings. Some of the assumptions include the following:

- 30% of volatile compounds released to air would be uncaptured emissions, and 70% would be stack emissions.
- Solvent-based ink systems would have a catalytic oxidizer with a 95% destruction efficiency.
- Press and prep-room workers would work a 7.5 hour shift, 250 days/year.
- Press and prep room workers would have routine two-hand contact (no gloves) with ink unless a substance was corrosive.
- Press speed would be 500 feet per minute.

In addition, the exposure estimates used for dermal contact were "bounding" estimates, which provide an upper and lower limit of exposure. The inhalation exposure estimates are considered "what-if" estimates because their probability of occurrence is not known.

The risk analysis used published studies of hazards and toxicity associated with each chemical, where available. When published studies were not available, EPA's Structure Activity Team (SAT) determined hazard levels based on analog data and/or structure activity considerations, in which characteristics of the chemicals were estimated in part based on similarities with chemicals that have been studied more thoroughly. Many chemicals in flexographic inks have not been studied thoroughly for environmental effects or health concerns. Chemicals in UV-cured inks, perhaps because they are newer, are much less likely than solvent- and water-based chemicals to have undergone in-depth testing.

Concerns posed by any ink system will vary depending upon many factors, such as the specific chemicals in the inks, how the inks are handled and used, the type of toxicity (systemic or developmental), and the exposure route (inhalation or dermal).

How the CTSA Defined Risk Levels

Each chemical substance evaluated was designated as having a "clear," "potential," or "low" concern for risk (Table ES.2). *Clear concern for risk* indicates that for the chemical in question, under the assumed exposure conditions of the Flexographic inks CTSA research, adverse effects were predicted to occur. *Potential concern for risk* indicates that for the chemical in question, under the assumed exposure conditions, adverse effects may occur. *Low or negligible concern for risk* indicates that for the chemical in question, under the assumed exposure conditions, no adverse effects were expected.

Table ES.2 Criteria for Risk Levels

Level of Concern for Risk	Hazard Quotient [a]	Margin of Exposure [b]		SAT Hazard Rating [c]
		NOAEL	LOAEL	
Clear	> 10	1 to 10	1 to 100	moderate or high
Potential	1 to 10	> 10 to 100	> 100 to 1,000	low-moderate
Low or negligible	< 1	> 100	> 1,000	low

[a] Hazard Quotient (HQ) is the ratio of the average daily dose (ADD) to the Reference Dose (RfD) or Reference Concentration (RfC), where RfD and RfC are defined as the lowest daily human exposure that is likely to be without appreciable risk of non-cancer toxic effects during a lifetime. The more the HQ exceeds 1, the greater the level of concern. HQ values below 1 imply that adverse effects are not likely to occur.

[B] NOAEL = No Observed Adverse Effect Level. LOAEL = Lowest Observed Adverse Effect Level. A Margin of Exposure (MOE) is calculated when a RfD or RfC is not available. It is the ratio of the NOAEL or LOAEL of a chemical to the estimated human dose or exposure level. The NOAEL is the level at which no significant adverse effects are observed. The LOAEL is the lowest concentration at which adverse effects are observed. The MOE indicates the magnitude by which the NOAEL or LOAEL exceeds the estimated human dose or exposure level. High MOE values (e.g., greater than 100 for a NOAEL-based MOE or greater than 1,000 for a LOAEL-based MOE) imply a low level of risk. As the MOE decreases, the level of risk increases.

[C] This column presents the level of risk concern if exposure is expected. If exposure is not expected, the level of risk concern is assumed to be low or negligible. SAT-based systemic toxicity concerns were ranked according to the following criteria: high concern — evidence of adverse effects in humans, or conclusive evidence of severe effects in animal studies; moderate concern — suggestive evidence of toxic effects in animals; or close structural, functional, and/or mechanistic analogy to chemicals with known toxicity; low concern — chemicals not meeting the above criteria.

Human Health Findings

The toxicity information was combined with estimated releases and exposures to develop a risk characterization of individual chemical substances. Each chemical substance was analyzed for systemic and developmental toxicity. *Systemic toxicity* means adverse effects on any organ system following absorption and distribution of a chemical throughout the body. *Developmental toxicity* refers to adverse effects on a developing organism that may result from as little as a single exposure prior to conception, during prenatal development, or postnatally up to the time of sexual maturation. The major manifestations of developmental toxicity are death, structural abnormality, altered growth, or functional deficiency. Although some inks in the CTSA also contained known or possible human carcinogens, there was not enough quantitative information to analyze specific cancer risk concerns.

Worker Health Risks

The study assessed possible risks via both the inhalation and dermal (skin) pathways. Each ink system contained chemicals that showed clear health risk concerns for workers who handle inks in the prep room or pressroom, under the assumptions used for the study.

Of the roughly 100 chemicals studied, 24 were found to pose *clear* worker health risk concerns (Tables ES.3 and ES.4).[***]

- Alcohols, amides and nitrogenous compounds, and acrylated polyols contained the most chemicals found to pose clear worker risk concerns.
- For pressroom workers, exposure was highest with solvent-based inks because of the higher air release rate.
- In the three *solvent-based* ink product lines studied, most of the chemicals presenting a clear occupational risk concern were solvents. Pressroom workers can be exposed to uncaptured (i.e., fugitive) emissions in the facility, while stack emissions from using solvent-based inks are destroyed by oxidizers. The use of oxidizers thus only impacts stack emissions and does not reduce occupational health hazards and risk concerns.
- In *water-based* formulations, amides or nitrogenous compounds often presented systemic risk concerns.
- The use of press-side solvents and additives increased the occupational risk concern for many of the solvent- and water-based ink formulations. In particular, alcohols and propylene glycol ethers in solvent-based inks, and amides and nitrogenous compounds, alcohols, and ethylene glycol ethers in water-based inks presented clear or potential occupational risk concerns in certain formulations.
- For *UV-cured* inks, some acrylated polyols and amides or nitrogenous compounds showed clear inhalation risk concerns for workers. It is important to understand, however, that the CTSA studied *uncured* UV inks only, due to resource limitations. The concerns associated with *cured* UV inks are not known, but anecdotal information from industry suggests that curing may greatly reduce such concerns.

[***] To protect manufacturers' proprietary information, when discussing formulations the risk results group the specific chemicals into categories rather than presenting results for individual chemicals.

Table ES.3 Clear INHALATION Risk Concerns for Flexographic Workers

Ink System	Chemical Categories with Chemicals of Clear Risk Concern	Systemic Risk Concern	Developmental Risk Concern
Solvent-based	Alcohols	X	X
	Alkyl acetates	X	
	Hydrocarbons (low molecular weight)	X	
	Propylene glycol ethers	X	
Water-based	Alcohols	X	
	Amides or nitrogenous compounds	X	X
	Ethylene glycol ethers	X	
UV-cured	Acrylated polyols	X	X
	Amides or nitrogenous compounds	X	X

Table ES.4 Clear DERMAL Risk Concerns for Flexographic Workers

Ink System	Chemical Categories with Chemicals of Clear Risk Concern	Systemic Risk Concern	Developmental Risk Concern
Solvent-based	Alcohols	X	X
	Alkyl acetates	X	
	Inorganics	X	X
	Organometallic pigments		X
	Organotitanium compounds		X
	Organic acids or salts		X
	Propylene glycol ethers	X	
Water-based	Alcohols	X	X
	Amides or nitrogenous compounds	X	X
	Ethylene glycol ethers	X	
	Organic pigments	X	
	Organometallic pigments	X	
UV-cured	Acrylated polyols	X	X
	Acrylated polymers	X	X
	Amides or nitrogenous compounds	X	X
	Inorganic pigments		X
	Organometallic pigments	X	
	Organophosphorus compounds	X	

Table ES.5 lists the potential effects on organ systems (e.g., cardiac, respiratory, reproductive) from dermal and inhalation exposure to chemicals and chemical categories of clear worker health risk concern. "Toxicological endpoints" are the *potential* effects on organ systems that have been reported in the medical literature and other scientific reports in association with use of a chemical. This does not mean, however, that any of these effects are necessarily *caused by* that chemical. Only the chemicals listed for a specific category were associated with clear worker risk concerns. Thus, for example, CI Pigment Red 23 was the only organic pigment that showed clear worker health risk concerns. A number of the ink chemical categories that were examined in the study (e.g., resins, olefin polymers, siloxanes) did not show clear risk concerns and thus are not included in this table.

Table ES.5 Toxicological Endpoints of CTSA Chemicals with CLEAR Worker Health Risk Concerns

Chemical Category	**Chemical**	**Potential Effects on Organ Systems (via oral and dermal paths)** [d]
Acrylated polymers	Glycerol propoxylate triacrylate	tissue necrosis at application site, decreased body weight, neurotoxic and respiratory effects
Acrylated polyols	Dipropylene glycol diacrylate (SAT)[a]	genotoxicity, neurotoxicity, oncogenicity, developmental and reproductive effects, dermal and respiratory sensitization, and skin and eye irritation
	1,6-Hexanediol diacrylate	developmental effects
	Hydroxypropyl acrylate	respiratory effects
	Trimethylolpropane triacrylate	decreased body weight, skin and neurotoxic effects, changes in clinical chemistry, altered organ weights, respiratory effects
Alcohols	Ethanol	blood, liver, neurotoxic, and reproductive effects, decreased cellularity of the spleen, thymus, and bone marrow; dev: fetal malformations
	Isobutanol	blood and neurotoxic effects, changes in enzyme levels; dev: cardiac septal defects
	Isopropanol	blood and skin effects, tissue necrosis at application site, increased kidney and liver weight; liver, neurotoxic, reproductive, respiratory, and spleen effects, changes in enzyme levels and clinical and urine chemistry; dev: fetal death, musculoskeletal abnormalities, fetotoxicity
Alkyl acetates	Butyl acetate	changes in serum chemistry, fluctuations in blood pressure; dev: fetotoxicity, musculoskeletal abnormalities
	Ethyl acetate	blood, cardiovascular, gastrointestinal, kidney, liver, neurotoxic, and respiratory effects, decreased spleen and liver weight, increased adrenal, lung, and kidney weight
Amides or nitrogenous compounds	Ammonia	corneal, liver, respiratory, and spleen effects
	Ammonium hydroxide	eye effects, nasal irritation, respiratory effects
	Ethanolamine	respiratory irritation; kidney, liver, neurotoxic, and respiratory effects
	Hydroxylamine derivative (SAT) [a]	genotoxicity, dermal sensitization, developmental toxicity

Chemical Category	**Chemical**	**Potential Effects on Organ Systems (via oral and dermal paths)** [d]
Ethylene glycol ethers	Butyl carbitol	blood and skin effect, liver effects
	Alcohols, C11-C15-secondary, ethoxylated (SAT)[a]	skin irritant; eye irritation and lung effects
	Ethyl carbitol	no data
Hydrocarbons — low molecular weight	n-Heptane	auditory and neurotoxic effects, altered serum chemistry
Inorganics	Barium	decreased body weight, reproductive and respiratory effects, increased arterial blood pressure; dev: decreased survival and weight gain, changes in hematology parameters
Organic acids or salts	Dioctyl sulfosuccinate, sodium salt	no data
Organo-phosphorous compounds	Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	no data
Organotitanium compounds	Isopropoxyethoxytitanium bis(acetylacetonate) (SAT)[a]	neurotoxicity, genotoxicity, oncotoxicity, and developmental/ reproductive toxicity; skin, eye, mucous membrane irritant
	Titanium diisopropoxide bis(2,4-pentanedionate)	SAT: irritation of the eyes, skin, and mucous membranes. Moderate concern based on release of hydrolysis products: 2,4 pentanedione, inorganic titanium, and isopropanol. 2,4 pentanedione: concern for neurotoxicity, mutagenicity, oncogenicity, and developmental/reproductive toxicity. Inorganic titanium: concern for mutagenicity and oncogenicity. Isopropanol: concern for liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzyme levels and clinical and urine chemistry; fetal death, musculoskeletal abnormalities, fetotoxicity, blood and skin effects, tissue necrosis at application site, increased kidney and liver weight
	Titanium isopropoxide	SAT: irritation of the eyes, skin, and mucous membranes. Moderate concern based on release of the hydrolysis products, inorganic titanium and isopropanol. Inorganic titanium: concern for mutagenicity and oncogenicity. Isopropanol: concern for liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzyme levels and clinical and urine chemistry; fetal death, musculoskeletal abnormalities, fetotoxicity, blood and skin effects, tissue necrosis at application site, increased kidney and liver weight.
Pigments — organic	CI Pigment Red 23	no data
Pigments — organometallic	D&C Red No. 7	no data

Chemical Category	**Chemical**	**Potential Effects on Organ Systems (via oral and dermal paths) [d]**
Propylene glycol ethers	Propylene glycol methyl ether	increased mortality; blood, neurotoxic, and skin effects; altered kidney weights; decreased growth, liver, neurotoxic, reproductive, and respiratory effects, increased liver and kidney weights; dev: delayed ossification of vertebrae, musculoskeletal abnormalities

These chemical categories posed risk concerns under the specific conditions of this study; they might be associated with different risks, or with no risk at all, under different conditions.
Dev = developmental effects. All endpoints not specifically indicated as developmental are systemic.

[a] SAT: Structure Activity Team and acute data reports.

[d] Developmental risks for SAT-evaluated chemicals were evaluated on a “concern/no concern” basis.

Many of the chemical substances that show hazard or risk concern are commonly used in flexographic inks, although they are not necessarily found in every ink formulation. To protect workers from such concerns, printing firms can take several steps:

- Review ink formulations against CTSA data, MSDS information, Table 8.13 of the Flexographic Inks CTSA, and other sources to identify chemicals that may present concerns under certain conditions of use.
- Establish effective policies that require workers to wear proper gloves and other personal protective gear when working with inks. If workers wear appropriate protections, the dermal concern is essentially zero.
- Ensure appropriate ventilation to minimize inhalation exposure.
- Adopt pollution prevention practices to minimize use and disposal of chemicals of concern (e.g., management of chemical inventory).

General Population Risks

For the general population (people who live near a printing facility), the study assessed possible inhalation risks. No chemical categories showed a clear risk concern to the general population. However, alcohols in solvent- and water-based inks, and acrylated polyols in UV-cured inks, included one or more chemicals that showed a *potential* risk concern for the general population. Exposures and risk concerns for the general population due to emissions from water-based and UV-cured inks were calculated to be significantly lower than those of solvent-based inks. This is because solvent-based inks showed higher *fugitive* emissions (e.g., chemicals released from a long web run between presses), which outweighed the decrease in stack emissions resulting from the use of oxidizers.

Environmental Findings

Ambient Air Releases

Releases to air result from the evaporation of chemicals during the flexographic printing process. Releases to air are used to estimate inhalation exposure to particular chemicals for workers and the general population. The CTSA examined two forms of air releases. Stack emissions are collected from the press and are released through a roof vent or stack to the outside air, sometimes undergoing treatment to reduce the emissions. Fugitive emissions escape from the printing process (e.g., from a long web run between presses), and exit the facility through windows and doors. It was assumed that 30% of the VOCs released to the air were fugitive emissions, and 70% were captured by the press system and released through a stack. It was also assumed that solvent-based ink releases would pass through a catalytic oxidizer with a destruction efficiency of 95%, but that water-based or UV-cured ink systems would not utilize an oxidizer. Environmental releases relate to the rates of vapor generation, which vary depending on press speed, VOC content of the ink mixture, equipment operating time, temperature of the ambient air and ink system, the capture efficiency of the press system, and the destruction efficiency of the air control devices.

The calculated volatilization rates of the solvent-based inks were considerably higher than those for the other two ink systems. The volatilization rates for water-based inks were considerably lower than those for solvent-based inks, but the stack releases were higher because the use of an oxidizer was not anticipated. On the other hand, the fugitive emissions of the water-based inks were considerably lower than those for solvent-based inks because of the lower average VOC content of water-based inks.

The UV-cured inks showed releases comparable to those of water-based inks and higher than those of solvent-based inks. These figures were calculated with the assumption that all VOCs would be released to the air. In reality, however, much of the volatile content would be incorporated into the coating during the UV curing process. The decrease in emissions under real-world conditions is unknown.

Adding solvents, reducers, extenders, cross-linkers, and other compounds to the inks increased their volatile content, resulting in greater environmental releases. During the CTSA performance demonstrations, solvents were added in higher quantities to solvent-based ink formulations than to water-based and UV-cured formulations, which further increased the releases from solvent-based inks.

Press speed greatly affected the amount of ink consumed, and thus the releases of volatile compounds. Air releases also varied among colors within each ink system; the differences were primarily due to different ink consumption rates, which will vary with every printing job.

Aquatic Toxicity
Roughly half of the ink chemicals showed a medium or high aquatic toxicity (capable of causing long-term effects to aquatic organisms, in a concentration of less than 0.1 mg/liter). Eighteen chemicals (Table ES.6) were found to have high aquatic toxicity. Another 35 chemicals showed medium aquatic toxicity. Because the inks were not expected to be released to the aquatic environment, water releases and subsequently related risks were not assessed. If any of these inks are in fact released untreated to water, however, there could be aquatic risk concern.

Table ES.6 CTSA Chemicals With High Aquatic Toxicity

Amides, tallow, hydrogenated	n-Heptane
Ammonia	2-Isopropylthioxanthone
C.I. Basic Violet 1 molybdatephosphate	4-Isopropylthioxanthone
C.I. Basic Violet 1 molybdatetungstatephosphate	Mineral oil
C.I. Pigment Violet 27	Resin acids, hydrogenated, methyl esters
Dicyclohexyl phthalate	Styrene
Distillates, petroleum, hydrotreated light	Thioxanthone derivative
2-Ethylhexyl diphenyl phosphate	Trimethylolpropane ethoxylate triacrylate
Glycerol propoxylate triacrylate	

PERFORMANCE

Because quality of printing is a critical need of flexographers, the CTSA conducted 18 performance tests, which examined quality aspects anticipated to be important for a broad range of flexographic printers. (See Chapter 4 for details.)

Eleven *performance demonstrations* were conducted at printing facilities that volunteered to participate, using inks donated by ink companies. The inks used were considered fairly representative of ink types commonly in use at that time. Five ink colors (cyan, magenta, blue, green, and white) were included, to allow testing of both process and line printing results. The performance demonstrations were brief printing runs of a representative test image (Figure ES.4), which was printed using wide-web presses onto three types of film substrates: oriented polypropylene (OPP); low-density polyethylene (LDPE); and polyethylene/ethyl vinyl acetate co-extruded film (PE/EVA). These substrates were chosen because they correspond to important flexographic market segments. To collect baseline data, *laboratory runs* were also conducted in the printing laboratory of Western Michigan University. This was done to give printers a better sense of the actual capabilities of the ink-substrate combinations.

Figure ES.4 Test Image Used in Demonstration Runs

This is a test image f he Design for the Environment (DfE) Flexography Pro   t Performance Demonstration

The DfE Flexography Project is a voluntary effort in which EPA and industry partners work together to identify non-regulatory ways to help flexographers improve their environmental performance. This image was developed for the Project's performance demonstration of solvent, water-based, and UV cured ink technologies. The project will also evaluate the costs and the environmental and health issues ass   ted with using these ink technologies.

Performance tests were conducted on the samples from both the performance demonstrations and the laboratory runs (Table ES.7).

Table ES.7 Performance Tests Conducted in CTSA

Adhesive lamination	Ice water crinkle adhesion
Block resistance	Image analysis
CIE L*a*b*	Jar odor
Coating weight	Mottle/lay
Coefficient of friction (COF)	Opacity
Density	Rub resistance
Dimensional stability	Tape adhesiveness
Gloss	Trap
Heat resistance/heat seal	Uncured residue (UV-cured inks only)

Performance Findings

The quality of performance varied widely across ink systems, substrates, and ink formulations. No clear evidence emerged that any one ink system performed best overall. For example,

- Water-based inks outperformed solvent-based inks on both LDPE and PE/EVA substrates. Solvent-based inks performed better than water-based inks on the adhesive lamination test.
- Gloss was highest for solvent-based inks on PE/EVA. Gloss was low on UV-cured inks, despite the fact that high gloss is considered to be a strength of UV finishes.
- Odors varied in both strength and type across both ink and substrate type.
- Mottle was significantly higher for water-based inks, as well as for blue inks overall.
- UV-cured inks displayed good resistance to blocking, particularly on PE/EVA and no-slip LDPE.
- UV-cured inks displayed relatively good trapping.
- Mottle results for UV-cured inks were better than that of the water-based inks and comparable to that of the solvent-based inks.
- Coating weight was greater for UV-cured inks, despite lower ink consumption.
- Some UV-cured inks showed unimpressive results on the rub resistance and tape adhesiveness tests.

The variances in results show the importance of a number of factors in the performance of these inks:

- Substrate type
- Type and amount of vehicle (e.g., solvent in solvent-based ink and water in water-based ink), as well as press-side solvents and additives
- Functional ink-substrate interactions such as wetting and adhesion

Table ES.8 lists the ink system, color, and substrate combinations showing “best in class” performance for selected tests that were run. Most of these tests do not have industry standards, and for some tests the determination of a better or worse result can depend on the needs of a specific printing situation. (The “worst” score is also provided, but only to give an indication of the large range in scores on almost all tests.) Due to a variety of issues that occurred at volunteer facilities, not all ink systems received all tests.

Table ES.8 Selected "Best in Class" Performances on Flexography CTSA Tests

Test	Best Score	Ink System	Substrate	Color	Worst Scoreb[a]
Adhesive lamination	.3040 kg (highest)	solvent[b]	OPP	N/A[c]	.2575 kg (lowest)
Block resistance	1.0 (lowest)	UV no slip	LDPE	N/A	3.2 (highest)
Density	2.17 (highest)	UV high slip	LDPE	blue	1.09 (lowest)
Gloss	59.08 (highest)	solvent	PE/EVA	N/A	32.31 (lowest)
Heat resistance	0 failures (lowest)	solvent[b]	OPP	N/A	24 failures (most)
Ice water crinkle	no ink removal (least)	solvent, water	LDPE, PE/EVA	N/A	30% ink removal (most)
Image analysis	324 μm^2 dot area (lowest)	solvent	PE/EVA	cyan	1050 μm^2 (highest)
Mottle	47 (lowest)	UV no slip	LDPE	green	812 (highest)
Rub resistance, wet	0 failures at 10 strokes	water, solvent	LDPE (PE/EVA)	N/A	failure at 2.2 strokes

[a] This score represents the opposite end of the range of all scores received on this test for all ink systems tested.

[b] UV-cured samples were not tested.

[c] N/A indicates that the test results were not color-specific.

These performance demonstrations were completed in 1997, since which time flexographic printing technology for UV-cured inks has made significant advances. The test results of this CTSA provide a snapshot of UV technology early in its technical development but do not necessarily lead to any conclusions about current or potential abilities of UV inks. In fact, just as for solvent-based and water-based inks, no one test can provide a reliable or accurate indicator of overall quality for any printer. Printers need to consider a variety of different factors in determining acceptable quality. These factors — among them cost, health and environmental risks, energy use, and pollution prevention opportunities — are discussed in other chapters of this CTSA.

In addition, because performance is a function of many factors — including equipment, ink, substrate, and operator experience — a printing facility that conducts its own performance tests might obtain different results than the CTSA. This potential for variability is demonstrated by the performance results, which differed widely among formulations within the same ink system. The performance variability indicates that there may not be one best overall choice of an ink system for all performance conditions and applications. A flexographic printer cannot simply assume that one ink system or ink-substrate combination will be best-suited to the firm's overall needs. Careful testing of a potential ink system on the various substrates that a printer will be using most often is critical to obtaining desired quality on a consistent basis.

UV curing technology, especially as it pertains to wide-web printing on film substrates, was in a developmental stage at the time these tests were conducted. The test results in this CTSA provide a snapshot of UV technology early in its technical development but do not necessarily lead to any conclusions about current or potential abilities of UV-cured inks. Since that time, improvements to this ink system have been made on several fronts. In addition, manufacturers of both solvent-based and water-based inks have made improvements in formulations since the performance demonstrations were completed. In particular, changes that have been made to resins and slip additives of inks may yield improved adhesive characteristics and other traits.

COSTS

A number of costs are important to facility profitability and have the potential to highlight differences among ink systems. The study evaluated the costs of materials (ink and press-side additions), labor, capital, and energy. Substrate costs were not evaluated because they are not dependent upon ink use. Input quantities for materials were obtained during the performance demonstrations. Suppliers provided information about costs.

This analysis averages industry information, and therefore it may not reflect the actual experience of any given printing facility in this short-term demonstration. For example, the efficiencies of a long run with familiar products were not achieved. Also, press speed under many printing conditions is expected to be different (and in general, higher) than in this analysis. While this study focused on those costs that typically account for the majority of total costs, other important costs (e.g., waste disposal, regulatory compliance, insurance, storage, clean-up, and permitting) should not be overlooked. In addition, press maintenance and other conditions may affect ink usage, and therefore ink costs.

Cost Findings

Highlights of the cost analysis include the following:

- Materials were the highest cost category for the CTSA printers among the categories studied. Water-based inks had the lowest material costs of the three systems, showing a higher mileage than solvent-based inks and a much lower per-pound cost than UV-cured inks.
- The analysis did not consider start-up and clean-up labor, and the press speed was assumed to be the same for all three ink systems. (Labor costs would have differed by ink system if the analysis had captured the costs of preparation, cleanup, etc.) Therefore, *labor cost* (wages and benefits for two press operators) was identical in the study for all three systems.
- *Energy cost* (electricity and natural gas) was highest for UV-cured inks. The water-based system showed the lowest energy cost because it assumed no energy use by oxidizers. If oxidizers were to be used, much of the water-based system's cost advantage would disappear.
- Water-based inks had the lowest *capital costs* (press and other required components), because the water-based printers did not use oxidizers. Solvent-based inks showed higher capital costs because of the expense of oxidizers. Because UV uses lamps to cure inks, this system also had higher capital costs. However, the capital costs of a new press for all three technologies were relatively similar. Therefore, they are likely to be only a small factor in the selection of an ink system.
- Assuming a press speed of 500 feet per minute, the CTSA found that the *total cost* was lowest for the water-based system, with the solvent-based and UV-cured systems costing on average 24% and 38% more respectively (Table ES.9).

Table ES.9 Cost Averages (per 6,000 square feet, at 500 feet per minute)

Ink system	Materials (Ink & Additions)	Labor	Energ y	Capital	Total
Solvent-based	$15.29	$5.29	$0.53	$11.87	$32.98
Water-based	$9.55	$5.29	$0.35	$11.41	$26.60
UV-cured	$18.63	$5.29	$1.03	$11.87	$36.82

Generally speaking, press speed appears to be the most important driver of a printer's total cost, because all costs except that of ink and substrate were impacted by press speed. Thus, press speed is a critical variable in maximizing profitability of flexographic printing, Therefore, if a facility can run one ink system (or one formulation) notably faster than another while meeting product quality standards, the faster system or formulation will probably also be the most cost-effective system.

RESOURCE USE AND ENERGY CONSERVATION

By minimizing resource and energy use, printers can improve both their bottom line and the environment. To identify potential issues on which printers may wish to focus their efforts, the study investigated several sources of resource consumption (Table ES.10) and pollutant generation related to the three ink systems studied:

- resources consumed,
- energy used,
- energy-related emissions generated by each ink system, and
- possible environmental impacts of energy-related impacts.

Table ES.10 Categories of Consumption Studied

Category of Consumption	Specific elements Included	Comments
Printing-related resources	Inks, solvents, and press-side additives	The *ink consumption* figures were calculated during the performance demonstrations, and were affected by several site-specific factors, such as type of cleaning equipment, anilox roll size, and the level of surface tension of the substrate.
Energy consumed by the printing of each ink-substrate combination	Natural gas and electricity to run presses presses and ancillary press equipment (oxidizers, hot air dryers, drying ovens, corona treaters, UV-curing lamps and coolers)	Equipment vendors estimated energy requirements in kilowatts for electricity and in Btus/hr for natural gas. These estimates were used instead of actual site-specific data to calculate energy consumption for the study.

The energy-related emissions from printing each ink-substrate combination include carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, particulate matter, dissolved solids, solid wastes, sulfur oxides, and sulfuric acid. With natural gas, the emissions are generated at the printing facility, but with electricity, the emissions are generated off-site at the power plant. Either way, the printing facility needs to know environmental impacts that can be attributed to the printing processes used. This allows a facility to plan ways to reduce energy use and the related environmental releases that are generated by different types of energy. Employing more energy-efficient technologies may benefit printers by reducing production costs, lowering energy-related emissions, and improving the facility's public image.

Resources Used and Emissions Generated

The study examined various specific inputs to the printing processes, including the press units, oxidizers, hot air dryers, drying ovens, corona treaters, UV-curing lamps, and coolers. When all of these were taken into consideration,

- The energy consumed was estimated to be lowest for the water-based system because no oxidizers or curing lamps were used. The solvent-based system, which used oxidizers to destroy stack emissions, consumed the most energy.
- The estimated emissions were lowest for the water-based system, because much of its energy derives from natural gas, which releases less emissions per unit of energy than does electricity. Although the UV-cured system consumed little more energy than the water-based system, it was estimated to result in the highest total energy-related emissions, because all of its energy comes from electricity.

Table ES.12 lists the amounts of resources consumed by each ink system, as well as the amounts of environmental releases of pollutants associated with energy production. Results are reported in terms of grams per 6000 square feet of substrate, which allows a direct comparison of pollutants generated by the different ink systems.

Table ES.11 Average Resource Use and Energy-Related Emissions (at 500 fpm)

Ink System	Resources Consumed [a] (lb/6,000 ft^2)	Energy Consumed per 6,000 ft^2 (Btu) [b, c]	Energy-Related Emissions Generated (g/6000 ft^2)[d]
Solvent-based	8.53	100,000	10,000
Water-based	4.14	73,000	6,800
UV-cured	2.16	78,000	18,000

[a] Ink consumption figures were averaged from the total costs of ink, solvents, and additives for all three substrates in Table 6.4; energy consumption figures are from Table 6.11; and energy-related emissions are from Table 6.21.

[b] Electrical energy was converted to Btus using the factor of 3,413 Btu per kW-hr.

[C] Electricity was generated offsite.

[d] Energy-related emissions were calculated using a computer model rather than by capturing and analyzing actual emissions from the facilities.

Pollutants that were released during energy production of the CTSA printing runs include carbon dioxide, carbon monoxide, dissolved solids, hydrocarbons, nitrogen oxides, particulate matter, solid wastes, sulfur oxides, and sulfuric acid. Again, because UV curing relies exclusively upon electricity, this ink system was shown to generate more of the pollutants that are associated with this form of energy (such as nitrogen oxides, carbon dioxide, and sulfur oxides), some of which affect environmental air quality and are important to global climate change. Energy use was analyzed using the methodology press speed (500 feet per minute) and actual press speed. The amount of pollutants generated was associated with press speed, and higher press speed produced fewer grams of pollutants for the same number of feet of substrate.

Overall, the water-based ink system generated the fewest grams of pollutants per 6000 feet of substrate printed, and the UV-cured ink system generated the most. Most of these pollutants fall into a category called "use impairment impacts," which includes global warming compounds, acid rain precursors, smog formers, corrosives, dissolved solids, odorants, and particulates.

CHOOSING AMONG FLEXOGRAPHIC INKS

This section summarizes important findings of the Flexographic Inks CTSA by ink system, and identifies ways to use the CTSA to incorporate health and environmental impacts of flexographic ink chemicals in business decision-making.

Choosing an ink system, an ink product line (e.g., solvent-based ink #1), or a specific ink formulation (e.g., color within a product line, such as solvent-based ink #1 white) is not a simple task. The study found substantial variation within each ink system in health and environmental impacts, performance, cost, and resource use. Each aspect of ink use has implications — important environmental health and safety implications as well as performance, cost, and energy use . Every product line analyzed in the CTSA included chemicals that are associated with multiple clear health risk concerns for flexographic press workers (Table 8.3). Each ink system also was found to have safety hazards for the workplace (flammability, ignitability, reactivity, or corrosivity concerns). All of the formulations released VOCs and sometimes HAPs as well (Table 8.4).

Highlights of CTSA Findings

Solvent-based Inks

- The solvent-based ink system, on average, had total operating costs that were lower than those of UV-cured inks but higher than those of water-based inks. This higher cost can be attributed mostly to higher material and capital costs of solvent-based technologies. In particular, average material costs for solvent-based systems (per 6,000 square feet of image) were approximately $5.00 higher than those for water-based systems.
- The solvent-based system on average outperformed both water-based and UV-cured systems. This system was the best with respect to gloss and trap and among the best on the other three summary performance tests.
- On average, solvent-based inks contained two to four chemicals with a clear concern for occupational risk, slightly higher than the ranges for water-based and UV-cured inks. This may indicate a higher occupational risk.
- Public health risk was evaluated through releases of smog-related compounds, VOC and HAP content, and the systemic and developmental risks to the general population. Despite the fact that this system used oxidizers, emissions were calculated to be considerably higher than the emissions of the other systems. VOC content was, as expected, much higher than either of the two other systems. This system did not contain any HAPs. For general population risks, two chemical categories in one solvent based ink (ink #2) contained chemicals that presented a potential concern for risk.
- In terms of process safety, solvent-based inks had more concerns than the other systems, although the results for UV-cured inks were incomplete. Only solvent-based inks presented an ignitability concern; they also presented a higher flammability concern than water-based inks.
- Solvent-based inks were shown to use more energy to produce the same square footage of image.

Water-based Inks

- Operating costs were lowest for the water-based ink product lines. In fact, in all cost categories, water-based ink systems had the lowest average cost. Cost savings were particularly pronounced for material costs.
- Though water-based ink formulations #2 and #4 had the best mottle scores of all product lines, overall the water-based inks did not perform as well as the solvent-based inks in the five summary performance categories. The system also was outperformed by the UV-cured inks in three categories. While this may indicate a lower quality product, it is important to note that in many cases the differences were small and may be insignificant.
- In the occupational health area, water-based inks presented a lower average number of chemicals with a clear concern for risk per product line, indicating a better chance of reducing occupational health risks compared to solvent-based inks.
- The amount of smog-related emissions that resulted from ink releases and energy production with the water-based system was considerably lower than that from solvent-based system, and was comparable to that from the UV-cured system. Water-based inks had a much lower VOC content than solvent-based inks, but were

the only inks that contained HAPs.

- Like with solvent-based inks, printers often add VOC solvents and additives at press side to water-based inks. In substantial amounts, these materials compromise the low-VOC content of the ink and can pose clear pressroom worker risks. At one site using water-based inks (Site 3), over half of the emissions resulted from materials added at press-side.
- The safety of water-based inks was better than that of solvent-based inks. There was no indication of ignitability or reactivity. However, water-based inks had a higher flammability risk than UV-cured inks.
- As for energy expenditures, water-based inks had the lowest average energy use.

UV-cured Inks

- The UV-cured inks had the highest average operating costs. However, since it is a new developing technology for wide-web film, these costs are likely to fall as the technology develops. The biggest cost differential was the material costs, falling approximately \$8.00 per 6,000 ft^2 of image above the average costs for water-based inks. It is also worth noting that energy costs of the UV systems were considerably higher — nearly two times the cost for solvent-based inks and nearly three times the cost for water-based inks.
- The performance of the UV-cured inks was generally worse than that of solvent-based inks, though this system had better blocking resistance, and individual product lines had ice water crinkle and mottle results that were equal to the solvent-based results. The performance results were slightly better than those of the water-based inks.
- The UV-cured inks presented the lowest chance of occupational health risk, and with respect to public health, had the lowest HAP and VOC contents. A couple of SAT-analyzed compounds present a potential concern for general population risk, however, indicating that research on some compounds is needed.
- Safety hazard data were incomplete for UV inks. However, UV inks were the only inks that present the potential for reactivity.
- Finally, the energy used by UV-cured systems was approximately 22% less than that of solvent-based inks, and was only slightly higher than that of the water-based inks. The air releases associated with the energy production were higher than solvent-based inks, however, because all energy required by the UV system was derived from electricity — a more pollution-intensive energy source in comparison to natural gas.

Choosing Cleaner, Safer Ink Chemicals

Because of the importance of the specific formulation to the results of the flexographic ink study, printers are advised to pay as much attention to selecting the "cleanest" formulation within an ink system as to the ink system itself.

Table 3-1 provides toxicity and risk screening information on the chemical substances that were included in this study. Many of the substances were found in multiple ink formulations and are likely to be found in other inks. Whether choosing amongst the ink systems or choosing an ink formulation, it is important to consider the health, safety, and environmental impacts of the chemical substances that make up a formulated product. The DfE Flexographic Inks CTSA can serve as a first step in bringing a more positive environmental profile into the printing shop. The DfE Program encourages printers and the ink manufacturer and distributors to actively engage in a dialog on “getting the right mix” in the print shop.

Table 8.13 summarizes hazard and risk information for every chemical category and chemical in the study. Flexographic professionals can use this table to compare chemicals within and across chemical categories, which can help to identify possible alternatives for a chemical that shows concerns. As an example, Table ES.12 below shows a partial entry for ethylene glycol ethers from Table 8.13. The Hazard columns indicate that ethylene glycol ethers have moderate (M) and moderate-high (M-H) hazards, and the Occupational Risk column shows several instances of clear risk concern for this chemical category under the conditions of use analyzed in this study.

Table ES.12 Summary of Hazard and Risk Data by Chemical Category (Excerpt)

Ink System	Chemicals	Data Source	Hazard			Occupational Risk[c]	
			Aquatic	Dermal[a]	Inhalation[ab]	Dermal	Inhalation
Ethylene glycol ethers							
Water	Alcohols, C11-15-secondary, ethoxylated 68131-40-8	SAT	M	M/M	M/M	clear	n.e.
	Butyl carbitol 112-34-5	Tox	L	L/L	M/L	clear	clear
	Ethoxylated tetramethyldecyndiol 9014-85-1	SAT	L	L-M/NA	L-M/NA	potential	n.e.
	Ethyl carbitol 111-90-0	Tox	L	M-H/L	M-H/L	clear	clear
	Polyethylene glycol 25322-68-3	Tox	L	L/NA	L/NA	potential	n.e.

[a] The first letter(s) represents systemic concern, the second represents developmental concerns. L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure

[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).

[c] Dermal occupational risk concern ratings are applicable for press and prep room workers; inhalation risk concern ratings are applicable for press room workers. The risk concern levels shown here represent the highest observed risk rating.

Other Suggestions for Reducing Impacts of Flexographic Inks

DfE partners, particularly the Steering Committee, include the major trade associations in the flexographic ink industry. These partners are an excellent source of information on both industry trends and concerns. Their willingness to maintain continued partnership with DfE over the years demonstrates their commitment to providing the industry with sound environmental information. Trade associations are considered essential DfE partners during a project as well as for industry-wide communication and implementation of project results. Associations are key to sharing information, including incentives to making change and recognition of businesses that have overcome obstacles.

In addition to your trade association, other useful resources include the EPA's Office of Pollution Prevention and Toxic's (OPPT) website. Please visit the site <http://www.epa.gov/opptintr/database.htm#cheminfo> to find tools, models, and chemical information for better understanding chemicals.

Also, important information on chemical categories can be found at the EPA's New Chemicals website <http://www.epa.gov/opptintr/newchems/chemcat.htm>. The chemical categories broadly describe potential concerns for substances that may fall into a specific chemical category. The category also describes bounds for determining whether a specific chemical substance, that would generally fall into a category, actually might be considered of concern. A category statement describes the molecular structure a chemical might have to be included in the category as well as boundary conditions such as molecular weight, equivalent weight, the log of the octanol/water partition coefficient (log P), or water solubility, that would determine inclusion in (or exclusion from) a category, and standard hazard and fate tests to address concerns for the category. Currently, there are a total of 45 categories.

A few excellent secondary sources of chemical information include the following:

- **The Hazardous Substances Data Bank, in TOXNET:**
  <http://toxnet.nlm.nih.gov>
- **Agency for Toxic Substances and Disease Registry (ASTDR):**
  <http://www.atsdr.cdc.gov/>
- **The National Library of Medicine Toxicology and Environmental Health Specialized Information Services:**
  <http://sis.nlm.nih.gov/tehip1.htm>
- **TOXLINE:** The National Library of Medicine's extensive collection of online bibliographic information covering the biochemical, pharmacological, physiological, and toxicological effects of drugs and other chemicals.
  <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?TOXLINE>
- **Integrated Risk Information System (IRIS):**
  <http://www.epa.gov/iris>

The DfE website (www.epa.gov/dfe) may also serve as a source of information on other chemical substances. The DfE Program has reviewed many other substances in similar cleaner technology evaluations, including previous partnerships focused on the activities of screen and lithographic printers.

There is another message here in understanding chemicals in the workplace: To be a proactive decision-maker, it is critical to have the best information available. Building as well as choosing a product formulation with a more positive environmental profile may require extra care and scrutiny, especially when selecting raw materials. A material data safety sheet (MSDS) and the product label provide an excellent starting place for understanding the potential impacts of a chemical; however, the MSDS or label may not provide all the information needed to make a better choice. Often, chemicals are generically described by chemical class or, by trade name. Structural and other differences in chemicals of the same general class and makeup may not be apparent from product literature or labels, especially for imported substances. Descriptions in distributor or supplier literature and catalogs may define a chemical type but not detail a chemical's actual structure (e.g., whether a carbon chain is branched or linear – a key distinction from an environmental standpoint since linear chains biodegrade more rapidly than branched). Also, sales materials may only list trade names, often an imprecise descriptor, since a name might remain the same while the actual product composition may change. The databases and resources described above identify chemical substances by specific chemical name; it is important to get correct chemical identify information that includes Chemical Abstract Service (CAS) names and CAS numbers when doing research on chemical formulations.

DfE encourages you to visit our website for more information on the DfE formulator initiative, at http://www.epa.gov/dfe/projects/formulat/index.htm. The DfE Program offers partnership and recognition to companies that act as environmental stewards by improving the environmental profile of their formulated products and processes.

Table ES.13 presents some suggestions for how flexographic professionals can quickly and easily take actions that may reduce the health and environmental impacts of using flexographic inks. The CTSA also includes more general ways to implement pollution prevention related to the flexographic industry.

Table ES.13 Ways to Reduce Environmental and Health Impacts of Flexographic Inks

Suggestion	Printers	Formulators	Other (Technology Assistance Providers, Colleges, etc.)
Read flexographic CTSA materials to become familiar with environmental and health impacts of chemicals in inks.	X	X	X
Select the cleanest inks that make business sense. Minimize use of hazardous inks.	X		
Minimize the need for and use of press-side solvents and other additives.	X	X	
Maximize good ventilation, particularly in the prep and press rooms.	X		
Ensure that all workers who handle inks wear butyl or nitrile gloves, to minimize exposure to chemicals.	X		
Ensure that all pollution control devices are maintained properly and work correctly at all times.	X		
Identify ways to improve operations and environmental performance by looking at all steps in the printing process throughout the facility.	X		X
Develop comprehensive safe working policies and practices for inks, and ensure that workers follow them.	X		X
Minimize the amount and number of hazardous ingredients in inks.		X	
Work to make environmental and health information about inks more accessible and understandable.		X	
Support research on untested and inadequately tested flexographic ink chemicals, especially those with clear or potential risk concerns and those that are produced in high quantities (high production volume chemicals).	X	X	X

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1. U.S. Census, 1999 Survey of Manufactures.
2. U.S. Census. 1997. Commercial Flexographic Printing.
3. *Flexo*, December 1998. "1999 Industry Forecasts," p. 32.
4. U.S. Census. 1997. Commercial Flexographic Printing.
5. National Association of Printing Ink Manufacturers. 2001 *State of the Industry Report,* p 4 (Printing Ink 2000 Market).

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Chapter 1: Introduction to the Cleaner Technologies Substitutes Assessment

1.1 BACKGROUND AND METHODOLOGY

Flexography is a process used primarily for printing on paper, corrugated paperboard, and flexible plastic materials. Flexography uses a soft, flexible printing plate that is mounted on a rotary cylinder. Flexographic presses are equipped with anywhere from one to as many as twelve color stations. Examples of items printed with flexography include comics, newspapers, appliance boxes, and many grocery store packages – including cereal boxes, shampoo and soda bottle labels, frozen food and bread bags, and milk cartons.

Flexography accounts for about 20 percent of U.S. printing industry output, and it is the world's fastest growing printing technology. The nearly 1,000 U.S. flexography companies employ 30,000 people, have annual sales of $4.7 billion, and use more than 475 million pounds of ink per year. Over 60% of flexography companies have fewer than 20 employees.

The Design for the Environment (DfE) Program comprises several voluntary partnership-based initiatives between the U.S. Environmental Protection Agency (EPA) and various industries. DfE works directly with companies to integrate health and environmental considerations into business decisions. DfE serves as a catalyst for lasting change that balances business practicalities with sound environmental decision-making. The DfE approach is intended to compare performance, risks, and costs associated with alternatives to traditional industrial systems, materials, and methods. A primary goal of DfE is to encourage pollution prevention rather than relying on end-of-pipe controls to reduce risks to human health and the environment.

In accordance with its mission, DfE's intention was to ensure that all work on the Flexography Project, including technical research, analysis, and outreach, would be performed collaboratively. Toward this end, DfE first formed a Steering Committee consisting of representatives of several flexographic trade associations. The Steering Committee provided leadership, technical expertise, and guidance, meeting about once a month throughout the Project. In addition, the Project set up a Technical Committee, which included representatives of flexographic trade associations, ink formulators, printers, suppliers to the printing industry, academic institutions, and EPA. The trade associations alone that participated in the Project represent over 1,600 flexographic printers and ink manufacturers. (The members of the Steering and Technical Committees are listed in the front of this book.) Also, to ensure substantial read-world technical expertise, other participants were brought into the Project, including the printing program at Western Michigan University, the University of Tennessee's Center for Clean Products and Clean Technologies, the Industrial Technology Institute, and a number of technical experts at the U.S. Environmental Protection Agency.

The Project Partners understood that many small fleography companies rarely have the time or resources to gather in-depth information on safer and lower-risk alternatives to current materials and processes. Therefore, they set a goal of providing information that could help flexographers make their businesses more environmentally sound, safer for workers and the public, and more cost-effective.

The Partners decided to make the Project a comparative assessment of flexographic inks, since inks constitute a major cost category and have a variety of environmental and health issues. Factors that were considered in selecting this research topic included awareness of health issues related to chemicals used in traditional solvent-based inks, growth of the flexographic industry, significant recent advances in flexographic technology, and increasing attention to regulations. They decided to particularly study printing of inks on film substrates because there was less documentation about some ink systems on these substrates and because this area presented technical and environmental challenges, including air regulations related to pollutant emissions, worker health and safety issues, and some hazardous waste concerns. The Partners decided to run the inks on wide-web presses because of the technical challenges facing flexographic printers in using water-based and UV-cured inks to print film substrates on these presses.

The Partnership analyzed three ink systems: solvent-based, water-based, and ultraviolet-cured, the last of which is a fairly new technology. Solvent-based inks represented the industry benchmark for ease of use and quality of results. The inks traditionally used in this system, however, contain solvents made of volatile organic compounds and other chemicals, which can pose risks to human health and the environment. (See Chapter 2 for an overview of the ink systems that were analyzed.)

The research compared more than 100 flexographic ink chemicals, based upon actual printing of the inks on three substrates. The research examined the tradeoffs associated with traditional and alternative flexographic ink chemicals. These tradeoffs include environmental concerns (such as risk, environmental releases, energy impacts, and resource conservation), performance, and cost. Many of these issues are frequently overlooked by conventional analyses. The industry Partners in the Project felt that a combination of production results from actual printing facilities in addition to laboratory research would help give printers a more comprehensive perspective. As with any "real-world" research, the Partners were confronted with situations that they could not have anticipated. Occasionally this required modifications of the methodology specifications. (Such situations are noted in relevant sections of the document.) Therefore, the results of the research are both more extensive and less comparative than they might have been if a smaller set of variables had been chosen.

The Partners developed a detailed methodology for testing the ink systems, which involved (1) performance demonstrations at eleven volunteer printing facilities and (2) laboratory runs conducted at the printing facility of Western Michigan University (WMU). The methodology included the following general steps:

The performance demonstration printing sites supplied detailed information about their facilities and the press used in the flexographic demonstration.

- Each printing site ran a demonstration.
- Western Michigan University conducted technical analyses of the printed samples, and provided them to the Partners.

- The University of Tennessee used facility information to analyze energy consumption and costs.
- The EPA Risk Workgroup used a variety of types of existing information to analyze the hazards and risks of the ink chemicals and ink systems.

The methodology is described in more detail in the relevant sections of this document. For example, the methodology for the performance demonstrations and laboratory runs can be found in Chapter 4 (Performance) and its appendices.

1.2 WHAT RESULTS DID THE PROJECT GENERATE?

Finally, all the information about methodology and findings was combined into this document, which is called a Cleaner Technologies Substitutes Assessment, or CTSA The foundation for this CTSA was the careful consideration of all facets that affect flexographic inks, including aspects that many firms fail to address at all. The goal of this project is to help industry include these aspects in business decisions, and thereby to improve both private business and the larger environment. Although this CTSA focuses on flexographic inks, the *approach* that was used is transferable to other business decisions.

In addition to the CTSA, the Project has developed a number of other documents and tools to help printers, ink formulators, technical assistance providers, and others interested in the findings. Case studies, a summary booklet of the CTSA results, a fact sheet that describes the Flexography Project's goals and products, and many other materials can be obtained from the DfE website (www.epa.gov/dfe).

1.3 WHO WILL BENEFIT FROM THIS RESEARCH?

The CTSA documents what is arguably the most detailed analysis ever performed on flexographic ink chemicals. Small printers, ink formulators, technical assistance providers to the printing industry, and others interested in technical information about flexography, printing inks, or environmentally focused information about the printing industry may all find this information useful.

The CTSA provides data to help **ink formulators** develop high-quality inks using fewer chemicals that pose risks to human health and the environment. **Printers** can identify formulations and ink systems that may print equally well for specific purposes while posing fewer safety, health, or environmental concerns as well as possibly easing regulatory compliance. **Technical assistance providers** can find a wealth of information in the CTSA to help small businesses think through the many issues in selecting an appropriate ink system that incorporates health and environmental considerations as well as performance and cost information.

The benefits of the CTSA include its wealth of detailed information about a large group of chemicals (more than 100), including many common chemical categories found in flexographic inks. In addition to the original performance demonstration study, a huge amount of work was done to bring all the existing information together in a way that would be helpful to flexographic professionals. The hundreds of tables and charts provide detailed data about hazards, risks, environmental releases, and other aspects of ink chemicals that can be difficult to locate but are very important to consider when choosing or evaluating ink technologies and systems.

The CTSA, despite its detail, represents only a "snapshot" taken of a specific printing sample demonstrated by a small, non-random number of performance sites at a specific time. In addition, the inks used in the performance demonstrations were selected and donated by ink manufacturers, and only three types of film were used as test substrates. Therefore, readers should not assume that the information in the CTSA represents the most comprehensive or current information about flexographic printers, inks in general, or results on other substrates. On the other hand, although many of the findings are specific to the flexographic sector, the systematic process of investigation and much of the data about chemicals will be valuable to many other printing professionals.

1.4 OVERVIEW OF THE CTSA

This CTSA consists of two volumes. Volume I contains the text, and Volume II includes Appendices that provide important background information about the CTSA. Because the CTSA contains so much information, it may be helpful to use specific sections to suit different needs.

The list that follows may help readers locate particular types of information quickly.

Table of Contents: The Contents at the front of Volume 1 contains a detailed breakdown of the topics discussed in every chapter. A scan of the Contents can provide a good orientation to the material contained in this document.

Results and Implications of the Research: Readers who want a quick overview of the most important findings of the research should begin by reading the **Executive Summary**, which precedes Chapter 1 of the CTSA. **Chapter 8 (Choosing Among Ink Technologies)** contains a more detailed discussion of the interactions between risk, performance, and cost, and provides comparative interpretations of the results by ink system and chemical category. This chapter will be most helpful to professionals who are interested in considering alternatives to current inks and in developing cleaner products.

Chapter Overview: A table of contents and overview are provided in a box at the beginning of each chapter to help readers quickly identify and locate relevant information.

Background: The **Glossary** at the front of Volume 1 defines a number of technical terms that are used in the document. A list of **Abbreviations** that are mentioned frequently in the text follows the Glossary. **Chapter 2 (Overview of Flexographic Printing)** provides general information about the flexographic industry, the components and safety aspects of the ink systems that were studied, and federal regulations relevant to flexographic printing.

Performance Information: The research examined 45 ink formulations. A total of 18 performance tests were chosen and run, combining performance demonstrations at volunteer printing facilities and laboratory runs and analysis. **Chapter 4 (Performance)** describes the results of the tests. The chapter first discusses the performance of solvent-based and water-based inks, then ultraviolet-cured (UV) inks, and finally profiles each facility where performance demonstrations were conducted.

Environmental Information: **Chapter 3 (Risk)** discusses the environmental issues, including hazards to aquatic life, exposure of printing industry employees and the general public, and risk concerns that were identified in the research. Information about natural resource consumption related to this study is discussed in **Chapter 6 (Resource and Energy Consumption),** and pollution prevention and control options are mentioned in **Chapter 7 (Additional Improvement Opportunities). Chapter 2 (Overview of Flexographic Printing)** discussed federal environmental regulations that are relevant to the flexographic printing industry.

Cost Information: Different aspects of cost are discussed in **Chapter 5 (Cost),** as well as in **Chapter 8 (Choosing Among Ink Technologies).**

Supplementary Information: **References** cited in the text are numbered and listed at the end of each chapter. The **Appendices**, which are provided in **Volume 2,** contain a great quantity of background information and research data to supplement the main text. Each appendix is numbered to match the chapter to which it relates; for instance, Appendix 3-A contains details about the information in Chapter 3.

Chapter 2: Overview of Flexographic Printing

CHAPTER CONTENTS

CHAPTER OVERVIEW

Flexography is an industry in the midst of major changes. Technological advances made in the past decade, combined with compelling market forces, have opened up major new growth areas for flexographic inks and printing. At the same time, regulatory pressures have caused printers and formulators to think carefully about the safety and environmental impacts of flexographic inks and the ways in which they use them. This chapter presents an overview of flexographic inks, the printing process used, some significant market trends, information about federal regulations that relate to the flexographic printing industry, and safety issues related to the printing process. The overview provides some context for interpreting the specific research that follows later in this document.

COMPONENTS OF FLEXOGRAPHIC INKS: Section 2.1 describes the major types of ink components for the three ink systems that the Flexography Project studied — solvent-based, water-based, and ultraviolet-cured. These categories include solvents, colorants, resins, additives, and compounds that are unique to ultraviolet-cured inks.

MARKET PROFILE: Section 2.2 describes the general flexographic printing market, including sub-categories, market trends, and flexographic inks in particular.

FEDERAL REGULATIONS: Section 2.3 provides an overview of federal regulations pertaining to environmental releases and workplace safety potentially affecting the flexographic printing industry. This section does not attempt to provide a comprehensive analysis of regulations. Also, this is not an official guidance document and should not be used to determine regulatory requirements.

PROCESS SAFETY: Section 2.4 describes safety issues related to the flexographic printing process.

2.1 INTRODUCTION TO FLEXOGRAPHIC INKS

Ink Systems

Three primary flexographic ink systems were in use when the CTSA was designed, and they differ primarily in the method of drying the ink and in the medium for delivering the ink. Solvent-based and water-based inks are dried using evaporation, whereas UV-cured inks are cured by chemical reactions. Solvent-based inks use solvents as the delivery medium, whereas water-based inks use water instead of or in addition to solvents. UV-cured inks do not require a medium per se; they utilize liquid components of the inks that are chemically cured during the printing process. Each ink system is briefly described below.

Solvent-based Inks

Solvent-based inks are widely used in many flexographic printing processes. They were the first printing inks to be available commercially. Historically they have been very popular because they dry quickly, perform well, and allow printers a wide choice of products. Solvent-based inks are generally considered to be the industry standard for ease of use and quality of printing. The solvents in these inks, however, are primarily volatile organic compounds (VOCs), which have caused concerns for health and safety, as they are usually very flammable and contribute to the formation of ground-level ozone, which is a component of smog and causes respiratory and other health problems. Partly because of these concerns, other types of inks were developed and markets for them began to develop.

Water-based Inks

Water-based inks were first used to print kraft linerboard for decorative corrugated cartons, and later developed new applications because of environmental concerns and regulations related to use of solvent-based inks. The primary solvent in water-based inks is water, but water-based inks also can and usually do contain varying and often substantial percentages of organic solvents and VOCs. The colorants for water-based inks are very similar to those for solvent-based inks, but resins and additives are generally quite different. Water-based inks are often less flammable than solvent-based inks and are thus easier to store and use. Depending on the VOC content, they may also have fewer environmental concerns. However, they may take significantly longer to dry and are often not as easy to use as solvent-based inks.

Ultraviolet-cured Inks

UV-cured inks comprise a comparatively new ink technology in the flexographic printing industry. They are very different from solvent- and water-based inks in that they are cured through chemical reactions rather than drying through evaporation. Because of this, UV-cured inks do not contain traditional organic solvents, which means they do not emit VOCs. However, they do contain many chemicals that have not been tested comprehensively for environmental, health, and safety impacts. Future research is needed on untested UV chemicals. UV inks have found a growing market outlet in narrow-web printing.

Ink Components

A functional flexographic ink must exhibit several qualities. It needs to produce a color or other visual effect. It must adhere to the material being printed (the substrate). It must withstand conditions to which it will be exposed in practical use, such as chemicals, abrasion, and extreme temperatures. Finally, it needs to produce a consistent finish.

Different types of ingredients contribute to a successful ink. Five types of components allow ink to adhere to a substrate and produce its visual effect. The solvent provides fluidity, which allows the ink to be transported from the ink fountain to the substrate. The colorant, which can be either a pigment or dye, provides the color associated with ink. The resin causes the ink to adhere to the substrate, among other traits. Additives modify the physical properties of the inks, such as flexibility and the coefficient of friction. Finally, in UV-cured inks, UV-reactive compounds participate in the photochemical reaction that cures the ink.

Solvents

Solvents are important in delivering the ink to the substrate. The solvent allows the ink to flow through the printing mechanism, and then evaporates so that the ink forms a solid coating on the substrate. Typically, inks are manufactured and transported in a concentrated form, and the printer must add solvent to the ink to attain the desired viscosity. A solvent must display several important characteristics. It must adequately disperse or dissolve the solid components of the ink, but must not react with the ink or with any part of the press. It must dry quickly and thoroughly, and have low odor. Finally, it is desirable for the solvent to have minimal flammability and toxicity concerns.

Common solvents in solvent-based inks include ethanol, propanol, and propyl acetate. In water-based inks, the solvent is water, which is amended with alcohols, glycols, or glycol ethers. UV-cured inks are different in that they do not have solvents per se, in that the chemicals are not added with the intention of being evaporated after application of the ink. Fluidity is provided by liquid, uncured components of the ink, such as monomers, which are incorporated chemically into the ink upon curing, instead of evaporating.

Colorants

Colorants are compounds that reflect and absorb certain wavelengths of light. Wavelengths that are reflected by a colorant are seen by the eye and perceived as colors. The two types of colorants used in printing are dyes and pigments. Dyes dissolve into the liquid solution. The most common dyes are basic, amino-based compounds. The transparent properties of dyes can be beneficial when transparency is desired, and the colors of dyes are often quite strong. However, dyes can be damaged by chemicals and water, and they can also be toxic.
Pigments are small, insoluble particles. They can be made from a wide range of organic and inorganic compounds, and as a result, have a variety of properties. Particle size and chemical stability are two variable properties that can yield differing ink characteristics. In general, pigment-containing inks are more resistant to chemicals and heat and are less prone to bleeding through the substrate than dye-containing inks.

Resins

Resins cause ink to adhere to the substrate, disperse the pigment, and provide gloss to the finished coating. They also can impart differing degrees of flexibility, scuff resistance, cohesive strength, block resistance, and compatibility with the printing plates. Resins are solid compounds that are soluble in the solvent and often have complex molecular structures. Common categories of resins include nitrocellulose, polyamides, carboxylated acrylics, and polyketones.

Additives

Several components can be added to inks to improve the performance of the finished products. Examples include plasticizers, which enhance the flexibility of resins; waxes, which enhance slip, rub and scuff resistance; wetting agents, which modify the surface tension to improve adherence to substrates; and defoaming agents, which in water-based inks reduce soap-like effects.

UV-Specific Compounds

The curing process of UV-cured inks is fundamentally different from that of solvent- and water-based inks. Chemicals in the inks react to form solid polymers upon exposure to ultraviolet light. Three types of compounds are necessary in order for such a reaction to occur: monomers, oligomers, and photoinitiators. Monomers are individual molecular units that can combine to form larger structures known as polymers. Oligomers are small polymers that can be further combined to form larger polymers. A photoinitator uses UV light to enable a chemical reaction to take place. Photoinitiators are often aromatic ketones, and monomers and oligomers are acrylate-based in most commonly used inks.

In free-radical curing (presently the most common commercial form), the photoinitiator fragments into reactive free radicals in the presence of ultraviolet light. These free radicals react with monomers and oligomers, which link together to form a polymer that binds the ink together. The reaction is illustrated in the box below. The photoinitiator (indicated by -CO-R) reacts in the presence of UV light to form a free radical (•R). This free radical then reacts with an acrylic monomer (or oligomer) so that the monomer/oligomer bonds with similar compounds to form a polymer.

$$\boxed{\begin{array}{c} -CO-R\xrightarrow{Energy} -CO\bullet + \bullet R \\ \bullet R + CH_2 = CH - COOR \rightarrow -[CH_2 - \underset{|}{C}R - COOR]_n \end{array}}$$

2.2 MARKET PROFILE OF THE FLEXOGRAPHIC PRINTING INDUSTRY

Flexographic printing was developed primarily to print materials used in packaging. Because the early quality of flexography was not high, the process was used mainly as a way to print low-quality corrugated materials. However, a series of technical advances in flexography starting in the late 1980s resulted in dramatic quality improvements and rapid expansion in the use of flexography to print high-quality packaging materials. During the 1990s, flexography experienced an average annual growth rate of about 6%,[1] which was above the average for the printing industry.

This large market depends upon a relatively small number of businesses. The last Census recorded 914 commercial printing establishments in which flexographic printing was the primary print process. These facilities employed more than 30 thousand employees and had a payroll exceeding $1 billion.[2] However, many more printing facilities — a total of about 2,300 nationally — operate flexographic presses in addition to other printing equipment.[3]

Flexographic facilities are typically small, and over 80% have fewer than 50 employees.[4] The smallest facilities tend to focus exclusively on flexographic printing and predominantly operate narrow-web presses, whereas larger facilities often include converting and wide-web presses. Historically, flexographic printing facilities have been concentrated in the Midwest. Although these states continue to dominate, more facilities have opened in California and Texas as the industry has expanded. The majority of flexographic facilities are located in California, Florida, Illinois, Missouri, New Jersey, New York, North Carolina, Ohio, Texas, and Wisconsin.[7]

Despite the small size of most individual flexographic printing companies, the industry overall used more than 513 million pounds of ink in 2000.[8] Thus, although the majority of flexographic facilities are small, combined they have the potential to make a major environmental impact. Also, for several years the industry has seen a trend of mergers and acquisitions. As these cause firms to grow in size, ink choices made by individual firms can have an increasingly significant effect.

The flexographic industry is embedded within a number of different industrial codes and is not clearly defined by any single one. Table 2.1 shows the U.S. Census Bureau's industry classifications for aspects of the flexographic industry sector, as well as the estimated revenues attributed to each code. The table provides information for two industry classification systems. In 1997, the North American Industry Classification System (NAICS) replaced the Standard Industrial Classification (SIC) system as the standard classification system for the United States, Canada, and Mexico. Although businesses now report required information under NAICS codes, some information is available using SIC codes.

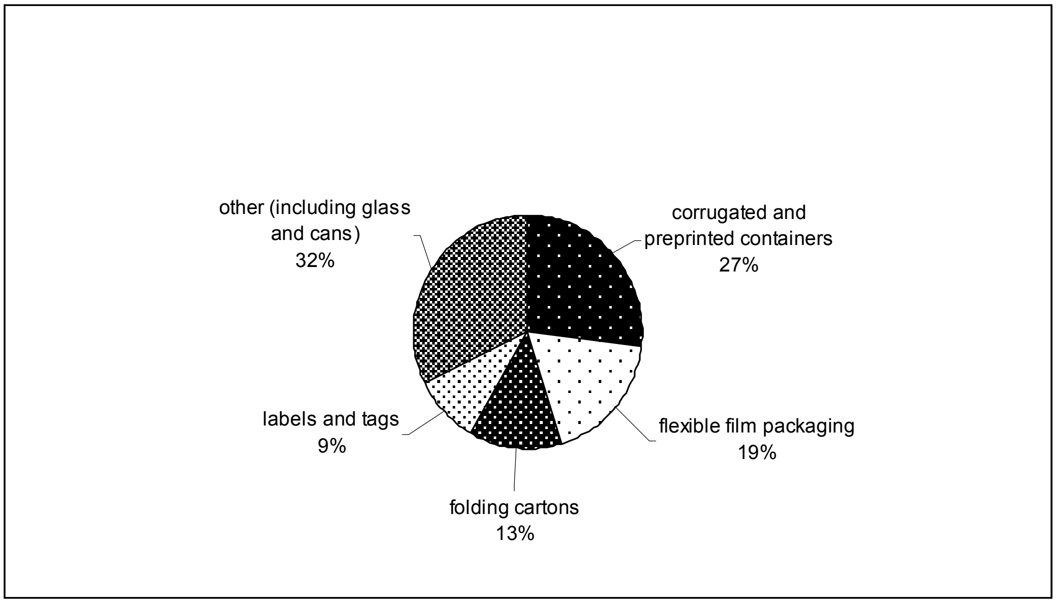
Table 2.1 Industrial Codes Related to Flexographic Printing

NAICS code	1997 NAICS U.S. Description	Value of Shipments*	SIC code	1987 SIC U.S. Description
322	**Converted Paper Product Manufacturing**			
322221	Coated and Laminated Packaging Paper and Plastics Film Manufacturing	$1.6 billion	2671**	Packaging Paper and Plastics Film, Coated and Laminated (single-web paper, paper multiweb laminated rolls and sheets)
322222	Coated and Laminated Paper Manufacturing	$12 billion	2672	Coated and Laminated Paper, Not Elsewhere Classified
			2679**	Converted Paper and Paperboard Products, Not Elsewhere Classified (wallpaper and gift wrap paper)
322223	Plastics, Foil, and Coated Paper Bag Manufacturing	$0.5 billion	2673**	Plastics, Foil, and Coated Paper Bags (coated or multiweb laminated bags)
322224	Uncoated Paper and Multiwall Bag Manufacturing	$2.8 billion	2674	Uncoated Paper and Multiwall Bags
322225	Laminated Aluminum Foil Manufacturing for Flexible Packaging Uses	$1.5 billion	3497**	Metal Foil and Leaf (laminated aluminum foil rolls and sheets for flexible packaging uses)
323	**Printing and Related Support Activities**			
323112	Commercial Flexographic Printing	$5.0 billion	2759**	Commercial Printing, Not Elsewhere Classified (flexographic printing)
			2771**	Greeting Cards (flexographic printing of greeting cards)
			2782**	Blankbooks, Loose-leaf Binders and Devices (flexographic printing of checkbooks)
325	**Chemical Manufacturing**			
325910	Printing Ink Manufacturing	$4.7 billion	2893**	Bronze Ink, Flexographic Ink, Gold Ink, Gravure Ink, Letterpress Ink, Lithographic Inc, Offset Ink, Printing Ink: base or unfinished, Screen Process Ink, Ink — duplicating
326	**Plastics Product Manufacturing**			
326111	Unsupported Plastics Bag Manufacturing	$7.8 billion	2673**	Plastics, Foil, and Coated Paper Bags (plastic bags)
326112	Unsupported Plastics Packaging Film and Sheet Manufacturing	$4.3 billion	2671**	Packaging Paper and Plastics Film, Coated and Laminated (plastics packaging film and sheet)

*Source: U.S. Census, 1999 Survey of Manufactures
** This was part of a 1987 Standard Industrial Classification (SIC) category.

By the year 2000 flexographic printing accounted for nearly a quarter of all U.S. printing revenues, including almost three-fourths of printing for the $108 billion packaging market.[9] Packaging includes many types of products that commonly utilize flexography (Figure 2.1). These product categories are described briefly in the paragraphs that follow.

Figure 2.1: Primary Types of Packaging Manufactured in the United States, 2000
(by % of sales dollars)



Source: Dowdell, William C. "Flexo 2001." *Flexo,* January 2001.
Data represent production across all printing technologies.

Corrugated and Preprinted Containers

Corrugated containers provide an economical source of strong, versatile packaging. Corrugated board is typically made of kraft linerboard, which uses virgin, unbleached, softwood pulp. Corrugated materials are characterized by irregularities, which in the past made it difficult or expensive to print high-quality graphics directly on the board. As the role of corrugated packaging has expanded from simply protecting its contents for transport and handling to generating customer interest at the point of sale, technology has also improved.

By the late 1990s, technical advances allowed flexography to print directly on corrugated substrates with high-quality results, thereby increasing the use of corrugated containers. This technological advance led to expansion of the market for corrugated and preprinted containers. By 2000 sales volume of these materials totaled $29 billion, or about 27% of the total market for packaging.[10] Over the long term, flexographic printing of corrugated materials should continue to grow because the use of complex and colorful graphics in this market is expected to increase.

Flexible Packaging

Flexible packaging is a package or part of a package with a thickness of ten millimeters or less whose shape can be readily changed. Most printing of flexible packaging is done by flexographic processes. The demand for flexible packaging is driven by food products (particularly fresh produce and snack foods), pharmaceutical products, surgical and medical equipment, agricultural products, industrial chemicals, household goods, garden supplies, pet food, cosmetics, and retail merchandise.

Flexible packaging accounts for about a fifth of the total packaging market.[11] In 1998 flexible packaging employed 375,000 people. Food products alone account for about half of flexible packaging; medical and pharmaceutical products constitute another 25%.[12] Flexography prints about 85% of all flexible packaging.[13] In 2000, flexographic printing of flexible packaging totaled over $20 billion.[14]

Folding Cartons

Folding cartons differ from corrugated containers in the type of substrate used (usually a high-quality, smooth paperboard), in the generally fine quality of the graphics, and in the types of inks used. Folding cartons are used in a variety of applications requiring colorful, complex graphics (foods, personal care products, etc.). About a fifth of all folding cartons are printed with flexography. Folding cartons accounted for $14 billion of revenue in 2000 — about 13% of the total packaging market. Sales of folding cartons grew by about 10% per year during much of the 1990s.[15]

Tags and Labels

The tag and label market includes many consumer applications requiring high-quality graphics, such as hair care and pharmaceutical products.[16] Flexography dominates the printing of tags and labels. This segment had revenues of $10.2 billion in 2000, or about 9% of the total packaging market.[17]

Trends in the Flexographic Printing Industry

In the past decade flexographic printing has successfully penetrated new printing markets and has grown substantially. Several factors are important in this growth:

- **Improved quality of flexographic printing:** Early print quality of flexography was typically inferior to that of lithography and gravure. Many technological advances have greatly improved the quality of flexography, leading to greater use of color and more sophisticated and colorful design. These improvements have resulted in increased acceptance of flexography by print buyers.
- **Increased use of flexible packaging:** General economic growth, increasing market segmentation, and technical improvements in flexible packaging and flexographic printing quality have spurred a shift from rigid to soft packaging as well as a trend toward increasing the alternatives available within a product line. For example, potato chip manufacturers may market a variety of product "segments" such as "light", "low salt", and "barbecue", where there once was only one product. These trends have increased the use of flexography in packaging of fresh produce, drugs, surgical and medical products, snack foods, and agricultural products/industrial chemicals.[18] These same trends have also led to more applications for pressure-sensitive labels, which in turn expands opportunities for flexographic printing.
- **Shorter printing runs and faster turnaround times:** Flexography is technically well positioned to respond to demands for shorter, more segmented, and more frequent runs.
- **UV-cured printing in narrow-web markets:** The entry of UV-cured inks into narrow-web flexographic printing of folding cartons, labels, and tags provided an economical way to produce high-quality small runs.[19]

Other general factors that are expected to influence the future of flexographic printing include the following:

- The general economic climate slowed significantly during 2000.
- Competition, especially in terms of globalization of trade and imports, takes on added importance in a more sluggish economy.
- Prices of some raw materials have increased.
- Uses for electronic/digital technologies have expanded dramatically.
- Industry consolidation has been extremely active in recent years (although it appears to have slowed in 2000[20]).
- Concerns about the environmental and health impacts of chemical use and printing processes continue to be of major interest nationally.

The combined long-term effects of all these aspects are not clear, but some industry experts have predicted potentially difficult times for small printers and those that do not continue to confront the rapidly changing marketplace.

Inks Used in Flexographic Printing

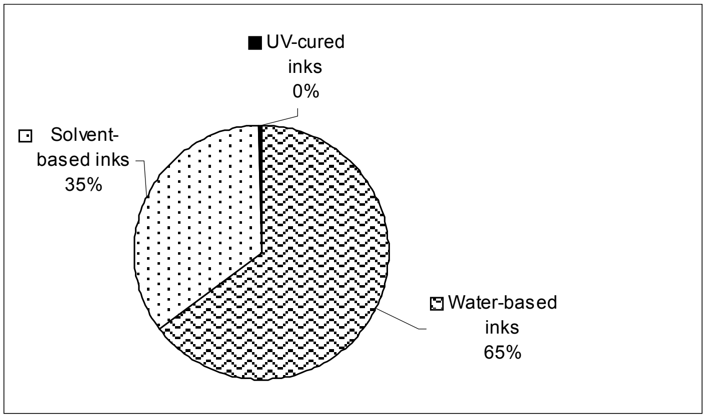
The global ink industry had revenues of more than $12.7 billion in 2000, with the U.S. representing the largest share.[21] U.S. printing ink sales in 1999 totaled $4.7 billion.[22] More than 550 U.S. firms manufacture printing inks,[23] employing about 14,000 workers.[24]

Due to the substantial growth of the flexographic printing industry throughout the 1990s, flexographic inks have been the fastest-growing ink segment, with sales of half a billion pounds and over $900 million in 2000[25]. Almost three-quarters of all flexographic inks ($648 million) were used in flexible packaging.[26]

Water-based inks account for more than half of all printing ink revenues[27] and for about 65% of inks used (Figure 2.2). Water-based inks are used for many flexographically printed products, including virtually all newsprint,[28] a third of all printed film,[29] and about half of all products printed on wide-web presses.[30] Solvent-based inks account for 35% of inks used by weight (Figure 2.2).

Over the past decade or so, UV-cured inks have established a strong foothold in narrow-web labels and tags. During the 1990s UV-cured inks showed technological improvements (including a decrease in the amount of photoinitiator needed, which is the most expensive component) and market growth, especially in the narrow-web field. These factors caused the price of UV inks to drop, so that by 1998 UV-cured inks accounted for at least $85 million in ink consumption,[31] and their use grew by 15% in 2000.[32]

Figure 2.2: Breakdown of Flexo Ink Market (in millions of wet pounds)



Source: Hess, Jen. *Ink World*. February 2001. "2001 Flexo Report."

The United States exported about 115 million pounds of printing ink in 1998, about a 10% increase over 1997. However, exports to Mexico grew by 76.4% during the same period,[33] perhaps because of increased trade opportunities made available through the North American Free Trade Agreement. Exports of black flexographic ink dropped by about 50% between 1998 and 1999, while exports of colored flexographic ink increased by 16%. The United States also imports printing ink — about 44 million pounds in 1998.[34] In 1999, however, imports of black ink fell by more than 50%, and imports of colored ink fell by 25%.[35]

In addition to the trends and events affecting the flexographic sector overall, several factors have specifically affected flexographic inks, and may continue to exert an influence in the future:

- Concerns about environmental hazards and potential risk concerns of solvent-based inks, as well as regulatory issues, led to improvements in the printability of water-based inks and to expanded applications for their use.
- The technology to remove VOCs and other harmful chemicals from solvent-based and water-based ink emissions has improved markedly.
- Prices of raw materials used for inks began to rise dramatically in the mid-1990s and accounted for more than half of the value of shipments in 1995 and 1996.[36] Faced with increasing raw material costs and aggressive pricing strategies by the largest manufacturers, many manufacturers began to experience decreased rates of sales growth sometime during the second half of the 1990s.
- In 2000, the general economy began to show early signs of a slump. A decrease in advertising and marketing activity negatively affected the printing of packaging and sales of flexographic inks in 2000 and beyond.[37] As a result of this more general decline in industries that utilize the majority of flexographic inks, the sales and profits of the printing inks industry increased only marginally in 2000.[38] According to NAPIM, the growth experienced by some manufacturers was balanced by the losses at others, so that overall there was very little change.[39]
- Newer developments have improved UV technology for potential use in packaging that has direct contact with food and medicine. Cationic inks, because they cure more thoroughly, could play a significant role in expanding these markets.[40] These factors may help UV-cured inks to increase market share and make inroads into wide-web printing.

- During the 1990s the printing ink industry experienced a very active period of mergers and acquisitions. Because the largest companies now control a much larger portion of the total ink market, Sun Chemical and Flint alone accounted for more than half of all ink sales worldwide in 2000 (Table 2.2). Sun Chemical, for example, acquired three companies in 2000, five in 1999, and three in 1998.[41]

Table 2.2 Leading Ink Manufacturers Worldwide in 2000

Rank	Company	Ink Sales ($ million)
1	Sun Chemical	$3,300
2	Flint Ink	$1,400
3	INX International	$300
4	Color Converting	$90
5	Wikoff Color	$81
6	Toyo Ink America	$79
7	Superior	$75
8	SICPA Industries	$68
9	Nazdar	$65
10	Van Son	$64
11	Central Ink	$56
12	Sericol	$50
12	Siegwerk	$50
14	Color Resolutions	$45
15	Braden Sutphin Ink	$43
16	DuPont	$40
16	Environmental Inks	$40
16	Handschy	$40
19	Akzo Nobel Inks	$36
20	Ink Systems	$32

Source: *Ink World*, April 2001. “The Top 20 Report.” (www.inkworldmagazine.com/top20.htm).

The future of the flexographic ink market may depend both upon the overall economic picture and continued advances in printability. Continued improvements in print quality could result in flexography taking a larger share of the overall printing market as well as continuing to print more packaging and cartons for new high-quality applications.[42]

2.3 FEDERAL REGULATIONS

This section describes federal environmental, health, and safety regulations that may affect the use of flexographic printing chemicals and inks. Regulatory requirements have significant effects on costs, equipment requirements, overhead, and owner/operator liability.

Flexographic printers may be subject to some of the following federal laws:

- Clean Air Act (CAA)
- Resource Conservation and Recovery Act (RCRA)
- Toxic Substances Control Act (TSCA)

- Clean Water Act (CWA)
- Safe Drinking Water Act (SDWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Emergency Planning and Community Right to Know Act (EPCRA)
- Occupational Safety and Health Act (OSH Act)

Federal environmental laws often provide for implementation by federally approved, authorized, or delegated state or local agency programs. These programs must be at least as stringent as the federal programs, and may be more stringent. There may also be additional state or local requirements that have no federal counterpart. This summary discusses only federal laws, and only covers ink chemicals referenced in this CTSA. Therefore, readers should be aware of state and local regulations, and requirements associated with chemicals not used in this CTSA. Also, this section only discusses regulations applicable to the flexographic printing process; other activities undertaken in a printing facility (such as prepress processes) may involve other requirements. A list of additional sources for regulatory information can be found in the box at the end of this section.

Clean Air Act

Air regulations represent the major environmental challenge for flexographic printers. The Clean Air Act (CAA) and amendments were established to protect and improve air quality and reduce damage to human health and the environment by air pollutants.

Three components of the Clean Air Act are particularly relevant to printers: the National Ambient Air Quality Standards (NAAQS), National Emission Standards for Hazardous Air Pollutants (NESHAP), and permitting.

National Ambient Air Quality Standards (NAAQS)

The National Ambient Air Quality Standards (NAAQS) set maximum concentration limits for six air pollutants. The most relevant to printers is ozone, which is the principal component of smog and is created in part by volatile organic compounds (VOCs) released from inks. Each state must develop a State Implementation Plan that identifies sources of pollution for these six pollutants and determines what reductions are required to meet the NAAQS. If the region violates the standard for ozone, it is classified as a nonattainment area. Depending on the degree of nonattainment, specific pollution controls may be mandated for sources with potentially uncontrolled VOC emissions. The three basic control guidelines developed for flexographic and gravure printing are the following:

- Use of add-on controls such as thermal and catalytic oxidizers, carbon absorption, or solvent recovery, with a reduction rate of 60%.
- Use of water-based inks that contain at least 75% by volume water and at most 25% by volume organic solvents.
- Use of high-solids inks that have a solvent content of no more than 40% by volume.

National Emissions Standards for Hazardous Air Pollutants

Section 112 of the CAA requires EPA to establish National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for all major source categories of stationary sources that emit any of the 188 Hazardous Air Pollutants (HAPs) listed in the CAA. HAPs are listed for regulation because they present, or may present, a threat of adverse human health effects or adverse environmental effects. EPA has promulgated NESHAPs for the printing and publishing industry, which cover wide-web flexography and rotogravure. NESHAPs require regulated sources to meet emission standards which represent the maximum degree of reduction in emissions that EPA determines is achievable for sources in the category. Such standards are known as Maximum Achievable Control Technology Standards or MACT. In addition to meeting the emission standard, the source must maintain records, file reports, and correctly install, use, and maintain monitoring equipment.

Each affected wide-web flexographic printing facility must limit monthly HAP emissions to one of the following measures:

- 5% of the organic[a] HAPs
- 4% of the mass of inks, coatings, varnishes, adhesives, primers, solvents, reducers, thinners, and other materials
- 20% of the mass of solids, or
- a calculated equivalent allowable mass based on the organic HAPs and solids contents of the inks, coatings, varnishes, adhesives, primers, solvents, reducers, thinners, and other materials

These limits can be achieved by substituting non-toxic chemicals for organic HAPs, installing traditional emissions capture and control equipment, or implementing some combination of these two compliance options.

Five HAPs are found in the inks used for this CTSA, and are listed in Table 2.6. Section 112(r) of the CAA lists chemicals that are acutely toxic or flammable. If a CAA 112(r) chemical is held in a process in a quantity above the applicable threshold level, the facility must establish a Risk Management Program to avoid the accidental release of the chemical. One chemical used in this CTSA, ammonia, is regulated under CAA 112(r), with a threshold of 10,000 (or 20,000 pounds in the case of ammonia hydroxide).

Permitting

Printers may be required to obtain two types of permits related to air emissions: construction and operating. Construction permits are issued by state or local agencies; they are required when building a new facility, and may be required when installing new equipment such as a printing press. It may be necessary to obtain a construction permit before beginning pre-construction activities such as moving existing equipment, pouring concrete, or making arrangements for utility connections.

Many printers also are required to obtain operating permits. One kind of operating permit is that issued by state or local agencies. These permits may contain enforceable operating conditions and control requirements, as well as recordkeeping and reporting requirements.

Under Title V of the Clean Air Act Amendments of 1990, major sources are required to obtain a Title V operating permit. The thresholds are lower for facilities in ozone nonattainment areas. Permit applications include a period of review by the public, neighboring states, and EPA. Permit requirements include emissions monitoring, record keeping, reporting, and all of a facility's other CAA requirements.

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[a] Organic HAPs are a subset of VOCs that excludes certain inorganic compounds.

Under certain conditions, an alternative to Title V permits may be available. These Federally Enforceable State Operating Permits (FESOPs) limit emissions from a facility to below the Title V thresholds. FESOPs are generally less complicated than Title V permits and are issued by states but can be enforced by EPA.

Table 2.6 CTSA Chemicals Regulated Under CAA

Chemical	112(b) Hazardous Air Pollutant	112(r) Risk Management Plan
Ammonia[a]		✔
Butyl carbitol	✔	
Ethyl carbitol	✔	
Styrene	✔	

[a] In concentrations greater than 20%.

Resource Conservation and Recovery Act

Hazardous wastes must be treated, stored, and disposed of only by approved methods. The Resource Conservation and Recovery Act (RCRA) governs the management of hazardous waste. Hazardous waste can be identified as *characteristic* (ignitable, corrosive, reactive, or toxic) or as a specific *listed* waste (e.g., certain spent solvents, such as toluene). (See Section 2.4, Process Safety Assessment, for an explanation of characteristic wastes.)

- RCRA hazardous wastes are categorized by codes. Categories most relevant to the printing industry follow:
- Characteristic wastes are indicated by a “D” code.
- The F list designates particular wastes from certain common industrial or manufacturing processes. They are wastes from non-specific sources, because processes producing these wastes can occur in different industries. This list includes certain spent solvents.
- The U list includes hazardous pure or commercial grade formulations of certain specific unused chemicals. These wastes include product that has been accidentally spilled or cannot be used because it does not meet specifications.

Some chemicals appear under multiple lists, depending on their use; for example, ethyl acetate is associated with waste codes U112 (as a product waste) and F003 (as a spent solvent waste). Table 2.7 lists chemicals used in this CTSA that may be regulated under RCRA.

Table 2.7 CTSA Chemicals Regulated Under RCRA

Chemical	D Waste Code[a]	F Waste Code	U Waste Code
Barium	D005		
Ethyl acetate	D001	F003	U112
Ignitable solvent-based inks	D001		
Isobutanol	D001	F005	U140

[a] Characteristic wastes (D code) are regulated as hazardous wastes when they exhibit the relevant characteristic (e.g., ignitable if the flashpoint is below 140°F) or contain the toxic constituent at levels above the level of regulatory concern.

Hazardous waste generators are subject to one of three sets of requirements, depending on the volume of hazardous waste generated:

- Large Quantity Generators (LQG) generate greater than 1000 kg (approximately 2200 lbs) of hazardous waste per month or greater than 1 kg (2.2 lbs) of acutely hazardous waste per month.

- Small Quantity Generators (SQG) generate between 100 kg (approx. 220 lbs.) and 1000 kg (approx. 2200 lbs.) of hazardous waste per month and less than 1 kg of acutely hazardous waste per month.

- Conditionally Exempt Small Quantity Generators (CESQG) generate no more than 100 kg (approx. 220 lbs.) of hazardous waste per month and less than 1 kg (2.2 lbs.) of acutely hazardous waste per month.

CESQG requirements include hazardous waste identification, waste counting to determine generator status, maximum quantity limits, and a requirement to treat or dispose of waste on-site or at specified off-site facilities. SQG and LQG requirements also include storage unit specifications, personnel training, recordkeeping, and contingency plans. See Table 2.8 for more information on the requirements for each generator status level. The substitution of materials that do not result in hazardous waste generation can reduce or eliminate RCRA requirements.

Table 2.8 Requirements for RCRA Generators

Requirement	Conditionally Exempt Small Quantity Generator	Small Quantity Generator	Large Quantity Generator
EPA ID Number	Not Required	Required	Required
On-site Accumulation Quantity	≤1,000 kg (~2,200 lbs.); ≤1 kg (2.2 lbs.) acute; 100 kg (~220 lbs.) acute spill residue	≤6,000 kg (~13,200 lbs.)	No Limit
Accumulation Time Limits	None	≤180 days or ≤270 days (if >200 miles)	≤90 days
Storage Requirements	None	Basic requirements with technical standards for tanks or containers	Full compliance for management of tanks, containers, drip pads, or containment buildings
Off-site Management of Wastes	State approved or RCRA permitted/interim status facility	RCRA permitted/interim status facility	RCRA permitted/interim status facility
Manifest	Not Required	Required	Required
Biennial Report	Not Required	Not Required	Required
Personnel Training	Not Required	Basic Training Required	Required
Contingency Plan	Not Required	Basic Plan	Full Plan Required
Emergency Procedures	Not Required	Required	Required
Transport Requirements	Yes [if required by U.S. Department of Transportation (DOT)]	Yes	Yes

Source: U.S. EPA, *RCRA, Superfund & EPCRA Hotline Training Module: Introduction to Generators*, 1999.

Toxic Substances Control Act

The Toxic Substances Control Act (TSCA), enacted in 1976 and subsequently amended, gives EPA a broad mandate to protect health and the environment from unreasonable chemical risks, to gather information, to identify harmful substances, and to control those substances whose risks outweigh their benefits to society and the economy. TSCA provides EPA the authority to regulate activities conducted by manufacturers, importers, processors, distributors, users, and disposers of chemical substances or mixtures. The major sections of interest to flexographic ink formulators and printers are described below.

Section 4

Section 4 authorizes EPA to require testing of certain chemical substances or mixtures identified as risks to determine their effects on human health or the environment. The TSCA Master Testing List is a list of chemical substances for priority testing consideration. Its major purposes are to 1) identify regulatory and voluntary chemical testing needs, 2) focus limited EPA resources on those chemicals with the highest priority testing needs, 3) publicize EPA's testing priorities for industrial chemicals, 4) obtain broad public comments on EPA's testing program and priorities, and 5) encourage initiatives by industry to help EPA meet those priority needs.

Section 5

Section 5 requires manufacturers and importers of new chemical substances (substances not previously listed on the TSCA Inventory) to submit a Premanufacture Notice to EPA 90 days prior to nonexempt commercial manufacture or import. Similar reporting is required for those existing chemical substances (substances listed on the TSCA Inventory) for which certain activities have been designated as a "significant new use." Upon reviewing these notices, EPA may 1) issue an order or rule regulating the manufacture, use, or disposal of the substance, 2) require a manufacturer, importer, or processor of the new chemical or a chemical for a significant new use to develop test data, and/or 3) promulgate a rule identifying significant new uses of the substance.

TSCA Section 5 and Acrylate Esters

A Significant New Use Rule (SNUR) was proposed for acrylate esters, which are found in some flexographic ink formulations. However, EPA withdrew the proposed SNUR after receiving, under the terms of a voluntary agreement, toxicity data from acrylate manufacturers that determined that neither triethylene glycol diacrylate nor triethylene glycol dimethacrylate were considered carcinogenic. As a result, EPA no longer supports the carcinogen concern for acrylates as a class. However, EPA may still regulate and maintain health concerns for certain acrylates on a "case-by-case" basis when they are structurally similar to substances for which EPA has supporting toxicity data or when there are mechanistic/toxicity data supporting the concern. Data from experimental studies show some acrylates can cause carcinogenicity, genotoxicity, neurotoxicity, reproductive and developmental effects, and respiratory sensitization. For dermal exposure, EPA continues to recommend the use of protective equipment, such as impervious gloves and protective clothing, for workers exposed to new or existing acrylates and methacrylates. For inhalation exposure, NIOSH-approved respirators or engineering controls to reduce or eliminate workplace exposures should be used. EPA continues to evaluate the acrylate chemical category for ecotoxicity.

Section 6

Section 6 provides EPA with the authority to regulate the manufacture, processing, distribution in commerce, use and disposal of chemical substances or mixtures determined to pose an unreasonable risk to health or the environment. EPA may prohibit or limit the manufacture, processing, distribution in commerce, use, or disposal of a substance. Action can range from a complete ban to a labeling requirement.

Section 8

Under section 8(a) of TSCA, EPA has promulgated regulations in the Code of Federal Regulations (40 CFR, part 712, subpart B (the Preliminary Assessment Information Rule (PAIR)), which established procedures for chemical manufacturers and importers to report production, use, and exposure-related information on listed chemical substances. Any person (except a "small manufacturer or importer") who imports or manufactures chemicals identified by EPA in this rule must report information on production volume, environmental releases, and certain other releases. Small manufacturers or importers may be required to report such information on some chemicals. TSCA section 8(a) affects large ink manufacturers with total annual sales from all sites owned or controlled by the domestic or foreign parent company at or above $30 million for the reporting period, and who produce or import 45,400 kilograms (100,000 pounds) or more of the chemical (see 40 CFR 712.25(c)).

Sections 8(a) and (b) and the implementing regulations, 40 CFR part 710, require EPA to compile, maintain and publish a list of all chemical substances manufactured in, imported into, or processed in the United States (the TSCA Inventory). Certain chemical manufacturers and importers are required to regularly report additional information necessary to allow EPA to maintain the inventory (TSCA Inventory Update Rule).

Under EPA's section 8(c) regulations at 40 CFR part 717, manufacturers, importers and processors must maintain records of significant adverse reactions to health or the environment for which certain allegations of harm have been made by plant personnel, consumers, or the surrounding community. See 40 CFR 717.5 to determine if these requirements apply to flexographic printing industry chemicals. A word of caution: an allegation may be of such a serious nature as to be considered an 8(e) notification.

Under section 8(d) of TSCA, EPA has promulgated regulations that require any person who manufactures, imports, or, in some cases, processes (or proposes to manufacture, import, or, in some cases, process) a chemical substance or mixture identified under 40 CFR part 716 must submit to EPA copies of unpublished health and safety studies with respect to that substance or mixture.

Section 8(e) provides that any person who 1) manufactures, imports, processes or distributes in commerce a chemical substance or mixture, and 2) obtains information which reasonably supports the conclusion that such substance or mixture presents a substantial risk of injury to health or the environment must immediately report that information to EPA unless the person has actual knowledge that EPA has been adequately informed of such information.

Section 12

Section 12 requires exporters of certain chemical substances or mixtures to notify EPA about these exports and EPA, in turn, must notify the relevant foreign governments.

Section 13

Section 13 requires importers of a chemical shipment to certify at the port of entry to the U.S. that either 1) the shipment is subject to TSCA and complies with all applicable rules and orders thereunder, or 2) the shipment is not subject to TSCA.

The Chemical Right-to-Know Initiative and the High Production Volume Challenge Program

The Chemical Right-to-Know (RTK) Initiative was launched in 1998 in response to studies by the Environmental Defense Fund, the American Chemistry Council, and EPA that found that most commercial chemicals have very little, if any, toxicity information on which to make sound judgements about potential risks. Three key components of the RTK Initiative are to:

- complete baseline testing on the most widely used commercial chemicals
- conduct extensive testing on chemicals to which children are disproportionately exposed
- collect TRI release information on high-priority PBT (persistent, bioaccumulative, toxic) chemicals

The ultimate goal of the RTK Initiative is to make this information publicly available so that the public can make informed choices and decisions about their health and local environment.

EPA challenged industry to voluntarily undertake testing on 2,800 HPV (high production volume) chemicals for which baseline data are not available. HPV chemicals were defined as those manufactured in, or imported into, the US in amounts equal to or exceeding 1 million pounds per year (based on 1990 Inventory Update Rule data). Many of the HPV chemicals have been sponsored by industry, and EPA hopes to have all HPV testing completed by 2004. The following chemicals in the Flexo CTSA are in the HPV challenge.

Table 2.7 Chemicals in the High Production Volume Challenge Program

Butyl acetate	2-Ethylhexyl diphenyl phosphate
Butyl carbitol	n-Heptane
C.I. Pigment Blue 15	1,6 Hexanediol acrylate
C.I. Pigment Blue 61	Hydroxypropyl acrylate
C.I. Pigment Green 7	Isobutanol
C.I. Pigment Red 48, barium salt	Isopropanol
C.I. Pigment Red 48, calcium salt	Paraffin wax
C.I. Pigment Yellow 14	Polyethylene glycol
C.I. Pigment Yellow 74	Propanol
Citric acid	Propyl acetate
D&C Red No. 7	Propylene glycol methyl ether
Dicyclohexyl phthalate	Propylene glycol propyl ether
Dioctyl sulfosuccinate, sodium salt	Resin acids, hydrogenated, methyl esters
Dipropylene glycol methyl ether	Solvent naphtha (petroleum), light aliphatic
Distillates, (petroleum), hydrotreated light	Styrene
Distillates, (petroleum), solvent-refined light paraffinic	Tetramethyldecyndiol
Erucamide	Titanium isopropoxide
Ethanol	Trimethylolpropane ethoxylate triacrylate
Ethanolamine	Trimethyolpropane triacrylate
Ethyl acetate	Urea
Ethyl carbitol	

Table 2.8 CTSA Chemicals Regulated Under TSCA

Chemical Name	Section 4	Section 8(a) PAIR	Section 8(d)	Section 12(b)
Ammonia		✔		
Butyl acetate	✔			✔
Butyl carbitol	✔			✔
Dicyclohexyl phthalate		✔	✔	
Dipropylene glycol methyl ether	✔	✔	✔	✔
Ethyl acetate	✔	✔	✔	✔
Ethyl carbitol		✔	✔	
2-Ethylhexyl diphenyl phosphate	✔	✔	✔	✔
n-Heptane	✔	✔	✔	✔
1,6-Hexanediol diacrylate		✔		
Hydroxypropyl acrylate		✔		
Isobutanol	✔	✔	✔	✔
Isopropanol		✔	✔	
Propylene glycol methyl ether		✔	✔	
Silicone oil		✔	✔	
Styrene		✔		
Urea		✔		

Clean Water Act

The Clean Water Act (CWA) protects the chemical, physical, and biological quality of surface waters (e.g., lakes or rivers) in the United States. The CWA regulates wastewater discharged directly into surface waters or into municipal sewer systems. Most printers discharge wastewater to regional or municipal sewer systems, which also are known as Publicly Operated Treatment Works (POTWs).

National Pollutant Discharge Elimination System Program

Discharges of wastewater from point sources directly into a navigable water body are regulated under the National Pollutant Discharge Elimination System (NPDES) program (CWA section 402). This program applies to commercial and industrial facilities, as well as to POTWs. This program requires affected facilities to apply for a NPDES permit that is issued either by EPA or an authorized state agency.

The permits issued under NPDES contain industry-specific, technology-based, and water quality-based limitations on wastewater effluent. Generally, all facilities must meet limitations reflecting the best available control technology, regardless of the quality of receiving waters. Additionally, water quality-based limitations may also be required depending on the classification of the waters to which the effluent is discharged. For example, state and locally mandated water quality criteria may be designated to protect surface waters for aquatic life and recreation. In addition, NPDES permits specify the pollutant monitoring and reporting requirements for each regulated facility.

In addition, a storm water permit may be required if storm water is released to waters of the United States or to a municipal separate storm sewer system. In states in which EPA is the NPDES permitting authority, printers are eligible for the Multi-Sector General Permit (MSGP). In states where state agencies are authorized to execute NPDES permitting, requirements may be different or more stringent. A MSGP application requires a Storm Water Pollution Prevention Plan (SWPPP), which includes site maps showing drainage and outfall locations, an inventory of exposed materials, and pollution prevention Best Management Practices (BMPs). At least two days prior to the commencement of industrial activity, the facility would submit a Notice of Intent (NOI). Compliance with the MSGP may require visual examinations and analytical and compliance monitoring. If contaminated storm water is (or is planned to be) dischaged to a POTW, the POTW must be notified and permission to discharge obtained.

Printing facilities may be eligible for a conditional no-exposure exclusion from storm water permitting. The exclusion is applicable if "all industrial materials and activities are protected by a storm resistant shelter to prevent exposure to rain, snow, snowmelt, and/or runoff," the facility operator submits a written *No Exposure Certification* form, and the operator allows the permitting authority to inspect the facility and make inspection reports publicly available upon request.

Wastewater Discharges to POTW

Printing facilities that discharge or otherwise introduce their wastewater to POTWs are not required to obtain a National Pollutant Discharge Elimination System (NPDES) permit. However, such facilities may be required to comply with regional and local discharge requirements and federal or local pretreatment standards, and obtain local permits. Such requirements are established by the local and regional sewerage authorities to prevent significant interference with the POTW. Certain requirements also prevent the pass-through of hazardous, toxic, or other wastes not removed by available treatment methods. A POTW may require commercial and industrial customers, including printers, to monitor wastewater, keep records, and notify the POTW of certain discharges.

A national pretreatment program (CWA section 307(b)) regulates the introduction of pollutants to POTWs by industrial users. Pretreatment standards include general prohibitions and categorical industry standards (implemented on a nationwide basis), as well as local limits. General prohibitions involve pollutants that may not be introduced by any POTW users. These include the following materials:

- Pollutants that cause a fire or explosion hazard in the POTW
- Pollutants that will cause corrosive structural damage to the POTW
- Solid or viscous pollutants in amounts which will cause obstruction to the flow in the POTW
- Any pollutant, including oxygen demanding pollutants (BOD, etc) released in a discharge at a flow rate and/or pollutant concentration that will cause interference with the POTW
- Heat in amounts that will inhibit biological activity in the POTW
- Petroleum oil, nonbiodegradable cutting oil, or products of mineral oil origin in amounts that will cause interference or pass-through
- Pollutants that result in the presence of toxic gases, vapors or fumes within the POTW in a quantity that may cause acute worker health and safety problems
- Any trucked or hauled pollutants, except at discharge points designated by the POTW

No categorical pretreatment standards have been established for the printing industry. However, POTWs may establish local limits for customers.

Listed Chemicals

CTSA chemicals specifically regulated under the CWA (Table 2.9) are included in one of the following categories:

- *Hazardous substances* that are listed under Section 311 of the CWA have Reportable Quantity (RQ) thresholds; should a release of such a chemical occur above the threshold (or the effluent limitation established in a facility's NPDES or POTW permit), notice must be made to the federal government of the discharge. Four chemicals found in the inks used in this CTSA are hazardous substances.
- *Priority Pollutants* are 126 chemicals that must be tested for as a requirement of NPDES permits. One priority pollutant — surfactants (e.g., dioctyl sulfosuccinate, sodium salt) — is found in the inks used in this CTSA.

Table 2.9 CTSA Chemicals Regulated Under CWA

Chemical	Hazardous Substance RQ (lbs.)	Priority Pollutant
Ammonia	100	
Ammonium hydroxide	1000	
Butyl acetate	5000	
Styrene	1000	
Surfactants (e.g., dioctyl sulfosuccinate, sodium salt)		✔

Safe Drinking Water Act

The goal of the Safe Drinking Water Act (SDWA) is to ensure that drinking water is safe for the public. Under the SDWA, EPA has established national primary drinking water regulations. The primary regulations set maximum concentrations for substances found in drinking water that can adversely affect human health. Flexographic chemicals that may be regulated by SDWA include barium and styrene.

Comprehensive Environmental Response, Compensation, and Liability Act

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or more commonly known as Superfund) was enacted in 1980. CERCLA is the Act that created the Superfund hazardous substance cleanup program and set up a variety of mechanisms to address risks to public health, welfare, and the environment caused by hazardous substance releases.

Two important components of CERCLA are the (1) hazardous substance release notification requirements, and (2) establishment of the parties that are liable for response costs for removal or remediation of a release. Substances defined as hazardous under CERCLA are listed in 40 CFR 302.4. Under CERCLA and other acts, EPA has assigned a Reportable Quantity (RQ) to most hazardous substances; regulatory RQs are either 1, 10, 100, 1000, or 5000 pounds (except for radionuclides). If a release greater than the RQ occurs, a person in charge of the facility must immediately notify the National Response Center to help EPA identify sites that potentially warrant a response action. If EPA has not assigned an RQ to a hazardous substance, typically its RQ is one pound. Eight chemicals used in this CTSA have RQs, and are provided in Table 2.10.

Table 2.10 CTSA Chemicals Regulated Under CERCLA

Chemical	RQ (lbs.)
Ammonia	100
Ammonium hydroxide	1000
Butyl acetate	5000
Butyl carbitol[a]	✔
Dicyclohexyl phthalate[b]	✔
Ethyl acetate	5000
Ethyl carbitol[a]	✔
Isobutanol	5000
Styrene	1000

[a] This chemical is part of the glycol ethers broad category; a reportable quantity is not listed.
[b] This chemical is part of the phthalate esters broad category; a reportable quantity is not listed.

Emergency Planning and Community Right-to-Know Act

In 1986, Congress passed the Emergency Planning and Right-to-know Act (EPCRA) as part of the Superfund Amendments and Reauthorization Act (SARA). Three provisions of EPCRA may be of concern for printers: emergency notification, community right to know reporting, and the Toxics Release Inventory (TRI).

EPCRA Section 302 defines and regulates certain extremely hazardous substances. If quantities of these chemicals at a facility exceed the threshold planning quantities, the facility must notify the state and local emergency planning committees. These chemicals are also regulated by EPCRA Section 304, which requires facilities to report releases in excess of reportable quantities to the same state and local authorities, and to the local fire department. One chemical used in this CTSA, ammonia, is listed as an extremely hazardous substance (EHS). EPCRA 304 also requires facilities to notify the state and local authorities of release of CERCLA hazardous substances so that state and local governments and citizens can be informed of potential hazards.

EPCRA Sections 311 and 312 require facilities to report inventory information on the hazardous chemicals present on-site. Facilities are regulated under these provisions if they are regulated under OSHA's Hazard Communication Standard and exceed established thresholds for hazardous chemicals as defined in 29 CFR 1910.1200(c) at any one time. Facilities using hazardous chemicals must submit reports containing information on each hazardous chemical's identity, physical and health hazards, and location to state and local emergency planning committees and the local fire department. Reporting thresholds are 10,000 pounds for a compound that is not classified as an EHS, and 500 pounds or the chemical's threshold planning quantity, whichever is lower, for an EHS. The EHS used in the CTSA, ammonia, has a reporting threshold of 500 pounds.

Under EPCRA Section 313, a facility in a covered SIC code (of which printing is one), that has 10 or more full-time employees or the equivalent, and that manufactures, processes, or otherwise uses a toxic chemical listed in 40 CFR Section 372.65 above the applicable reporting threshold, must either file a toxic chemical release inventory reporting form (EPA Form R), or if applicable, an annual certification statement (EPA Form A). The Form R details a facility's release and other waste management activities of these listed toxic chemicals, including those releases specifically allowed by EPA or state permits. Except for the specific exemptions listed in 40 CFR372.45(d), printers should be aware that suppliers of products containing TRI chemicals above certain *de minimis* (minimum) concentrations are required to notify each customer (to whom the mixture or trade name product is sold or otherwise distributed from the facility) of the name of each listed toxic chemical and the percent by weight of each toxic chemical in the mixture or trade name product. Table 2.11 lists the six chemicals used in this CTSA that must be reported to TRI when annual use exceeds the TRI thresholds. The annual reporting thresholds for these chemicals[a] are 25,000 pounds for manufacture and process, and 10,000 pounds for otherwise use.

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[a] Recently promulgated rules lowered the reporting thresholds for compounds that are persistent, bioaccumlative toxins (PBTs)in the environment. Although none of the chemicals researched for the Flexography Project are PBTs, other flexographic chemicals could be. Information about PBTs can be obtained by contacting the RCRA, Superfund, and EPCRA Hotline at the number and website listed at the end of this section.

Table 2.11 CTSA Chemicals Regulated Under EPCRA

Chemical	EPCRA 302 Extremely Hazardous Substances	EPCRA 313 TRI Chemicals
Ammonia	✔	✔[a]
Barium		✔
Butyl carbitol		✔
Ethyl carbitol		✔
Isopropanol[b]		✔
Styrene		✔

[a] Includes anhydrous ammonia and aqueous ammonia from water dissociable ammonium salts and other sources; 10% of total aqueous ammonia is reportable.
[b] Processors and users of isopropanol are not required to report it. It is reportable by manufacturers using the strong acid process.

Occupational Safety and Health Act

The Occupational Safety and Health Administration (OSHA) was established to reduce occupational health hazards. OSHA regulations outline the educational and informational resources that a printer must utilize to assure the safe use of chemicals and the health of employees, including the following basic requirements:

- Material Safety Data Sheets (MSDSs) for certain hazardous chemicals must be provided by suppliers and maintained in-house for use by employees. For chemicals stored and used in amounts in excess of threshold levels established by OSHA, copies of MSDSs must be submitted to state and local emergency planning agencies and the local fire department.
- If a chemical is claimed to be proprietary, the appropriate information must be supplied to the designated health official.
- All containers must be properly labeled.
- A Job Safety and Health Protection workplace poster that indicates employee rights and responsibilities must be posted in a prominent place.
- A safety training program must be developed, and all employees must be trained.
- Facilities must submit an annual report indicating the aggregate amount of chemicals (above threshold quantities) used at their facilities, classified by hazard category.

OSHA regulations also require the use of personal protection equipment for specific situations, such as the use of gloves and goggles when working with certain solvents and inks. Other requirements relevant to printers include the installation of emergency eye wash stations in areas where eye irritants are used, and the development of a hearing conservation program if noise levels are equal to or exceed an eight-hour time weighted average of 85 decibels.

OSHA lockout/tagout regulations require the control of energy to equipment during servicing and maintenance. To prevent a machine from unexpectedly energizing, a facility must develop a plan to ensure that the energy source of a machine is locked out (with a locking device) or tagged out (with a prominent sign and fastener) when servicing or maintenance is being performed. For routine servicing (such as minor cleaning), printers may use effective alternative protection such as the "inch-safe-service" method, which allows energization of the press to inch it forward for servicing purposes as long as, at a minimum, a stop/safe/ready function is available at designated control stations and other requirements are followed.

OSHA also regulates the exposure of workers to chemicals in the workplace. OSHA has established permissible exposure limits (PELs) for air contaminants, which are regulatory limits on the amount or concentration of a substance in the air (29 CFR 1910.1000 Subpart Z) based on an 8-hour time weighted average. (PELs also may have a skin designation.) Other chemical exposure concentrations potentially used for regulation by OSHA include ceiling limits and short term exposure limits.

Many OSHA regulations are concerned with workplace processes. Section 2.4 of this chapter (Process Safety) deals with these issues as well.

Table 2.12 Flexography Federal Regulations Chemical Worksheet

Regulation	Affected Chemicals
Clean Air Act (CAA)	
112(b) Hazardous Air Pollutant	Butyl carbitol Ethyl carbitol Styrene
112(r) Risk Management Plan	Ammonia (in concentrations greater than 20%)
Resource Conservation and Recovery Act (RCRA)	
Characteristic Wastes (D Wastes)	Barium (D005) Ethyl acetate (D001) Ignitable solvent-based inks (D001) Isobutanol (D001) Any other waste that exhibits ignitability, corrosivity, reactivity, or toxicity as defined by RCRA
Non-specific Source Wastes (F Wastes)	Ethyl acetate (F003) Isobutanol (F005)
Specific Unused Chemicals (U Wastes)	Ethyl acetate (U112) Isobutanol (U140)
Toxic Substances Control Act (TSCA)	
Section 4	Butyl acetate Butyl carbitol Dipropylene glycol methyl ether Ethyl acetate 2-Ethylhexyl diphenyl phosphate n-Heptane Isobutanol
Section 8(a) PAIR	Ammonia Dicyclohexyl phthalate Dipropylene glycol methyl ether Ethyl acetate Ethyl carbitol 2-Ethylhexyl diphenyl phosphate n-Heptane 1,6 Hexanediol diacrylate Hydroxypropyl acrylate Isobutanol Isopropanol Propylene glycol methyl ether Silicone oil Styrene Urea

Table 2.12 Flexography Federal Regulations Chemical Worksheet (continued)

Regulation	Affected Chemicals
Section 8(d)	Dicyclohexyl phthalate Dipropylene glycol methyl ether Ethyl acetate Ethyl carbitol 2-Ethylhexyl diphenyl phosphate n-Heptane Isobutanol Isopropanol Propylene glycol methyl ether Silicone oil
Section 12(b)	Butyl acetate Butyl carbitol Dipropylene glycol methyl ether Ethyl acetate 2-Ethylhexyl diphenyl phosphate n-Heptane Isobutanol
Clean Water Act (CWA)	
Hazardous Substances (Reportable Quantities)	Ammonia (100 lbs.) Ammonium hydroxide (1000 lbs.) Butyl acetate (5000 lbs.) Styrene (1000 lbs.)
Priority Pollutants	Surfactants
Safe Drinking Water Act (SDWA)	
National Primary Drinking Water Regulations	Barium Styrene
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)	
Reportable Quantities (RQs)	Ammonia (100 lbs.) Ammonium hydroxide (1000 lbs.) Butyl acetate (5000 lbs.) Butyl carbitol (RQ not listed) Dicyclohexyl phthalate (RQ not listed) Ethyl acetate (5000 lbs.) Ethyl carbitol (RQ not listed) Isobutanol (5000 lbs.) Styrene (1000 lbs.)

Table 2.12 Flexography Federal Regulations Chemical Worksheet (continued)

Regulation	Affected Chemicals
Emergency Planning and Community Right-to-Know Act (EPCRA)	
Extremely Hazardous Substances	Ammonia
TRI Chemicals	Ammonia (10% of total aqueous ammonia) Barium Butyl carbitol Ethyl carbitol Isopropanol Styrene
Occupational Safety and Health Act (OSHA)	
Personal Exposure Limits (PELs)	Ammonia Barium 2-Butoxyethanol Butyl acetate Dipropylene glycol methyl ether Ethanol Ethanolamine Ethyl acetate n-Heptane Isobutanol Isopropanol Kaolin Propanol Propyl acetate Styrene

Additional Information on Printing-Related Regulations

GENERAL INFORMATION

Printers' National Environmental Assistance Center (PNEAC)
A website with links to compliance assistance and pollution prevention information and state-specific requirements
Website: www.pneac.org

Federal Environmental Regulations Potentially Affecting the Commercial Printing Industry (1994)
A short booklet that describes important points about the Clean Air Act, Clean Water Act, RCRA, etc., and how the printing industry is affected by each. Available from the National Service Center for Environmental Publications. Ask for Document EPA 744-B-94-001.
Telephone: 800-490-9198 or 513-489-8190
Website: www.epa.gov/ncepihom/ordering.htm

Government Printing Office (GPO)
The GPO website provides links to the full text of the Code of Federal Regulations (CFR), Federal Register notices for the past several years, and other resources.
Website: www.access.gpo.gov/nara/

INFORMATION ABOUT THE CLEAN AIR ACT

The **Clean Air Technology Center** (CATC)
A source of general information on air emissions-related technology.
Telephone: 919-541-0800
Website: www.epa.gov/ttn/catc

INFORMATION ABOUT THE RESOURCE CONSERVATION AND RECOVERY ACT

The **RCRA, Superfund & EPCRA Hotline** offers information and publications that are relevant to RCRA.
Telephone: 800-424-9346
Website: www.epa.gov/epaoswer/hotline

RCRA in Focus: Printing
A short booklet that provides an overview of the federal regulations that the printing industry is required to follow and lists the printing industry wastes that are likely to be hazardous. Available from the RCRA, Superfund & EPCRA Hotline. Ask for Document EPA 530-K-97-007.

Understanding the Hazardous Waste Rules: A Handbook for Small Businesses, 1996 Update
A manual that is targeted to small quantity generators of hazardous wastes. The manual helps small businesses determine whether they generate hazardous waste and provides comprehensive information on how to comply with the federal hazardous waste regulations for small quantity generators. Available from the RCRA, Superfund & EPCRA Hotline. Ask for Document EPA 530-K-95-001.

INFORMATION ABOUT THE TOXIC SUBSTANCES CONTROL ACT

The **TSCA Assistance Information Service** (TSCA hotline) can provide information TSCA.
Telephone: 202-554-1404
Website: www.epa.gov/opptintr/chemtest

INFORMATION ABOUT THE CLEAN WATER ACT

EPA's **Office of Water**, especially the Office of Wastewater Management, can be contacted for information on Clean Water Act provisions that relate to the printing industry.
Telephone: 202-564-5700
Website: www.epa.gov/ow

INFORMATION ABOUT THE SAFE DRINKING WATER ACT

The **Safe Drinking Water Hotline** can provide information on issues related to the Safe Drinking Water Act.
Telephone: 800-426-4791
Website: www.epa.gov/ogwdw

INFORMATION ABOUT THE COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

The **RCRA, Superfund & EPCRA Hotline** offers information and publications that are relevant to CERCLA.
Telephone: 800-424-9346
Website: www.epa.gov/epaoswer/hotline

The **Superfund Website** provides general information on CERCLA.
Website: www.epa.gov/superfund

INFORMATION ABOUT THE EMERGENCY PLANNING AND RIGHT-TO-KNOW ACT

The **Chemical Emergency Preparedness and Prevention Office** website
Website offers information on the emergency response aspects of EPCRA, which are administered under the Chemical Emergency Preparedness and Prevention Office.
Website: www.epa.gov/swercepp/

The **Toxics Release Inventory** website
Provides information on the Toxics Release Inventory reporting requirements, which are implemented by the Office of Pollution Prevention and Toxics.
Website: www.epa.gov/tri

The **RCRA, Superfund & EPCRA Hotline** offers information and publications that are relevant to EPCRA.
Telephone: 800-424-9346
Website: www.epa.gov/epaoswer/hotline

INFORMATION ABOUT THE OCCUPATIONAL SAFETY AND HEALTH ACT

The **Occupational Safety and Health Administration (OSHA)** website
Provides information on the Occupational Safety and Health Act, OSHA regulations, standards, interpretations, and other information.
Website: www.osha.gov/

INFORMATION ABOUT THE DEPARTMENT OF TRANSPORTATION

The **Department of Transportation (DOT) Hazardous Materials Information Center** provides information about transporting hazardous materials.
Telephone: 800-467-4922
Website: http://hazmat.dot.gov/

2.4 PROCESS SAFETY

Procedures for safely preparing, operating, and cleaning press equipment help to avoid serious injuries and health problems to employees. An effective process safety program identifies workplace hazards and seeks to eliminate or reduce their potential for harm. Chemicals used in the flexographic printing process present safety hazards to workers and the facility; therefore they must be handled and stored properly using appropriate personal protective equipment and safe operating practices.

The U.S. Department of Labor and OSHA have established safety standards and regulations to assist employers in creating a safe working environment and protect workers from potential workplace hazards. In addition, individual states may also have safety standards regulating chemical and physical workplace hazards for many industries. Federal safety standards and regulations affecting the flexographic printing industry can be found in the Code of Federal Regulations (CFR) Title 29, Part 1910 and are available by contacting the local OSHA field office. State and local regulations are available from the appropriate state office.

Reactivity, Flammability, Ignitability, and Corrosivity of Flexographic Ink Chemicals

Table 2.13 lists four safety hazard factors for the nine ink product lines that were tested in the performance demonstrations, and Table 2.14 summarizes the safety hazards by ink system. (Where available, the reactivity and flammability values were extracted directly from Section One of the MSDS, which contains the National Fire Protection Association (NFPA) values for these factors.) Printers should be aware of the safety hazards for all chemicals used and stored in a facility, should post the relevant MSDSs as required, and should consider whether ink products with lower safety ratings are available and suitable.

For **reactivity**, NFPA ranks materials on a scale from 0 to 4, with 0 being the safest:

0 — materials that are normally stable, even under fire exposure conditions, and that do not react with water; normal fire fighting procedures may be used.

1 — materials that are normally stable but may become unstable at elevated temperatures and pressures, as well as materials that will react (but not violently) with water, releasing some energy; fires involving these materials should be approached with caution.

2 — materials that are normally unstable and readily undergo violent chemical change, but are not capable of detonation; this includes materials that can rapidly release energy, materials that can undergo violent chemical changes at high temperatures and pressures, and materials that react violently with water. In advanced or massive fires involving these materials, fire fighting should be done from a safe distance from a protected location.

3 — materials that, in themselves, are capable of detonation, explosive decomposition, or explosive reaction, but require a strong initiating source or heating under confinement; fires involving these materials should be fought from a protected location.

4 — materials that, in themselves, are readily capable of detonation, explosive decomposition, or explosive reaction at normal temperatures and pressures. If a material having this Reactivity Hazard Rating is involved in a fire, the area should be immediately evacuated.

For the CTSA inks, all inks except the UV product lines were rated as completely non-reactive. One UV product line was given a rating of 1, and the others did not have a rating.

For **flammability**, NFPA ranks materials also on a scale from 0 to 4, with 0 being the safest:

0 — materials that will not burn.

1 — materials that must be preheated before ignition will occur and whose flash point exceeds 200 °F (93.4 °C), as well as most ordinary combustible materials.

2 — materials that must be moderately heated before ignition will occur and that readily give off ignitible vapors.

3 —flammable liquids and materials that can be easily ignited under almost all normal temperature conditions; water may be ineffective in controlling or extinguishing fires in such materials.

4 — flammable gases, pyrophoric liquids, and flammable liquids. The preferred method of fire attack is to stop the flow of material or to protect exposures while allowing the fire to burn itself out.

Flammability ratings for the CTSA ink product lines ranged widely. Both solvent-based inks were rated at 3, and water-based inks received ratings ranging from 0 to 3. One UV product line was given a rating of 1, but the others were unrated.

For **ignitability**, the inks are classified as either ignitable (y) or not ignitable (n). Ignitability is based on the flash point of the ink product line, which is the lowest temperature at which it can be ignited. A chemical is considered ignitable if it is a liquid, other than an aqueous solution containing less than 24% alcohol by volume and has a flash point less than 60°C (140 °F).[43] For the CTSA product lines, only the two solvent-based inks were rated as ignitable.

For **corrosiveness**, the inks are classified as either corrosive (y) or not corrosive (n). Corrosiveness was determined based on the pH of the product.[44] A chemical is corrosive if it is aqueous and has a pH less than or equal to 2 or greater than or equal to 12.5. This information was not available for any product lines except one, which was rated as non-corrosive.

Table 2.13 Safety Hazard Factors for CTSA Ink Product Lines[a]

Product line	Formulation (Color)	Reactivity	Flammability	Ignitability	Corrosivity
Solvent-based #S1	All	0	3	y	
Solvent-based #S2	All	0	3	y	
Water-based #W1	Blue, green	0	3	n	
	White, cyan	0	2	n	
	Magenta	0	1	n	
Water-based #W2	Blue, green, white	0	0	n	n
	Cyan, magenta	0	1	n	
Water-based #W3	All	0	1	n	
Water-based #W4	Blue	0	0	n	
		0	2	n	
		0	3	n	
	Green	0	2	n	
		0	2	n	
		0	3	n	
	White	0	2	n	
	Cyan	0	0	n	
		0	3	n	
	Magenta	0	2	n	
UV-cured #U1	All			n	
UV-cured #U2	All	1	1	n	
UV-cured #U3	All			n	

[a] A blank cell indicates that there was not enough information available to develop a safety hazard factor ranking. For inks that were blended and therefore have more than one MSDS, the ratings for all components in each formulation are given.

Table 2.14 Summary of Safety Hazard Factors by Ink System

Ink system	Reactivity	Flammability	Ignitability	Corrosiveness
Solvent-based	0	3	y	ND[a]
Water-based	0	0-3	n	[b]
UV-cured	[c]	[d]	n	ND[a]

[a] No data
[b] Incomplete data — three formulations of one product line were not corrosive.
[c] Incomplete data — all formulations of one product line were given reactivity levels of 1.
[d] Incomplete data — all formulations of one product line were given flammability levels of 1.

The following observations can be noted from the tables:

- All of the solvent- and water-based inks had reactivity levels of zero. One UV-cured ink (#U2) had a reactivity level of one; the reactivity of other UV-cured inks was unknown.
- Flammability was more of a concern for some inks than others. All of the solvent-based inks had flammability levels of three. Some of the water-based inks (Water-based inks #W2 and #W3) had flammability levels of zero or one. However, some formulations of Water-based inks #W1 and #W4 had flammability levels of two or three. The flammability levels for UV-cured ink #U2 was one; the flammability of the other UV-cured inks were not known.
- Ignitability was a concern primarily for solvent-based inks.
- Although information for corrosiveness was sparse, the water-based inks for which information was available were listed as not corrosive.

Process Safety Concerns

Exposure to chemicals is just one of the safety issues that flexographic printers may have to deal with during their daily activities. By establishing and following proper safeguards and practices, printers can benefit in three ways: increased worker safety, lower insurance rates, and fewer work days missed due to accidents and injuries. To maintain a safe and efficient workplace, employers and employees need to understand the importance of establishing safety procedures and using appropriate safeguards. The most important safety practices include the following:

Training

A critical element of workplace safety and an efficiently running press is a well-educated workforce. To help achieve this goal, OSHA's Hazard Communication Standard requires that all employees be trained in the use of hazardous chemicals to which they may be exposed. Training may be conducted either by facility staff or by outside parties who are familiar with the flexography process and the pertinent safety concerns. The training should be held for each new employee, and all employees should have retraining when necessary (for example, if new equipment is installed or new ink types are used) or on a regular schedule. The training program should explain the types of inks, solvents, cleaning compounds, and other chemicals used, and precautions for handling or storing them; when and how personal protective equipment should be worn; the need for other safety features such as equipment guards and their proper use; and how to maintain equipment in good operating condition.

Contingency Plan for Chemical Spills and Emergencies

Most states require manufacturing facilities, including flexographic printing facilities, to establish a contingency plan in the event of an accidental chemical release. Having a plan in place can reduce injuries to employees, help protect the community and environment, and minimize downtime. The plan should include the following:

- a list of chemicals in the facility
- how the chemicals are stored and used
- information on the likely cause, nature, and route of a chemical release
- emergency response devices and procedures including alarm systems, evacuation plans, and arrangements with local hospitals, police, and fire departments
- contact information for the facility emergency coordinators

- emergency equipment information, such as the location of fire extinguishers and spill control kits.[45]

Electrical Grounding

Grounding is an important safety precaution when using machinery. When conductive material, like a steel central impression drum, is not grounded, the conductor may generate and/or store electricity. Non-conductive or ungrounded conductive materials become electrostatically charged by friction.[46] Static may be generated when the web is unwinding, when the web leaves the rollers, or by friction from shoes and clothing. Static is also increased by low humidity.[47] Static may result in sparks that can cause explosions and electrical interference. Proper grounding is the simplest way to control static.

Storing Chemicals

Chemicals that are ignitable or flammable should be labeled accordingly and stored in the appropriate storage space. Chemicals that are incompatible with other chemicals or that require special precautions during use should also be appropriately labeled and stored. For example, solvents and solvent-based inks should be stored in ventilated, explosion-proof rooms. Since some of the chemicals used in the press room may be flammable, the facility should be inspected periodically by the local fire marshall to ensure that the chemicals are stored properly and ventilated, thus reducing the potential for a fire.

Storing Rags and Towels

Rags and towels that are used to wipe up chemicals or clean presses may be considered hazardous waste by EPA and state and local agencies if they contain specified hazardous chemicals in sufficient amounts. These towels should be stored and disposed of in accordance with federal, state, and local regulations. If uncertain about whether or not the shop's used rags or towels require special treatment as hazardous waste, a printer should contact the state environmental agency or state technical assistance program.

Preventive Worker Behavior

Personal safety considerations are also the responsibility of the worker. Workers should be discouraged from eating or keeping food near presses or chemicals. Since presses contain moving parts, workers should also refrain from wearing jewelry or loose clothing that may become caught in the machinery and cause injury to the worker. In particular, the wearing of rings or necklaces may lead to injury. Workers with long hair should pull their hair back or wear a hair net to prevent the hair from getting caught in the machinery.

Material Safety Data Sheets

Since flexographic printing requires the use of a variety of chemicals, it is important that workers know and follow the correct procedures for handling the chemicals. Much of the information about the use, disposal, and storage of chemicals may be obtained from the MSDS provided by the manufacturer for each ink product line, cleaner, and other chemicals. The MSDS also recommends the appropriate personal protective equipment for handling a particular chemical. The MSDS for each chemical used should be placed in an easily accessible location in the vicinity of the press room.

Personal Protective Equipment (PPE)

OSHA has developed several PPE standards that are applicable to the printing industry. These standards address general safety requirements (29 CFR Part 1910.132), the use of eye and face protection (Part 1910.133), head protection (Part 1910.135), foot protection (Part 1910.136), and hand protection (Part 1910.138).

The standards for eye, face, and hand protection are particularly important for printers who have frequent contact with chemicals (including solvents, dispersants, surfactants, and inks) that may irritate or harm the skin and eyes, or that may be absorbed dermally. To prevent or minimize exposure to such chemicals, workers should be trained in the proper use of personal protective equipment. For many chemicals, appropriate equipment includes goggles, aprons or other impervious clothing, and gloves. In some printing facilities with loud presses, hearing protection may be recommended or required.

Equipment Guards

In addition to the use of proper personal protective equipment for all workers, OSHA has developed safety standards that apply to the actual equipment used in printing facilities. These machine safety guards are described in 29 CFR Part 1910.212 and are applicable to all sectors of the printing industry, including flexography. Barrier guards, two-hand trip devices, and electrical safety devices are among the safeguards recommended by OSHA. Safeguards for the normal operation of press equipment are included in the standards for mechanical power-transmission apparatus (29 CFR Part 1910.219) and include belts, pulleys, flywheels, gears, chains, sprockets, and shafts.

The National Printing Equipment and Supply Association has available copies of the American National Standard for Safety Specifications for Printing Press Drive Controls. These safety recommendations address the design of press drive controls specifically, as well as safety signaling systems for printing presses. Printers should be familiar with the safety requirements included in these standards and should contact their local OSHA office or state technical assistance program for assistance in determining how to comply with them.

OSHA also has a lockout/tagout standard (29 CFR part 1910.147). This standard is designed to prevent the accidental start-up of electric machinery during cleaning or maintenance operations. This standard may pose particular problems for flexographic printers during minor, routine procedures that require frequent stops (e.g., cleaning the press or on-press maintenance). For such cases, OSHA has granted an exemption for minor servicing of machinery provided the equipment has other appropriate safeguards, such as a stop/safe/ready button which overrides all other controls and is under the exclusive control of the worker performing the servicing. Such minor servicing of printing presses has been determined to include clearing jams, minor cleaning, lubricating, adjusting operations, plate changing tasks, paper webbing, and roll changing. Rigid finger guards should also extend across the rolls, above and below the area to be cleaned. Proper training of workers is required under the standard whether lockout/tagout is employed or not. For further information on the applicability of the OSHA lockout/tagout standard to printing operations, printers should contact their local OSHA field office.

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Chapter 3: Risk

CHAPTER CONTENTS

CHAPTER OVERVIEW

This chapter presents the hazards, exposures, and associated health and environmental risks that may result from the chemicals in the solvent-based, water-based, and UV-cured ink systems studied in the CTSA.

INTRODUCTION TO RISK: Section 3.1 presents an introduction to the central concepts of risk. Common steps of a risk assessment are described, including hazard identification, dose-response assessment, exposure assessment, and risk characterization. Finally, three major types of potential effects of hazardous substances on living organisms (systemic toxicity, developmental toxicity, and carcinogenic effects) are described.

HAZARD IDENTIFICATION: Section 3.2 discusses the human health and ecological hazards of all the chemicals in the flexographic inks included in this study. The information is based on data found in published toxicological studies as well as reports prepared by the EPA Structure Activity Team (SAT). Detailed information can be found in Appendices 3-A and 3-B. Additionally, some chemicals are regulated under major federal regulations; information about the applicability of these regulations can be found in Chapter 2.

CHEMICAL CATEGORIES: Section 3.3 describes the chemical categories into which the flexographic ink chemicals were organized for this CTSA. Subsequent sections of the risk assessment discuss these chemical categories rather than specific chemicals, in order to protect the confidentiality of ink manufacturers regarding specific ink formulations. This section also identifies the relevant chemical categories for each of the ink formulations studied.

AIR RELEASES: Section 3.4 presents the environmental air releases that may result from using these flexographic inks. The results were generated with mass balance calculations.

EXPOSURE ASSESSMENT FOR WORKERS AND GENERAL POPULATION: Section 3.5 discusses the potential dermal and inhalation exposures to workers that can occur as a result of working with these inks. The exposure assessment was performed under two modeled scenarios: the ink preparation room (Scenario 1) and the press room (Scenario 2). The results of both scenarios are presented in this section, but only the results from Scenario 2, which yielded higher exposure rates, are used for the subsequent Risk Characterization. Section 3.6 presents potential inhalation exposures for the general population.

RISK CHARACTERIZATION: Lastly, Section 3.7 describes the risk characterization for these flexographic inks. The risk characterization integrates the hazard and exposure information to arrive at risk estimates to workers and the exposed general population near to a flexographic facility.

HIGHLIGHTS OF RESULTS

Useful information can be gleaned from each section of this chapter. However, when comparing the overall impacts of ink formulations, the risk characterization (Section 3.7) is the most relevant. These results are based on modeled assumptions about conditions and practices in flexographic printing facilities, and therefore may not represent all printing facilities. However, in any printing facility, workers are exposed to printing chemicals to some extent. Chapter 7 contains information about practices that can reduce or eliminate pollution and worker exposure from many steps in the printing process. Several of the important findings are noted on the next page.

- **Thirty of the 48 chemicals for which toxicological information is available were found to represent medium or high hazard levels for systemic or developmental toxic effects.** In addition, ethanol has been documented to be carcinogenic to humans. Another six chemicals show evidence of carcinogenicity via inhalation or dermal exposure routes, but are not classified as carcinogenic at this time. (See Section 3.2)
- With regard to **ecological hazard, the analysis found that 18 chemicals were of high concern, and another 35 had medium hazard rankings**. (See Section 3.2)
- **The solvent-based inks released considerably more volatile matter than the water-based and UV-cured inks.** Water-based and UV-cured ink releases were comparable; however, the UV-cured results should be interpreted as an upper limit or worst-case scenario, because in practice much of the volatile material reacts and becomes nonvolatile. (See Section 3.4)
- Inhalation exposure is related to air releases. **For workers in the press room, exposure is highest with solvent-based inks** because of their higher air release rate. For the general population, however, exposure from solvent-based inks is lower than that from water-based inks because of the anticipated use of emission control equipment with solvent-based inks.
- The dermal exposure for prep room and press room workers is comparable for all three ink systems, and there is no expected dermal exposure for the general population. (See Sections 3.5 and 3.6)
- **Each ink system contained chemicals of clear risk concern for occupational health.** For both solvent-based and water-based inks, the chemicals that most commonly were a clear concern for risk were solvents, with some colorants and other chemicals also listed. For UV-cured inks, chemicals of clear concern for occupational risk were monomers, pigments, additives, and some chemicals that crossed functional categories.
- **Regarding risk to the general population, no chemicals were found to be of clear concern.** Potential concern for risk was posed by some solvents in solvent-based and water-based inks, and by some monomers and other chemicals in UV-cured inks. (See Section 3.7)

CAVEATS

- These results analyze only 45 of the many thousands of ink formulations that are available. They represent only a snapshot taken at a small selection of printing facilities, and should not be taken as representative of inks in general.
- The results presented in this chapter were based on the ink formulations as submitted to DfE; reaction products or other changes in chemical composition resulting from the printing process (e.g., the curing process for UV-cured inks) were not considered.
- Information for some chemicals was incomplete. EPA's Structure Activity Team (SAT) estimated properties for these chemicals based on molecular structure, similarity to well-studied chemicals, and other factors, but SAT reports are less preferable than direct toxicological research results.
- The results of this analysis also are dependent on assumptions that may or may not be true for other printing situations. (The assumptions are stated in the chapter and accompanying appendices.) For example, dermal results were calculated based on the assumption that no gloves are worn. If workers wear gloves when working with these chemicals, dermal exposure and risk would be substantially lower than reported here. Readers are advised to use caution when applying any results from this analysis to other situations.
- The designation of a chemical as being of "high" hazard or "clear" concern for risk does not give any indication of the potency of a chemical other than the fact that it meets the defined minimum threshold. A chemical with a high hazard or clear concern for risk, therefore, may be slightly above the respective threshold, or may be far beyond that threshold.

3.1 INTRODUCTION TO RISK

This section describes common concepts and components of a risk assessment. This information provides a context in which to understand the risk assessment that was performed on the flexographic chemicals studied in this CTSA.

Background

Chemicals affect the health of humans and the environment in a variety of ways. Human exposure to chemicals may occur through air that is inhaled, through water and food that are ingested, or through skin contact. Exposure to particular chemicals may create concentration levels that result in cellular damage, which in turn may cause disease and death. A risk assessment is a four-step process that identifies chemicals that may present harm to humans and other organisms.

A risk assessment includes four primary parts:

1. hazard identification[a]
2. dose-response assessment
3. exposure assessment
4. risk characterization

Hazard Identification

The first step in a risk assessment is hazard identification. This asks whether a chemical *could* cause adverse health effects in humans or in nature. That is, have toxic or carcinogenic effects been observed in previous studies of the chemical? Hazard is independent of exposure, so it is necessary to conduct a dose-response assessment and exposure assessment before applying hazard information directly to a specific set of conditions.

Dose-response Assessment

A dose-response assessment determines the chemical's toxicity — the relationship between the dose of a chemical received and the incidence and severity of adverse health effects in the exposed population. Epidemiological or historical human-based data are the preferred sources used to determine toxicity values. If those types of data are not available, laboratory animal studies are evaluated to see how their data may apply to humans. Toxicity values are used to estimate effects resulting from exposure to a chemical.

In this CTSA, results of the hazard identification and dose-response assessment are presented together in one section.

Exposure Assessment

An exposure assessment identifies populations (e.g., different groups such as factory workers or residents of an area) that are or could be exposed to a chemical. The exposure assessment describes the population's composition and size, and it identifies the types, magnitudes, frequencies, and durations of their exposure to the chemical. For this project, the exposure assessment assumes that workers in a flexographic printing plant can be exposed to chemicals via dermal (skin) or inhalation (breathing) absorption, and that the general

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[a] In Europe, hazard is referred to as "toxicity."

population can be exposed via inhalation only. It is assumed that neither population is subject to toxic effects via oral exposure (e.g., drinking or eating contaminated substances).

Risk Characterization

A risk characterization uses hazard, dose-response, and exposure information to develop quantitative and qualitative expressions of risk. A good risk characterization describes the assumptions, scientific judgments, and uncertainties embodied in the assessment.

Quantitative Expressions of Hazard and Risk

The manner in which estimates of hazard and risk are expressed depends on the nature of the hazard and the types of data upon which the assessment is based. For example, cancer risks are most often expressed as the probability of an individual developing cancer over a lifetime of exposure to the chemical in question. Risk estimates for adverse effects other than cancer are usually expressed as the ratio of the toxicological potency of the chemical to the estimated dose or exposure level received. A key distinction between cancer and other toxicological effects is that *most carcinogens are assumed to have no dose threshold*. That is, exposure to *any* amount of the chemical is assumed to carry some risk. Other toxicological effects are generally assumed to have a dose threshold — an exposure level below which a significant adverse effect is not expected.

The Reference Dose (RfD) is an estimate of the lowest daily human exposure that is likely to occur without appreciable risk of deleterious, non-cancerous effects during a lifetime. The RfD is usually expressed as an oral dose per kilogram of body weight (given in units of mg/kg/day). The Reference Concentration (RfC) is an analogous value for continuous inhalation exposure, usually expressed in mg/m^3 (milligrams per cubic meter).

Deriving an RfD or RfC involves determining a No Observed Adverse Effect Level (NOAEL) or Lowest Observed Adverse Effect Level (LOAEL) from an appropriate toxicological or epidemiological study, and then applying various uncertainty and modifying factors to arrive at the RfD or RfC. The NOAEL is the highest exposure level that can occur without statistically or biologically significant adverse effects, and the LOAEL is the lowest exposure level at which adverse effects have been shown to occur. Although some RfDs and RfCs are based on actual human data, they are most often calculated from results obtained in laboratory animal studies. The following represents the equation for a RfD:

$$\mathrm{RfD} = \frac{\mathrm{NOAEL\ (or\ LOAEL)}}{\mathrm{UF} * \mathrm{MF}} .$$

In this equation, the Uncertainty Factor (UF) reflects the various types of data sets used to estimate the RfD. For example, a valid chronic animal NOAEL is normally divided by a UF of 100. Several forms of uncertainty are accounted for in the UF: variation in sensitivity among members of the human population, the uncertainty in extrapolating animal data to the case of humans, the uncertainty in extrapolating from data obtained in a study that is of less-than-lifetime exposure, and the uncertainty in using LOAEL data rather than NOAEL data. The Modifying Factor (MF) is applied based on a professional judgment of the quality of the data available for the chemical. The default value for MF is 1.

Definitions of Systemic Toxicity, Developmental Toxicity, and Carcinogenic Effects

This risk assessment identifies systemic toxicity, developmental toxicity, and carcinogenic risks of chemicals found in the ink formulations used in the performance demonstrations. These measures are explained in more detail below.

Systemic Toxicity

Systemic toxicity refers to adverse effects on any organ system following absorption and distribution of a chemical throughout the body. *Adverse effects other than cancer and gene mutations are generally assumed to have a dose or exposure threshold.* Thus, much of the evaluation for systemic toxicity for each chemical will depend on the relationship between the threshold and the anticipated exposure.

RfDs and RfCs can be used to evaluate risks from chronic (long-term) exposures to systemic toxicants. EPA has defined an expression of risk called a Hazard Quotient (HQ), which is the ratio of the average daily dose to the RfD or RfC. HQ values below 1 imply that adverse effects are very unlikely to occur. The more the HQ exceeds 1, the greater the level of concern. It is important to remember that the HQ is not a probabilistic statement of risk; a quotient of 0.001 does not mean that there is a one-in-a-thousand chance of the effect occurring. Furthermore, it is important to remember that the level of concern does not necessarily increase linearly as the HQ approaches or exceeds 1. The HQ is calculated by the following equation:

$$\mathrm{HQ} = \frac{\mathrm{ADD}}{\mathrm{RfD\ (or\ RfC)}}\,.$$

The derivation of the Average Daily Dose (ADD) is described in Section 3.7, Risk Characterization.

When an RfD or RfC is not available, risk may be expressed as the Margin of Exposure (MOE) instead of a HQ. The MOE is the ratio of a NOAEL or LOAEL (preferably from a chronic study) to an estimated dose or exposure level. The following equation represents the calculation of a MOE:

$$\mathrm{MOE} = \frac{\text{NOAEL (or LOAEL)}}{\text{calculated or measured human dose}}\,.$$

High MOE values (e.g., greater than 100 for a NOAEL-based MOE or 1,000 for a LOAEL-based MOE) imply a low level of risk. As the MOE decreases, the level of risk increases. As with the HQ, it is important to remember that the MOE is not a probabilistic statement of risk.

Reproductive toxicity is also an important aspect of systemic toxicity. For purposes of this assessment, toxicity information on adult male and female reproductive systems was assessed.

Developmental Toxicity

EPA defines developmental toxicity as adverse effects on a developing organism that may result from exposure prior to conception, during prenatal development, or postnatally up to the time of sexual maturation. This is different from reproductive toxicity, which is a component of systemic toxicity and represents adverse effects on the reproductive systems of mature organisms. Adverse developmental effects may be detected at any point in the life span of the organism. The major manifestations of developmental toxicity are (a) death, (b) structural abnormality, (c) altered growth, or (d) functional deficiency.

Because many elements associated with the hazard and exposure components of developmental toxicity risk assessment are unique, this assessment treats these risks separately from other systemic toxicity risks.

Developmental toxicity assessments usually assume that a single exposure at any developmental stage may be sufficient to produce an adverse developmental effect. In the case of intermittent exposures, an examination of the peak exposure(s) is as important as the average dose over the time period of exposure. In this project, however, an acute (short-term) risk sampling showed an insignificant likelihood of acute effects; therefore, further peak exposure modeling was not performed, and only average exposure values are presented in this report.

EPA has derived RfDs and RfCs for developmental toxicants in a manner similar to its derivation of RfDs and RfCs for systemic toxicants. The RfD_{DT} or RfC_{DT} is an estimate of a daily exposure to developmental toxicants by a human population that is assumed to be without appreciable risk of deleterious developmental effects. The use of the subscript "$_{DT}$" refers specifically to developmental toxicity.

Developmental toxicity risk can be expressed as a Hazard Quotient (dose or exposure level divided by the RfD_{DT} or RfC_{DT}) or a Margin of Exposure (NOAEL or LOAEL divided by the dose or exposure level).

Carcinogenic Effects

Carcinogenic effects are malignant tumors caused by cancer. EPA groups chemicals into one of the five weight-of-evidence categories, which indicate the extent to which the available data support the hypothesis that a substance causes cancer in humans. The categories are listed below:

- Group A — human carcinogen
- Group B — probable human carcinogen (B1 indicates limited human evidence, B2 indicates sufficient evidence in animals but inadequate or no evidence in humans)
- Group C — possible human carcinogen
- Group D — not classifiable as to human carcinogenicity
- Group E — evidence of noncarcinogenicity for humans

The International Agency for Research on Cancer (IARC) has an analogous categorization system; in this CTSA, both categorization systems are used wherever information is available.

The 1996 EPA proposed guidelines for carcinogenicity assessment use three categories to describe human carcinogenic potential:

- Known/Likely — available tumor effects and other key data are adequate to demonstrate carcinogenic potential for humans convincingly
- Cannot Be Determined — available tumor effects or other key data are suggestive, conflicting, or limited in quantity, and therefore are not adequate to demonstrate carcinogenic potential for humans convincingly
- Not Likely — experimental evidence is satisfactory for deciding that there is no basis for human hazard concern

When the available data are sufficient, EPA calculates a quantitative estimate of the chemical's carcinogenic potency. Three measures are the slope factor, unit risk, and cancer risk.

- **Slope factors** express carcinogenic potency in terms of the estimated upper-bound incremental lifetime risk, in milligrams per kilogram of body weight (mg/kg) average daily dose.

- **Unit risk** is a similar measure of potency for air or drinking water concentrations. Unit risk is expressed as risk per µg/m^3 (micrograms per cubic meter) in air or as risk per µg/L (micrograms per liter) in water for continuous lifetime exposures.[b]

- **Cancer risk** is calculated by multiplying the estimated dose or exposure level by the appropriate measure of carcinogenic potency. For example, an individual who has a lifetime average daily dose of 0.003 mg/kg of a carcinogen with a potency of 0.02 mg/kg/day would experience a lifetime cancer risk of 0.00006 (1 in 17,000) from exposure to that chemical. In general, risks from exposure to more than one carcinogen are assumed to be additive (the risk caused by each additional chemical leads to a larger overall risk), unless other information points toward a different interpretation.

Definition of Aquatic Toxicity

Aquatic toxicity refers to an adverse effect on an aquatic organism following exposure to a toxicant. For this analysis, acute and chronic aquatic toxicity values were gathered for fish, aquatic invertebrates, and green algae. The acute values are reported in either of two ways:

- LC_{50}, the concentration at which 50 percent of test organisms die within a specified short-term exposure period
- EC_{50}, the concentration at which 50 percent of the organisms show an adverse (non-lethal) effect, such as growth inhibition, at the end of the exposure period.

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[b] Sufficient input data were not available for the flexographic ink chemicals considered in this CTSA; therefore, slope factors or unit risk measures were not calculated for this analysis.

3.2 HUMAN HEALTH AND ECOLOGICAL HAZARDS

Human Health Hazards

Human Health Hazard Methodology

As a first step toward determining the hazards and potential exposure associated with each chemical found in the flexographic inks used in this study, EPA compiled information about their chemical and physical properties. Profiles of the CTSA chemicals are presented in Appendix 3-A. The profiles include the chemical structure and key properties, including molecular weight, melting and boiling point, vapor pressure, flash point, water solubility, density, and function in ink. The chemicals are listed alphabetically, with their synonyms and CAS numbers, in Table 3-A.1 of that Appendix.

Databases exist that list chemical hazard information used to characterize systemic, developmental, and carcinogenic effects. Most databases are available through online searching and are maintained by a variety of government and private organizations. They may contain both numeric and textual information relating to the chemicals. Some of the hazard databases used in the initial literature search for this CTSA include the following:

- EPA's Integrated Risk Information System (IRIS)
- National Library of Medicine's Hazardous Substances Data Bank (HSDB)
- TOXLINE
- TOXLIT
- GENETOX
- Registry of Toxic Effects of Chemical Substances (RTECS)
- American Conference of Governmental Industrial Hygienists (ACGIH)
- Agency for Toxic Substances and Disease Registry (ATSDR)
- National Toxicology Program (NTP)
- International Agency for Research on Cancer (IARC)
- National Institute for Occupational Safety and Health (NIOSH)
- Occupational Safety and Health Administration (OSHA)

These databases yielded secondary data for this report; no attempts were made to verify the information. Other data were also reviewed, including toxicological data developed under EPA's Office of Pollution Prevention and Toxics' Chemical Testing Program, as well as unpublished data submitted under TSCA §§ 8(d) and 8(e) found in the TSCA Test Submissions System and TRIAGE databases.

Human health hazard profiles were prepared for chemicals about which human toxicological data exist in databases. A hazard level (low, medium, or high) was assigned to each chemical based on the available data for dermal and inhalation routes for systemic and developmental effects.

When toxicity data were not available for particular exposure routes, toxicity values were estimated based on data from other exposure routes. For example, the systemic LOAEL (dermal exposure route) for ammonia was derived from oral exposure data. In addition, some data originating from an inhalation study, for example, may have been systematically converted to oral toxicity value before being converted back to an inhalation value for this analysis. In general, using toxicity values derived from alternate pathway data increases the uncertainty of the risk results.

Many of the chemicals contained in the flexographic inks researched in this CTSA were not represented adequately in the databases listed above. These chemicals were evaluated by the Structure Activity Team (SAT) of EPA's Office of Pollution Prevention and Toxics. The SAT provided hazard levels based on analog data and/or structure activity considerations, in which characteristics of the chemicals were estimated in part based on similarities with chemicals that have been studied more thoroughly. Using SAT hazard evaluations introduces a greater level of uncertainty in the results. SAT-based systemic toxicity concerns were ranked according to the following criteria:

- **High concern** — evidence of adverse effects in humans, or conclusive evidence of severe effects in animal studies
- **Moderate concern** — suggestive evidence of toxic effects in animals; or close structural, functional, and/or mechanistic analogy to chemicals with known toxicity
- **Low concern** — chemicals not meeting the above criteria

When a chemical did not clearly fit one of the SAT concern level categories, ratings of low-moderate or moderate-high were assigned. It should be noted that SAT-based developmental toxicity concerns were not ranked; the SAT only indicated whether a concern for developmental toxicity existed for a given chemical.

Human Health Hazard Results

Tables 3.1 A-F present a summary of the hazard information for each chemical used in this CTSA. The tables contain the following columns.

- **Chemical Category** indicates the category under which the chemical is grouped. These categories are the basis of the subsequent release, exposure, and risk analyses.
- **Ink System** lists the ink systems that contain at least one chemical within each chemical category.
- **Chemical/CAS#** presents the name of the chemical and the Chemical Abstracts Service (CAS) registry number assigned to the chemical.
- **Expected Exposure Route** indicates whether the data presented in subsequent columns is based on inhalation or dermal exposure. If inhalation exposure is not provided for a chemical, that indicates that the compound has a vapor pressure below 0.01 mm Hg, and therefore inhalation would not be expected.
- **Estimated Concentration of Concern** is a calculated figure based on toxicological data; it indicates the concentration at which systemic or developmental effects may begin to appear.
- **Concern for Toxic Effects** indicates whether the chemical poses a low, medium, or high hazard concern (see "Systemic Toxicological Effects" and "Developmental Toxic Effects" in this section for more information). There are two values presented in each cell: the first indicates the hazard level for systemic effects, and the second lists the hazard for developmental effects. An indication of whether the hazard level is based on toxicological data (Tox) or on a SAT report (SAT) follows in parentheses.
- **Toxicological Endpoints** presents the type of anticipated health effects that have been reported for animal or human studies. This is a qualitative listing of reported effects; it does not imply anything about the severity of the effects or the doses at which the effects occur.

This section describes the overall hazard findings and then presents a summary for each ink function (e.g., solvents and colorants). For a more detailed presentation of health hazard results, see Tables 3-B.1 and 3-B.2 in Appendix 3-B.

Hazard is summarized for systemic and developmental effects. For chemicals with toxicological data, a level of low, medium, or high are assigned based on the available dose-response information.

Systemic Toxic Effects: Hazard levels for systemic toxic effects of the flexographic ink chemicals were derived from subchronic/chronic toxicity information found in the human health hazard profiles (see Appendix 3-B).[3] The following results are shown in Table 3.1:

- Twenty-one chemicals presented a low hazard (practically non-toxic to slightly toxic, dermal $LD_{50} > 2$ g/kg).[c]
- Twenty presented a medium hazard (moderately toxic at subchronic/chronic oral doses > 50 mg/kg).
- One, ethanol, presented a high hazard (severe to frank toxicity at subchronic/chronic oral doses ≤ 50 mg/kg).

The most common systemic effects observed in animal studies are listed below. Toxic effects seen in animals were presumed to be also manifested in humans.

- respiratory and neurotoxic effects (19 chemicals)
- altered organ weights (19 chemicals)
- liver effects (18 chemicals)
- blood effects (15 chemicals)
- decreased body weight or body weight gain (15 chemicals)
- reproductive effects (14 chemicals)
- kidney effects (12 chemicals)
- changes in serum or clinical chemistry (nine chemicals)
- skin effects (eight chemicals)

Chemicals without adequate systemic toxicity data were evaluated by the SAT. The SAT reports indicated that 14 chemicals were of low hazard, 35 were of low to moderate hazard, and four were of moderate hazard.[4] None were of high hazard.

Developmental Toxic Effects: Adequate developmental toxicity data (including NOAELs or LOAELs) were available for 24 flexographic ink chemicals. RfD_{DT} and RfC_{DT} were not available for any of the chemicals. Hazard levels for developmental effects of these chemicals were derived from developmental toxicity information found in the human health hazard profiles.[5] The following are shown in Table 3.1:

- Sixteen chemicals presented a low hazard (no effects or effects seen at oral doses >250 mg/kg/day).
- Four presented a medium hazard (effects seen at oral doses of 50 to 250 mg/kg/day).
- Four (barium, ethanolamine, isopropanol, and styrene) presented a high hazard (effects seen at oral doses ≤50 mg/kg/day).

The most common developmental effects observed in animal studies are listed below. Toxic effects seen in animals were presumed to be also manifested in humans.

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[c] LD_{50} is the dose of a chemical taken by mouth, adsorbed by the skin, or injected that is estimated to cause death in 50 percent of the test animals.

- decreased pre- or post-natal survival and decreased fetal body weight or body weight gain (nine chemicals)
- fetal malformations (seven chemicals)
- retarded skeletal and/or muscle growth and development (four chemicals)
- inhibited or altered fetal growth and/or development (three chemicals)
- delayed, poor, or non-ossification of bones (three chemicals)
- altered fetal organ weights (three chemicals)
- central nervous system structural anomalies (two chemicals)
- altered gonad growth and development (two chemicals)
- skeletal variants (three chemicals)
- unspecified fetotoxicity (two chemicals)

Of the chemicals without adequate developmental toxicity data, SAT reports indicated a developmental hazard for 15 chemicals.

Table 3.1 lists each chemical used in the study and is separated into six sections; each table corresponds to the chemicals' function in the ink. Basic definitions of each function can be found in Chapter 2.

Solvents (Table 3.1-A): Sixteen of the chemicals studied in this CTSA are categorized as solvents. Nearly all are volatile, and therefore can be inhaled. Twelve of them have toxicological data; the remaining four were studied by the SAT. As indicated in Table 3.1-A, propylene glycol ethers generally had the lowest hazard rankings, and ethylene glycol ethers and alcohols had the highest rankings.

Colorants (Table 3.1-B): Seventeen chemicals were colorants. In this CTSA, all of the colorants used were pigments, or dispersed solid particles. Few of the chemicals have undergone toxicological testing, so most (all but five) were analyzed by the SAT. Because the compounds are solids with essentially no vapor pressure, none were expected to result in inhalation exposure. Table 3.1-B presents the hazard information on the colorants; most present a low-moderate dermal hazard as determined by the SAT.

Resins (Table 3.1-C): Ten chemicals in this CTSA were classified as resins. Eight were analyzed by the SAT, and one (miscellaneous resins) could not be studied because there was not enough information to perform a SAT analysis. Toxicological data were available for one chemical. As shown in Table 3.1-C, most chemicals have a low hazard.

Additives (Table 3.1-D): Twenty one chemicals were categorized as additives. Toxicological data were available for five chemicals, and the SAT analyzed 12 others. There was not enough information available for the SAT to analyze four chemicals. Table 3.1-D indicates that the organotitanium compounds were the category with most concern, with all chemicals in that category having a medium hazard level according to the SAT.

UV-Reactive Compounds (Table 3.1-E): Seventeen chemicals are included in this group. Table 3.1-E further groups these compounds according to three functions: monomers, oligomers, and photoinitiators. Toxicological data were available for five chemicals, and the SAT analyzed the remaining chemicals. Monomers were the most consistently hazardous chemicals — all had medium hazard concern for systemic toxic effects. However, two photoinitators and an oligomer also were found to have a medium hazard level.

Multiple-Function (Table 3.1-F): This group contains chemical categories for which the included chemicals are used in two or more ink functions. For example, the category *amides* *and nitrogenous compounds* contains chemicals that are solvents or additives. Of the 18 chemicals in Table 3.1-F, toxicological data are available for 13, and the others were analyzed by the SAT. Six chemicals in this category have either medium or high hazard levels for toxic effects (either systemic or developmental).

Table 3.1-A Hazard Information for SOLVENTS Used in the Flexography CTSA

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Alcohols	Solvent Water UV	Ethanol 64-17-5	dermal	H/M (Tox)	endocrine, gastrointestinal, liver, reproductive, neurotoxic, pancreatic, rectal, heart, hormone, immune and developmental effects [c]
			inhalation	L/L(Tox)	blood, liver, spleen, thymus, bone marrow, neurotoxic, reproductive and developmental effects
		Isobutanol 78-83-1	dermal	L-M/NA (Tox)	neurotoxic effects
			inhalation	M/NA (Tox)	blood, enzyme, and neurotoxic effects
		Isopropanol 67-63-0	dermal	L-M/H (Tox)	blood, skin, and developmental effects, altered organ weights [c]
			Inhalation	M/L (Tox)	liver, neurotoxic, reproductive, respiratory, spleen and developmental effects, changes in enzymes, clinical, and urine chemistry
		Propanol 71-23-8	dermal	M/L (Tox)	liver, bone marrow and neurotoxic effects, altered organ weights [c]
			inhalation	M/L (Tox)	liver, reproductive, and developmental effects
		Tetramethyldecyndiol 126-86-3	dermal	L/NA (SAT)	concern for eye, skin, lung, and mucous membrane irritation, and neurotoxic, liver, and kidney effects
Alkyl acetates	Solvent	Butyl acetate 123-86-4	dermal	L/L (Tox)	changes in serum chemistry and blood pressure[c]
			inhalation	L/L (Tox)	changes in serum chemistry and blood pressure, developmental effects
		Ethyl acetate 141-78-6	dermal	L/NA (Tox)	neurotoxic and respiratory effects, mortality, altered body and organ weights [c]
			inhalation	M/NA (Tox)	blood, heart, gastrointestinal, kidney, liver, neurotoxic and respiratory effects, altered organ weights
		Propyl acetate 109-60-4	dermal	L-M/L-M (SAT)	Dermal LD50 > 20 mL/kg (species not indicated)
			inhalation	L-M/L-M (SAT)	

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from a different exposure route.

Table 3.1-A Hazard Information for SOLVENTS Used in the Flexography CTSA (continued)

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Ethylene glycol ethers	Water	Alcohols, C11-15-secondary, ethoxylated, 68131-40-8	dermal	M/M (SAT)	lung effects, eye and severe skin irritation
			inhalation	M/M (SAT)	lung effects, eye and severe skin irritation
		Butyl carbitol 112-34-5	dermal	L/L (Tox)	blood and skin effects
			inhalation	M/L (Tox)	liver effects
		Ethoxylated tetramethyldecyndiol 9014-85-1	dermal	L-M/NA (SAT)	concern for eye, skin, lung, and mucous membrane irritation and neurotoxic, liver and kidney effects.
			inhalation	L-M/NA (SAT)	concern for eye, skin, lung, and mucous membrane irritation and neurotoxic, liver, kidney, and lung effects
		Ethyl carbitol 111-90-0	dermal	M-H/L (Tox)	bladder, blood, kidney, liver, neurotoxic, reproductive, spleen, and blood chemistry effects, altered organ weights [c]
			inhalation	M-H/L (Tox)	bladder, blood, kidney, liver, neurotoxic, reproductive, spleen, and blood chemistry effects, altered organ weights [c]
		Polyethylene glycol 25322-68-3	dermal	L/NA (Tox)	Not reported to be a dermal sensitizer based on studies with several materials.
			inhalation	L/NA (Tox)	
Propylene glycol ethers	Solvent Water	Dipropylene glycol methyl ether 34590-94-8	dermal	L/NA (Tox)	neurotoxic effects; not reported to be a dermal sensitizer in humans.
			inhalation	L/NA (Tox)	decreased growth, liver and neurotoxic effects, increased kidney weights
		Propylene glycol methyl ether 107-98-2	dermal	L/L (Tox)	increased mortality, blood, neurotoxic, and skin effects, altered organ weights
			inhalation	L/L (Tox)	decreased growth, liver, neurotoxic, reproductive, and respiratory effects, altered organ weights, and developmental effects
		Propylene glycol propyl ether 1569-01-3	dermal	M/L (Tox)	eye and neurotoxic effects, altered body and organ weights [c]
			inhalation	M/L (Tox)	eye and neurotoxic effects, altered body and organ weights

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from a different exposure route.

Table 3.1-B Hazard Information for COLORANTS Used in the Flexography CTSA

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Pigments – Inorganic	Solvent Water UV	C.I. Pigment White 6 13463-67-7	dermal	L/NA (Tox)	bile duct, lymphatic, and respiratory effects [c]
		C.I. Pigment White 7 1314-98-3	dermal	L-M/L-M (SAT)	concern for mutagenicity, developmental toxicity, and immunotoxicity
Pigments – Organic	Solvent Water UV	C.I. Pigment Blue 61 1324-76-1	dermal	L/L (SAT)	low concern overall
		C.I. Pigment Red 23 6471-49-4	dermal	L/NA (Tox)	blood, kidney, and stomach effects [c]
		C.I. Pigment Red 269 67990-05-0	dermal	L/L (SAT)	low concern overall
		C.I. Pigment Violet 23 6358-30-1	dermal	L/L (SAT)	low concern overall
		C.I. Pigment Yellow 14 5468-75-7	dermal	L-M/L-M (SAT)	concern for oncogenicity, mutagenicity, neurotoxicity, and liver effects
		C.I. Pigment Yellow 74 6358-31-2	dermal	L/L (SAT)	low concern overall
Pigments – Organo-metallic	Solvent Water UV	C.I. Basic Violet 1, molybdatephosphate 67989-22-4	dermal	L-M/L-M (SAT)	concern for oncogenicity, mutagenicity, and developmental toxicity
		C.I. Basic Violet 1, molybdatetungstatephosphate 1325-82-2	dermal	L-M/L-M (SAT)	concern for oncogenicity, mutagenicity, developmental toxicity, immunosuppression, methemoglobinemia, and liver effects
		C.I. Pigment Blue 15 147-14-8	dermal	L/NA (Tox)	low or negligible concern
		C.I. Pigment Green 7 1328-53-6	dermal	L/NA (Tox)	altered body weight [c]
		C.I. Pigment Red 48, barium salt (1:1) 7585-41-3	dermal	L-M/NA (SAT)	concern for oncogenicity
		C.I. Pigment Red 48, calcium salt (1:1) 7023-61-2	dermal	L-M/NA (SAT)	concern for oncogenicity
		C.I. Pigment Red 52, calcium salt (1:1) 17852-99-2	dermal	L-M/L-M (SAT)	concern for mutagenicity, developmental toxicity, and oncogenicity
		C.I. Pigment Violet 27 12237-62-6	dermal	L-M/L-M (SAT)	concern for oncogenicity, mutagenicity, developmental toxicity, and neurotoxicity.
		D&C Red No. 7 5281-04-9	dermal	M/L (Tox)	thymus, reproductive, and kidney effects, altered organ weights and clinical chemistry

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from a different exposure route.

Table 3.1-C Hazard Information for RESINS Used in the Flexography CTSA

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Polyol derivatives	Solvent UV	Nitrocellulose 9004-70-0	Dermal	L-M/L-M (SAT)	Oral LD_{50} in rats and mice >5 grams/kg. Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Polyol derivative A[c] CAS: NK	Dermal	L/L (SAT)	low concern overall
Resins	Solvent Water	Fatty acid, dimer-based polyamide CAS: NK	Dermal	L/L (SAT)	low concern overall
		Fatty acids, C 18-unsatd., dimers, polymers with ethylenediamine, hexamethylenediamine, and propionic acid 67989-30-4	Dermal	L/L (SAT)	low concern overall
		Resin acids, hydrogenated, methyl esters 8050-15-5	Dermal	L/L (SAT)	low concern overall
		Resin, acrylic CAS: NK	Dermal	L/L (Tox)	no effects
		Resin, miscellaneous CAS : NK		NA/NA	
		Rosin, fumarated, polymer with diethylene glycol and pentaerythritol 68152-50-1	Dermal	L/L (SAT)	Low concern overall unless respirable particles of high molecular weight species (>10,000) are inhaled. There is uncertain concern for respiratory sensitization.
		Rosin, fumarated, polymer with pentaerythritol, 2-propenoic acid, ethenyl benzene, and (1-methylethylenyl) benzene CAS: NK	Dermal	L/L (SAT)	
		Rosin, polymerized 65997-05-9	Dermal	L/L (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled. There is uncertain concern for respiratory sensitization.

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Actual name is confidential business information.

Table 3.1-D Hazard Information for ADDITIVES Used in the Flexography CTSA

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Acrylic acid polymers	Water	Acrylic acid-butyl acrylate-methyl methacrylate-styrene polymer 27306-39-4	Dermal	L/L (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Acrylic acid polymer, acidic (#1 and #2) CAS: NK	Dermal	L/NA (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Butyl acrylate-methacrylic acid-methyl methacrylate polymer 25035-69-2	Dermal	L/L (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Styrene acrylic acid polymer #1 CAS: NK	Dermal	NA/NA (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Styrene acrylic acid polymer #2 CAS: NK	Dermal	NA/NA (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Styrene acrylic acid resin CAS: NK	Dermal	NA/NA (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
Hydrocarbons – high molecular weight	Solvent Water	Distillates, petroleum, hydrotreated light 64742-47-8	Dermal	M/M (SAT)	concern for skin, eye, and mucous membrane irritation, carcinogenicity, genotoxicity, and narcosis at high doses; skin carcinogenicity (rats)
			Inhalation	M/M (SAT)	concern for skin, eye, and mucous membrane irritation, carcinogenicity, genotoxicity, and narcosis at high doses.
		Distillates, petroleum, solvent-refined light paraffinic 64741-89-5	Dermal	L/NA (Tox)	skin effects, benign skin tumors
			Inhalation	L/NA (Tox)	skin effects, benign skin tumors [c]
		Mineral oil 8012-95-1	Dermal	L/L (Tox)	oral study found low or negligible concern.
			Inhalation	L/L (Tox)	oral study found low or negligible concern.
		Paraffin wax 8002-74-2	Dermal	L-M/NA (SAT)	concern for respiratory effects
Olefin polymers	Water UV	Polyethylene 9002-88-4	Dermal	L/NA (SAT)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.
		Polytetrafluoroethylene 9002-84-0	Dermal	L/NA (Tox)	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from a different exposure route.

Table 3.1-D Hazard Information for ADDITIVES Used in the Flexography CTSA (continued)

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Organic acids or salts	Solvent Water	Citric acid 77-92-9	Dermal	L/L (Tox)	oral study found low or negligible concern
		Dioctyl sulfosuccinate, sodium salt 577-11-7	Dermal	L-M/L-M (SAT)	developmental effects [c]
		Methylenedisalicylic acid 27496-82-8	Dermal	L-M/L-M (SAT)	concern for effects on blood clotting, sensitization, immunosuppression, irritation of mucous membranes, developmental toxicity, endocrine disruption, and genotoxicity
Organo-titanium compounds	Solvent	Isopropoxyethoxytitanium bis(acetylacetonate) 68586-02-7	Dermal	M/M (SAT)	concern for neurotoxicity, genotoxicity, oncotoxicity, and developmental/reproductive toxicity. This material is expected to be reactive which may result in irritation of the eyes, skin, and mucous membranes.
		Titanium diisopropoxide bis (2,4-pentanedionate) 17927-72-9	Dermal	M/M (SAT)	This compound is reactive, with moderate concern for eye, mucous membrane, and localized skin irritation. Hydrolysis products: concern for neurotoxicity, mutagenicity, oncogenicity, and developmental/reproductive toxicity (2,4-pentanedione); mutagenicity and oncogenicity (inorganic titanium); blood, liver, and skin effects, reproductive/developmental toxicity, and neurotoxicity (isopropanol)
		Titanium isopropoxide 546-68-9	Dermal	M/M (SAT)	This compound is reactive, with moderate concern for eye, mucous membrane, and localized skin irritation. Hydrolysis products: concern for mutagenicity and oncogenicity (inorganic titanium); blood, liver and skin effects, reproductive/developmental toxicity, and neurotoxicity (isopropanol)
Siloxanes	Solvent Water UV	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-, hydrolysis products with silica 68909-20-6	Dermal	L/L (SAT)	Low to moderate concern for lung effects (silicosis) if crystalline material is inhaled.
		Silicone oil 63148-62-9	Dermal	L/M (Tox)	reproductive and developmental effects
		Siloxanes and silicones, di-Me, 3-hydroxypropyl Me, ethers with polyethylene glycol acetate 70914-12-4	Dermal	NA/NA	Low to moderate concern for lung effects if respirable particles of high molecular weight species (>10,000) are inhaled.

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from a different exposure route.

Table 3.1-E Hazard Information for UV-REACTIVE COMPOUNDS Used in the Flexography CTSA

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Monomers					
Acrylated polyols	UV	Dipropylene glycol diacrylate 57472-68-1	Dermal	M/M (SAT)	concern for genotoxicty, neurotoxicity, oncogenicity, developmental and reproductive effects, dermal and respiratory sensitization, and skin and eye irritation
			Inhalation	M/M (SAT)	concern for genotoxicty, neurotoxicity, oncogenicity, developmental and reproductive effects, dermal and respiratory sensitization, and skin and eye irritation
		1,6 Hexanediol diacrylate 13048-33-4	Dermal	M/L (SAT)	developmental effects [c]
			Inhalation	M/L (SAT)	developmental effects [c]
		Hydroxypropyl acrylate 25584-83-2	Dermal	M/NA (Tox)	respiratory effects [c]
			Inhalation	M/NA (Tox)	respiratory effects [c]
		Trimethylolpropane triacrylate 15625-89-5	Dermal	M/L (Tox)	skin and neurotoxic effects, altered organ and body weights, changes in clinical chemistry
Oligomers					
Acrylated polymers	UV	Acrylated epoxy polymer CAS: NK	Dermal	L-M/L-M (SAT)	If the polymer is terminated with acrylates, there is concern for mutagenicity, oncogenicity, developmental toxicity, and dermal sensitization.
		Acrylated oligoamine polymer CAS: NK	Dermal	L-M/L-M (SAT)	If the polymer is terminated with acrylates, there is concern for mutagenicity, oncogenicity, developmental toxicity, and dermal sensitization.
		Acrylated polyester polymer (#1 and #2) CAS: NK	Dermal	L-M/L-M (SAT)	If the polymer is terminated with acrylates, there is concern for mutagenicity, oncogenicity, developmental toxicity, and dermal sensitization.
		Glycerol propoxylate triacrylate 52408-84-1	Dermal	M/NA (Tox)	skin, neurotoxic, and respiratory effects, altered body weights
		Trimethylolpropane ethoxylate triacrylate 28961-43-5	Dermal	L-M/NA (SAT)	
		Trimethylolpropane propoxylate triacrylate 53879-54-2	Dermal	L-M/L-M (SAT)	concern for oncogenicity, mutagenicity, developmental and reproductive effects, sensitization, and irritation

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from a different exposure route.

Table 3.1-E Hazard Information for UV-REACTIVE COMPOUNDS Used in the Flexography CTSA (continued)

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Photoinitiators					
Aromatic ketones	UV	2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone 119313-12-1	Dermal	L/NA (Tox)	oral study found low or negligible concern
		2-Hydroxy-2-methylpropiophenone 7473-98-5	Dermal	M/NA (Tox)	liver effects, altered organ weights [c]
			Inhalation	M/NA (Tox)	liver effects, altered organ weights [c]
		1-Hydroxycyclohexyl phenyl ketone 947-19-3	Dermal	L/L (SAT)	low concern overall
		2-Isopropylthioxanthone 5495-84-1	Dermal	L/L (SAT)	low concern overall
		4-Isopropylthioxanthone 83846-86-0	Dermal	L/L (SAT)	low concern overall
		2-Methyl-4'-methylthio-2-morpholinopropiophenone 71868-10-5	Dermal	M/M (Tox)	blood, liver, eye, and neurotoxic effects, altered body weights [c]
		Thioxanthone derivative CAS NK	Dermal	L-M/NA (SAT)	concern for neurotoxicity

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from other exposure pathways.

Table 3.1-F Hazard Information for MULTIPLE-FUNCTION COMPOUNDS Used in the Flexography CTSA

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Amides or nitrogenous compounds	Solvent Water UV	Amides, tallow, hydrogenated 61790-31-6	Dermal	L/L (SAT)	low concern overall
		Ammonia 7664-41-7	Dermal	M/NA (Tox)	bone effects [c]
			Inhalation	L/NA (Tox)	corneal, liver, respiratory, and spleen effects
		Ammonium hydroxide 1336-21-6	Dermal	L/NA (Tox)	eye and respiratory effects [c]
			Inhalation	L/NA (Tox)	eye and respiratory effects
		Erucamide 112-84-5	Dermal	L/NA (SAT)	concern for myocardial effects
		Ethanolamine 141-43-5	Dermal	L/H (Tox)	developmental effects [c]
			Inhalation	L/H (Tox)	respiratory, kidney, liver, neurotoxic, and developmental effects [c]
		Hydroxylamine derivative CAS: NK	Dermal	M/M (SAT)	concern for genotoxicity, dermal sensitization, and developmental toxicity.
		Urea 57-13-6	Dermal	L/L (Tox)	not reported to be a dermal sensitizer
			Inhalation	L/L (Tox)	
Aromatic esters	UV	Dicyclohexyl phthalate 84-61-7	Dermal	L/L (Tox)	oral study found low or negligible concern.
			Inhalation	L/L (Tox)	oral study found low or negligible concern.
		Ethyl 4-dimethylaminobenzoate 10287-53-3	Dermal	L-M/L-M (SAT)	concern for genotoxicity, oncogenicity, neurotoxicity, cardiac sensitization, and developmental toxicity
			Inhalation	L-M/L-M (SAT)	concern for genotoxicity, oncogenicity, neurotoxicity, cardiac sensitization, and developmental toxicity

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from other exposure pathways.

Table 3.1-F Hazard Information for MULTIPLE-FUNCTION COMPOUNDS Used in the Flexography CTSA (continued)

Chemical Category	Ink System	Chemical/ CAS #	Expected Exposure Route[a]	Concern for Toxic Effects[b]	Toxicological endpoints and comments
Hydrocarbons—low molecular weight	Solvent Water	n-Heptane 142-82-5	Dermal	L/NA (Tox)	
			Inhalation	L/NA (Tox)	auditory and neurotoxic effects, altered serum chemistry
		Solvent naphtha, (petroleum), light aliphatic 64742-89-8	Dermal	L-M/NA (SAT)	concern for neurotoxicity and lung inhalation. This material may also cause defatting of the skin through prolonged exposure.
			Inhalation	L-M/NA (SAT)	concern for neurotoxicity and lung inhalation
		Styrene 100-42-5	Dermal	M-L/L (Tox)	
			Inhalation	M/H (Tox)	developmental effects
Inorganics	Solvent Water	Barium 7440-39-3	Dermal	M/H (Tox)	heart, kidney, reproductive, and developmental effects, altered organ weights, decreased survival [c]
		Kaolin 1332-58-7	Dermal	L/L (Tox)	respiratory effects, increased lung weight, lung carcinogenicity (rat), decreased pup body weight [c]
		Silica 7631-86-9	Dermal	NA/NA (Tox)	Concern for inhalation route.
Organophosphorous compounds	Solvent UV	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 75980-60-8	Dermal	L/NA (Tox)	blood, reproductive, and skin effects, and altered body weights [c]
		2-Ethylhexl diphenyl phosphate 1241-94-7	Dermal	L-M/M (Tox)	liver, reproductive, spleen, and developmental effects, altered organ and body weights, changes in clinical chemistry [c]
		Phosphine oxide, bis(2,6-dimethoxybenzoyl)(2,4,4-trimethylpentyl)-, 145052-34-2	Dermal	M/NA (Tox)	neurotoxic, adrenal, blood, skin, enzyme, and liver effects, altered body weights, changes in serum chemistry [c]

[a] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001mmHg).

[b] The first letter(s) represents systemic concern; the second represents developmental concerns.
L= Low; M=Medium; H=High; NA=No data or information available

[c] Reported effects may have been observed from other exposure pathways.

Summary of Carcinogenic Information

The available information on the carcinogenic characteristics of chemicals in the flexographic inks studied is presented in Table 3.2. Quantitative data were not sufficient to calculate slope factors; therefore, the information in Table 3.2 is qualitative in nature.

Seven chemicals have been given classifications by either the International Agency for Research on Cancer (IARC) or EPA:

- Ethanol is an IARC Group 1 chemical, which indicates that there is sufficient evidence that it is carcinogenic to humans.
- Amorphous silica, isopropanol, polyethylene, and polytetrafluoroethylene are IARC Group 3 chemicals, which indicates that their characteristics with respect to cancer cannot be determined. The evidence of carcinogenicity in humans is inadequate, and in experimental animals it is inadequate or limited.
- Propanol has been categorized by EPA as a Group C chemical, or possible human carcinogen.

Six additional chemicals are listed for which evidence of carcinogenicity via inhalation or dermal exposure routes has been documented in literature, but which have not been assigned IARC or EPA classifications. Three of these chemicals, C.I. Pigment White 6, kaolin, and acrylic resin, have been documented to cause lung tumors in rats. Two types of petroleum distillates, hydrotreated light and solvent-refined light paraffinics, have been shown to cause skin tumors in mice. Styrene has been documented to cause mammary tumors in rats. It is important to note that because there are physiological differences between animals and humans, a chemical that produced evidence of carcinogenicity in animal studies will not necessarily be carcinogenic in humans. Conversely, because not all chemicals have been subjected to carcinogenicity studies, this list does not imply that chemicals not on the list are without concern.

SAT reports indicated low to moderate carcinogenicity hazard levels for 17 chemicals. All other chemicals for which SAT reports were generated indicated either low or negligible carcinogenicity hazard.

Table 3.2 Carcinogenicity Information for CTSA Chemicals

Chemical	Carcinogenicity Information
Ethanol	Classified as Group 1 by IARC: Inadequate evidence for carcinogenicity of ethanol and of alcoholic beverages in experimental animals, but sufficient evidence for carcinogenicity of alcoholic beverages in humans.
C.I. Pigment White 6	Evidence of lung tumors in rats.
Kaolin	
Resin, acrylic	
Distillates (petroleum), hydrotreated light	Evidence of skin tumors in mice.
Distillates (petroleum), solvent-refined light paraffinics	Evidence of benign skin tumors in mice.
Styrene	Evidence of mammary or breast tumors in rats.
Propanol	Classified as Group C by U.S. EPA: Possible human carcinogen, based on no evidence of carcinogenicity in humans and limited evidence of carcinogenicity in experimental animals.
Amorphous silica	Classified as Group 3 by IARC: Not classifiable as to its carcinogenicity to humans based on no or inadequate evidence in humans and experimental animals.
Isopropanol	
Polyethylene	
Polytetrafluoroethylene	
Acrylated epoxy polymer	These chemicals had no carcinogenicity study data, but SAT reports indicated low to moderate concern for carcinogenicity based on analogous structural, functional, and/or mechanistic data for chemicals with known carcinogenicity.
Acrylated oligoamine polymer	
Acrylated polyester polymer #1	
Acrylated polyester polymer #2	
C.I. Basic Violet 1, molybdatephosphate	
C.I. Basic Violet 1, molybdatetungstate-phosphate	
C.I. Pigment Red 48, barium salt (1:1)	
C.I. Pigment Red 48, calcium salt (1:1)	
C.I. Pigment Red 52, calcium salt (1:1)	
C.I. Pigment Violet 27	
C.I. Pigment Yellow 14	
Dipropylene glycol diacrylate	
Ethyl 4-dimethylaminobenzoate	
1,6-hexanediol diacrylate	
Isopropoxyethoxytitanium bis(acetylacetonate)	
Trimethylolpropane ethoxylate triacrylate	
Trimethylolpropane propoxylate triacrylate	

See "Definitions of Systemic Toxicity, Developmental Toxicity, and Carcinogenic Effects" in Section 3.1 for more information about cancer classifications.

Ecological Hazards

Ecological Hazard Methodology

This analysis addressed the ecological hazards of flexographic ink chemicals to aquatic species (fish, aquatic invertebrates, and green algae). Hazards to terrestrial species were not assessed because sufficient toxicity data were not available. Aquatic toxicity values may be obtained from the results of standard toxicity tests reported to EPA, published in the literature, or estimated using predictive techniques. Please see Appendix 3-B for more information about the methodology used in this analysis for determining ecological hazards.

For this study, discrete organic chemicals were assessed using predictive equations called Structure Activity Relationships (SARs), which estimate the acute and chronic toxicity of chemicals to aquatic organisms. The toxicity values relate to individual chemicals only; interactions among chemicals within a formulation were not considered. Although measured values are preferred, SAR estimates can be used in the absence of test data to estimate toxicity values within a specific chemical class. The equations are derived from correlation and linear regression analyses based on measured data.

Aquatic hazard profiles for each flexographic ink chemical consisted of a maximum of three acute toxicity values and three chronic values:

- Fish acute value (usually a fish 96-hour LC_{50} value)
- Aquatic invertebrate acute value (usually a daphnid 48-hour LC_{50} value)
- Green algal toxicity value (usually an algal 96-hour EC_{50} value)
- Fish chronic value (ChV) (usually a fish 28-day early life stage no-effect-concentration chronic value)
- Aquatic invertebrate chronic value (usually a daphnid 21-day ChV)
- Algal chronic value (usually an algal 96-hour value for biomass)

The ecological hazards of the chemicals were determined in a similar manner to the human hazards presented earlier in this section. The analysis was complicated by two issues: 1) many of the compounds were not addressed by existing aquatic toxicity test literature; and 2) some of the chemicals (e.g., petroleum-based products) were mixtures, not discrete compounds.

The concentration of concern was also derived for each chemical. This value was calculated by dividing the lowest of the three chronic values by a factor of ten. If the discharge of a chemical to the aquatic environment resulted in an estimated concentration equal to or greater than the concern concentration, then the chemical would likely be hazardous to organisms found in the aquatic environment.

For the purpose of an overall assessment, the listed chemicals can be given an aquatic hazard level according to the concentration of concern to obtain an estimated chronic value. A chronic value is the concentration of the chemical that results in no statistically significant sub-lethal effects on the test organism following a longer-term or chronic exposure. The hazard level is assigned according to the following criteria:

- High hazard chemicals: estimated chronic value $\leq$ 0.1 mg/L
- Medium hazard chemicals: 0.1 mg/L $<$ estimated chronic value $\leq$ 10 mg/L
- Low hazard chemicals: estimated chronic value $>$ 10 mg/L

Lower chronic values indicate higher hazard levels. For example, the presence of 0.1 mg of a high-hazard chemical in a liter of water could cause a problem, while at least 10 mg of a low-hazard chemical would have to be present to cause similar effects.

Ecological Hazard Limitations and Uncertainty

Some petroleum products, such as mineral spirits, petroleum distillates, and solvent naphtha, are mixtures. They do not lend themselves readily to the standard hazard assessment process using SARs, because the chemical constituents and the percentage of each in the mixture vary. The constituents in these products include linear and branched paraffins, and cyclic paraffins, with the total number of carbons ranging from five to sixteen.

For this CTSA, the toxicity of a mixture was determined by estimating the toxicity of each individual constituent. Lacking adequate description and characterization, it was assumed that each component was present in equal proportions in the product. The geometric mean of the range of estimates provided the best estimate of the toxicity. (These assumptions may not have been representative of the mixture currently on the market.) The toxicity of the individual components of the petroleum products was based on tests using pure samples. The potential byproducts or impurities of petroleum distillation that are typically found in these mixtures were not incorporated into this hazard assessment.

It was also not possible to estimate the hazard of some polymers, such as acrylic acid and polyamide polymers. However, these chemicals have molecular weights above 1,000 and structures that would make it difficult for them to be toxic to aquatic organisms. In general, nonionic polymers and those which are insoluble are of low aquatic hazard.

The aquatic hazard profiles for flexographic ink chemicals may consist of only measured data, only predicted values, or a combination of both, because data sources may be chemical-specific toxicity tests or SARs. Uncertainty or assessment factors were used to incorporate the concepts of uncertainty and variability into concern concentration calculations. These uncertainty factors include laboratory tests versus field data, measured versus estimated data, and differences in species' sensitivities. In general, if only one toxicity value is available, there is great uncertainty about the applicability of this value to other organisms in the environment. Conversely, when more information is available, there is more certainty about the toxicity values.

Ecological Hazard Results

The results of the estimated aquatic toxicity determinations are presented in Tables 3-B.3 and 3-B.4 in Appendix 3-B. The lowest or most sensitive values from SAR analysis or from actual measured test data were used. No valid, published literature was found to conflict with the estimated values. In many cases, the predicted and measured values were similar; for these chemicals, the lower value was selected for inclusion in Table 3-B.4. For each chemical, the estimated toxicity values are given in mg/L for acute and chronic effects to fish, daphnids, and algae. The last column lists the concern concentration set for the chemical in water.

For 26 chemicals, no aquatic toxic effects were expected, because the chemical structures are too large (molecular weight greater than 600 or 1,000) to pass through biological membranes. Nevertheless, concern concentrations were calculated whenever possible. Concern concentrations ranged from 0.001 to 20 mg/L.

All the chemicals then were ranked, based on the lowest of the three estimated chronic toxicity values. This relative toxicity ranking provides guidance to the selection and use of chemicals that are less hazardous to aquatic organisms. The chemicals with high and medium hazard rankings are summarized in Table 3.3. A more detailed presentation is provided in Table 3-B.4 in Appendix 3-B.

High hazard rankings were assigned to 18 chemicals. Thirty-five chemicals had medium hazard rankings. A low hazard rank was assigned to those chemicals for which a chronic value could not be calculated.

This study did not characterize risk for aquatic organisms, because routine water releases or discharges of hazardous chemicals were not anticipated from the use of the flexographic ink chemicals. Should such a release or discharge occur, the estimated or predicted environmental concentration would need to exceed the lowest chronic or acute toxicity value that was estimated for these chemicals to result in adverse effects.

However, all flexographic ink chemicals can theoretically be subject to accidental spills or releases. Also, many flexographic printing facilities routinely release wastewater to publicly owned water treatment plants (POTWs). Different geographic regions and different POTWs have different levels of acceptability for such wastes, and the acceptable levels can change over time. Discontinuing the use of chemicals that appear in Table 3.3 can help avoid potential problems.

Table 3.3 Chemicals of High and Medium Aquatic Toxicity (Based on Toxicological Studies)

18 Chemicals of high aquatic toxicity	
Amides, tallow, hydrogenated	Ammonia
C.I. Basic Violet 1, molybdatephosphate	C.I. Basic Violet 1, molybdatetungstatephosphate
C.I. Pigment Violet 27	Dicyclohexyl phthalate
Distillates (petroleum), hydrotreated light	2-Ethylhexyl diphenyl phosphate
Glycerol propoxylate triacrylate	n-Heptane
1,6-Hexanediol diacrylate	2-Isopropylthioxanthone
4-Isopropylthioxanthone	Mineral oil
Resin acids, hydrogenated, methyl esters	Styrene
Thioxanthone derivative	Trimethylolpropane ethoxylate triacrylate

35 Chemicals of medium aquatic toxicity	
Acrylic acid polymer, acidic #1	Acrylic acid polymer, acidic #2
Alcohols, C11-15-secondary, ethoxylated	Ammonium hydroxide
2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone	Butyl acetate
C.I. Pigment Blue 61	C.I. Pigment Red 48, barium salt (1:1)
C.I. Pigment Red 48, calcium salt (1:1)	C.I. Pigment Red 52, calcium salt (1:1)
Citric acid	D&C Red No.7
Dioctyl sulfosuccinate, sodium salt	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide
Dipropylene glycol diacrylate	Ethanolamine
Ethyl acetate	Ethyl 4-dimethylaminobenzoate
1-Hydroxycyclohexyl phenyl ketone	Hydroxylamine derivative
Hydroxypropyl acrylate	Isopropoxyethoxytitanium bis(acetylacetonate)
Methylenedisalicylic acid	2-Methyl-4'(methylthio)-2-morpholinopropiophenone
Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	Propyl acetate
Resin, acrylic	Solvent naphtha (petroleum), light aliphatic
Styrene acrylic acid polymer #1	Styrene acrylic acid polymer #2
Styrene acrylic acid resin	Tetramethyldecyndiol
Titanium diisopropoxide bis (2,4-pentanedionate)	Trimethylolpropane propoxylate triacrylate
Trimethylolpropane triacrylate	

3.3 CATEGORIZATION OF FLEXOGRAPHIC INK CHEMICALS FOR THIS CTSA

This section describes the categories that each flexographic ink chemical was assigned for the purposes of the CTSA analysis. This was done because the specific chemical formulations of flexographic inks are generally considered to be proprietary. Manufacturers prefer not to reveal their formulations, because a competitor can potentially use this information to formulate and sell a nearly identical ink, often at a lower price without having to invest in research and development. Therefore, the Flexography Project developed a system to mask specific ink formulations discussed in the CTSA.

Each participating supplier voluntarily submitted a product line to EPA, where it was entered as Confidential Business Information (CBI). EPA completed the risk characterization using the exact formulations but without knowledge of the supplier. Each brand name was replaced with an ink system number (e.g., Solvent-based Ink #S1). This numbering system is used throughout the CTSA. In addition, to maintain the confidentiality of the formulations, the CTSA reports the results using the categorization system shown in Table 3.4. Results were reported for chemical categories only, and specific chemicals are not linked in the CTSA to any particular formulation. The final column in Table 3.4 presents the Chemical Abstracts Service (CAS) number for each chemical. Many chemicals have multiple names, so CAS numbers are used as a universal way of identifying unique chemicals.

In addition to the chemicals found in the flexographic ink formulations, press-side solvents and additives were used in most of the performance demonstration runs. Table 3-A.2 in Appendix 3-A lists the press-side solvents and additives used for each ink formulation at each demonstration site. These chemicals were also considered in this risk assessment.

Table 3.4 Categorization of Ink Chemicals

Category	Chemicals in category	CAS number
Acrylated polyols	Dipropylene glycol diacrylate	57472-68-1
	1,6-Hexanediol diacrylate	13048-33-4
	Hydroxypropyl acrylate	25584-83-2
	Trimethylolpropane triacrylate	15625-89-5
Acrylated polymers	Acrylated epoxy polymer[c]	NA[a]
	Acrylated oligoamine polymer[c]	NA
	Acrylated polyester polymer (#'s 1 and 2)[c]	NA
	Glycerol propoxylate triacrylate	52408-84-1
	Trimethylolpropane ethoxylate triacrylate	28961-43-5
	Trimethylolpropane propoxylate triacrylate	53879-54-2
Acrylic acid polymers	Acrylic acid-butyl acrylate-methyl methacrylate-styrene polymer	27306-39-4
	Acrylic acid polymer, acidic (#'s 1 and 2)[c]	NA
	Acrylic acid polymer, insoluble[c]	NA
	Butyl acrylate-methacrylic acid-methyl methacrylate polymer	25035-69-2
	Styrene acrylic acid polymer (#'s 1 and 2)[c]	NA
	Styrene acrylic acid resin[c]	NA
Alcohols	Ethanol	64-17-5
	Isobutanol	78-83-1
	Isopropanol	67-63-0
	Propanol	71-23-8
	Tetramethyldecyndiol	126-86-3
Alkyl acetates	Butyl acetate	123-86-4
	Ethyl acetate	141-78-6
	Propyl acetate	109-60-4
Amides or nitrogenous compounds	Amides, tallow, hydrogenated	61790-31-6
	Ammonia	7664-41-7
	Ammonium hydroxide	1336-21-6
	Erucamide	112-84-5
	Ethanolamine	141-43-5
	Hydroxylamine derivative	NA
	Urea	57-13-6
Aromatic esters	Dicyclohexyl phthalate	84-61-7
	Ethyl 4-dimethylaminobenzoate	10287-53-5
Aromatic ketones	2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone	119313-12-1
	1-Hydroxycyclohexyl phenyl ketone	947-19-3
	2-Hydroxy-2-methylpropiophenone	7473-98-5
	2-Isopropylthioxanthone	5495-84-1
	4-Isopropylthioxanthone	83846-86-0
	2-Methyl-4'-(methylthio)-2-morpholinopropiophenone	71868-10-5
	Thioxanthone derivative[c]	NA
Ethylene glycol ethers	Alcohols, C11-15-secondary, ethoxylated	68131-40-8
	Butyl carbitol	112-34-5
	Ethoxylated tetramethyldecyndiol	9014-85-1
	Ethyl carbitol	111-90-0
	Polyethylene glycol	25322-68-3

Table 3.4 Categorization of Ink Chemicals (continued)

Category	Chemicals in category	CAS number
Hydrocarbons — high molecular weight	Distillates (petroleum), hydrotreated light Distillates (petroleum), solvent-refined light paraffinic Mineral oil Paraffin wax	64742-47-8 64741-89-5 8012-95-1 8002-74-2
Hydrocarbons — low molecular weight	n-Heptane Solvent naphtha (petroleum), light aliphatic Styrene	142-82-5 64742-89-8 100-42-5
Inorganics	Barium Kaolin Silica	7440-39-3 1332-58-7 7631-86-9
Olefin polymers	Polyethylene Polytetrafluoroethylene	9002-88-4 9002-84-0
Organic acids or salts	Citric acid Dioctyl sulfosuccinate, sodium salt Methylenedisalicylic acid	77-92-9 577-11-7 27496-82-8
Organophosphorus compounds	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 2-Ethylhexyl diphenyl phosphate Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	75980-60-8 1241-94-7 145052-34-2
Organotitanium compounds	Isopropoxyethoxytitanium bis(acetylacetonate) Titanium diisopropoxide bis(2,4-pentanedionate) Titanium isopropoxide	68586-02-7 17927-72-9 546-68-9
Pigments — inorganic	C.I. Pigment White 6 C.I. Pigment White 7	13463-67-7 1314-98-3
Pigments — organic	C.I. Pigment Blue 61 C.I. Pigment Red 23 C.I. Pigment Red 269 C.I. Pigment Violet 23 C.I. Pigment Yellow 14 C.I. Pigment Yellow 74	1324-76-1 6471-49-4 67990-05-0 6358-30-1 5468-75-7 6358-31-2
Pigments — organometallic	C.I. Basic Violet 1, molybdatephosphate C.I. Basic Violet 1, molybdate-tungstatephosphate C.I. Pigment Blue 15 C.I. Pigment Green 7 C.I. Pigment Red 48, barium salt (1:1) C.I. Pigment Red 48, calcium salt (1:1) C.I. Pigment Red 52, calcium salt (1:1) C.I. Pigment Violet 27 D&C Red No. 7	67989-22-4 1325-82-2 147-14-8 1328-53-6 7585-41-3 7023-61-2 17852-99-2 12237-62-6 5281-04-9
Polyol derivatives	Nitrocellulose Polyol derivative A[c]	9004-70-0 — [b]
Propylene glycol ethers	Dipropylene glycol methyl ether Propylene glycol methyl ether Propylene glycol propyl ether	34590-94-8 107-98-2 1569-01-3

Table 3.4 Categorization of Ink Chemicals (continued)

Category	Chemicals in category	CAS number
Resins	Fatty acid, dimer-based polyamide[c]	NA
	Fatty acids, C18-unsatd., dimers, polymers with ethylenediamine, hexamethylenediamine, and propionic acid	67989-30-4
	Resin acids, hydrogenated, methyl esters	8050-15-5
	Resin, acrylic[c]	NA
	Resin, miscellaneous[c]	NA
	Rosin, fumarated, polymer with diethylene glycol and pentaerythritol	68152-50-1 NA
	Rosin, fumarated, polymer with pentaerythritol, 2-propenoic acid, ethenylbenzene, and (1-methylethylenyl)benzene[c]	65997-05-9
	Rosin, polymerized	
Siloxanes	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-, hydrolysis products with silica	68909-20-6
	Silicone oil	63148-62-9
	Siloxanes and silicones, di-Me, 3-hydroxypropyl Me, ethers with polyethylene glycol acetate	70914-12-4

[a] No data or information available.

[b] Actual chemical name is confidential business information.

[c] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.

Chemical Categories by Product Line

This CTSA examined the health risks associated with two solvent-based, four water-based, and three UV-cured flexographic ink product lines run at 11 different performance demonstration sites. Tables 3.5, 3.6, and 3.7 list the chemical categories for each of these nine product lines. The categories are listed alphabetically. An "x" denotes that a chemical within that category is found at least once in the corresponding formulation.

Table 3.5 Categorization of Chemicals in Solvent-based Inks Used in the Performance Demonstrations

Chemical category	Solvent-based Ink #S1					Solvent-based Ink #S2				
	Blue	Green	White	Cyan	Magenta	Blue	Green	White	Cyan	Magenta
Alcohols	x	x	x	x	x	x	x	x	x	x
Alkyl acetates	x	x	x	x	x	x	x	x	x	x
Amides or nitrogenous compounds						x	x	x	x	x
Aromatic esters	x									
Hydrocarbons - high molecular weight			x							
Hydrocarbons - low molecular weight			x			x	x	x	x	x
Inorganics					x					
Organic acids or salts	x		x			x	x	x	x	x
Organophosphorous compounds						x	x		x	x
Organotitanium compounds	x		x							
Pigments - inorganic			x				x	x		
Pigments-organic		x					x			
Pigments-organometallic	x	x		x	x	x	x		x	x
Polyol derivatives	x	x	x	x	x	x	x		x	x
Propylene glycol ethers		x		x	x					
Resins	x	x	x	x	x	x	x	x	x	x
Siloxanes						x	x	x	x	x

Table 3.6 Categorization of Chemicals in Water-based Inks Used in the Performance Demonstrations

Chemical category	Water-based Ink #W1					Water-based Ink #W2					Water-based Ink #W3					Water-based Ink #W4				
	Blue	Green	White	Cyan	Mag-enta	Blue	Green	White	Cyan	Mag-enta	Blue	Green	White	Cyan	Mag-enta	Blue	Green	White	Cyan	Mag-enta
Acrylic acid polymers	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Alcohols	x	x	x	x				x				x	x	x	x	x	x	x	x	x
Amides or nitrogenous compounds	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Ethylene glycol ethers	x	x		x	x	x	x	x	x	x	x	x	x	x	x					
Hydrocarbons - high molecular weight	x	x				x	x	x		x						x	x	x	x	x
Hydrocarbons - low molecular weight						x	x			x										
Inorganics						x												x		
Olefin polymers											x	x	x	x	x					
Organic acids or salts			x	x	x						x	x	x	x	x					
Pigments - inorganic			x					x					x				x	x		
Pigments-organic		x			x	x	x			x	x	x					x			
Pigments-organometallic	x	x		x		x			x			x		x	x	x	x		x	x
Propylene glycol ethers														x	x	x			x	
Resins	x	x	x			x	x		x	x						x	x		x	
Siloxanes											x	x	x	x	x	x	x	x	x	x

Table 3.7 Categorization of Chemicals in UV-cured Inks Used in the Performance Demonstrations

Chemical category	UV-cured Ink #U1					UV-cured Ink #U2					UV-cured Ink #U3				
	Blue	Green	White	Cyan	Mag-enta	Blue	Green	White	Cyan	Mag-enta	Blue	Green	White	Cyan	Mag-enta
Acrylated polymers	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Acrylated polyols		x				x	x	x	x	x	x	x		x	x
Alcohols						x	x	x	x	x					
Amides or nitrogenous compounds	x	x	x	x	x						x	x	x	x	x
Aromatic esters	x	x	x	x	x						x	x	x	x	x
Aromatic ketones	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Olefin polymers	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Organophosphorous compounds			x					x					x		
Pigments - inorganic			x					x					x		
Pigments-organic	x					x	x				x				x
Pigments-organometallic		x		x	x	x	x		x	x		x		x	
Polyol derivatives						x	x		x	x					
Siloxanes	x	x	x	x	x						x	x	x	x	x

3.4 ENVIRONMENTAL AIR RELEASE ASSESSMENT

Releases to air result from the evaporation of chemicals during the flexographic printing process. This section of the chapter describes the methodology and results of the assessment of releases to air that can occur during makeready and production runs on a flexographic press. Releases to air are used to estimate inhalation exposure to particular chemicals for workers and the general population.

Two forms of air releases were examined: *stack* and *fugitive*. Stack emissions are collected from the press and are released through a roof vent or stack to the outside air, sometimes undergoing treatment to reduce the emissions. Fugitive emissions escape from the printing process (e.g., from a long web run between presses), and exit the facility through windows and doors.

Environmental Air Release Methodology

Air releases were calculated based on the amount of ink used and the weight percentages and vapor pressures of the ink components. Releases were estimated for the three types of ink (solvent-based, water-based, and UV-cured) and for each of the five colors (blue, green, white, cyan, and magenta). Figure 3.1 illustrates the overall mass balance, for which it is assumed that an equal amount of material enters and exits the system. The mass balance model does not take into account air releases from the use of cleaning solutions. For a detailed explanation of the method used to calculate the environmental releases and sample calculations, see Table 3-C.1 in Appendix 3-C.

Environmental Air Release Assumptions

The following assumptions were used to calculate environmental releases:

- Ink components with a vapor pressure greater than or equal to 0.001 millimeters of mercury (mmHg) at 25ºC will volatilize.[6]
- 0.1% of the volatile components will be retained on the substrate.[7]
- 30% of the volatile compounds released to the air will be fugitive emissions, and 70% will be captured by the press system and released through a stack.[8]
- Solvent-based ink releases will pass through a catalytic oxidizer with a destruction efficiency of 95%.[9] There are no air pollution control devices for the water-based or UV-cured ink systems.
- Ink components that do not volatilize (those with a vapor pressure less than 0.001 mmHg at 25ºC) will remain with the substrate, which ends up as product or is recycled.

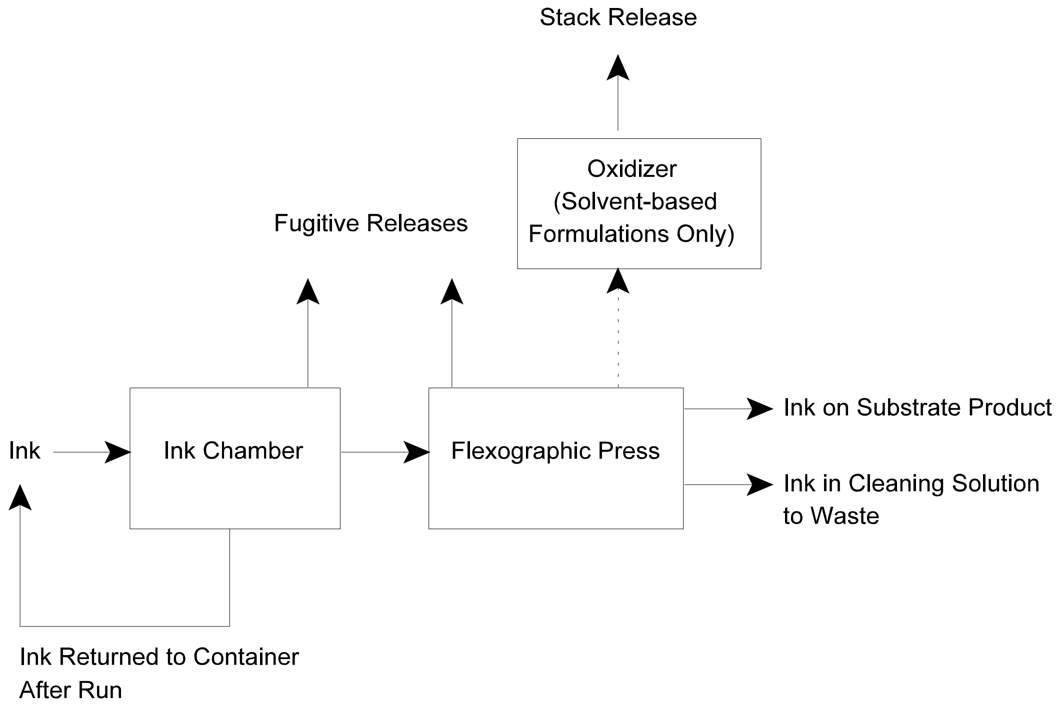

Figure 3.1 Mass Balance of Ink During Flexographic Printing

Environmental Air Release Limitations and Uncertainty

Uncertainties about the amounts of environmental releases relate to the rates of vapor generation, which vary depending on the following factors:

- speed of the printing press
- volatile content of the ink mixture
- equipment operating time
- temperature of the ambient air and ink system

In addition, release rates may vary depending on the capture efficiency of the press system and the destruction efficiency of the air control devices. If the capture or destruction efficiency increases, the release rate declines.

Environmental Air Release Results

Table 3-D.1 in Appendix 3-D presents the calculated environmental releases for each ink formulation. This table shows the total amount of chemicals volatilized, fugitive air releases, and stack air releases per press. Table 3.8, an excerpt from Table 3-D.1, presents environmental air release data for Solvent-based Ink #S2 at Site 10 and Water-based Ink #W2 at Site 1. Table 3.8 is included in the text to show the format of the data and to indicate the magnitude of air releases.

The calculated volatilization rates of the solvent-based inks were considerably higher than those for the other two ink systems. The total amount volatilized averaged 6.23 g/sec. The average stack emissions (0.216 g/sec) were considerably lower than fugitive emissions (1.87

g/sec), reflecting the anticipated use of oxidizers with stack emissions. Therefore, of the total amount volatilized, only a portion would ultimately be released to the atmosphere.

The volatilization rates for water-based inks were considerably lower than those for solvent-based inks, with an average rate of 0.347 g/sec. However, the stack releases, averaging 0.250 g/sec, were calculated to be higher than those for solvent-based inks, because the use of an oxidizer was not anticipated. On the other hand, the fugitive emissions, with an estimated average of 0.105 g/sec, were anticipated to be considerably lower than those for solvent-based inks, because of the lower average VOC content of water-based inks.

The UV-cured inks were calculated to have releases comparable to those of water-based inks, with a total volatilization rate of 0.438 g/sec. The estimated stack and fugitive releases were calculated to be 0.304 and 0.141 g/sec, respectively. These figures were calculated with the assumption that 100 percent of the volatile components of the inks would be released to the air. In reality, much of the volatile content would be incorporated into the coating during the UV curing process. The decrease in emissions under real-world conditions is unknown.

Air releases also varied among colors within each ink system; the differences are primarily due to different consumption rates. White ink had significantly higher emission and consumption rates than the other colors because it covered a greater percentage of the image area (see Table 6.1 in Chapter 6: Resource and Energy Conservation). Blue and green inks had slightly higher air releases and consumption rates than cyan and magenta inks.

Press speed also greatly affected the amount of ink consumed. All estimates were made assuming a press speed of 500 feet per minute (fpm) for all three ink systems. With this press speed, ink consumption rates were approximately the same for the different ink formulations. If the speeds observed during the performance demonstrations were used instead, however, a reduction in the ink consumption rate and environmental air releases would result. A reduction in UV-cured formulation press speed from 500 fpm to 340 fpm (a 32.0% reduction in press speed) would be expected to decrease the consumption rates and releases by approximately 32%. Similarly, reductions in press speed to 453 fpm and 394 fpm for solvent-based and water-based formulations, respectively, would be expected to cause reductions in ink consumption rates and environmental releases of 9% and 21%, respectively. Equipment specifics, such as the choice of anilox roll volume, also may affect ink consumption rates. In particular, UV-cured inks often require lower-volume anilox rolls than the other two ink systems because less UV-cured ink generally is needed per unit of printed area.

Adding solvents, reducers, extenders, cross-linkers, and other compounds to a printing ink usually increases its volatile content, resulting in greater environmental releases. During the CTSA performance demonstrations, solvents were added in greater quantities to the solvent-based formulations than to water-based or UV-cured formulations, which further increased releases from solvent-based inks.

Table 3.8 Sample Environmental Air Release Results [a]

Chemical category *(Press-side solvents and additives in italics)*	Blue			Green			White			Cyan			Magenta		
	Air releases per press (g/sec)														
	Total amount volatilized	Amount of fugitive releases	Amount of stack releases	Total amount volatilized	Amount of fugitive releases	Amount of stack releases	Total amount volatilized	Amount of fugitive releases	Amount of stack releases	Total amount volatilized	Amount of fugitive releases	Amount of stack releases	Total amount volatilized	Amount of fugitive releases	Amount of stack releases
Solvent-based Ink #S2 – Site 10															
Alcohols	0.197	0.059	0.007	0.244	0.073	0.008	0.407	0.122	0.014	0.199	0.060	0.007	0.208	0.062	0.007
Alkyl acetates	0.126	0.038	0.004	0.125	0.038	0.004	0.142	0.043	0.005	0.154	0.046	0.005	0.062	0.019	0.002
Hydrocarbons - low molecular weight	0.074	0.022	0.003	0.102	0.030	0.004	0.334	0.100	0.012	0.060	0.018	0.002	0.137	0.041	0.005
Alcohols	0.045	0.013	0.002	0.047	0.014	0.002	0.069	0.021	0.002	0.042	0.013	0.001	0.075	0.023	0.003
Hydrocarbons - low molecular weight	0.004	0.001	0.000	0.003	0.001	0.000	0.014	0.004	0.000	0.004	0.001	0.000	0.005	0.001	0.000
Alcohols	0.603	0.181	0.021	0.659	0.198	0.023				0.345	0.104	0.012	0.792	0.238	0.028
Added: Propanol							*1.220*	*0.366*	*0.043*						
Added: Propylene glycol monomethyl ether										*0.315*	*0.095*	*0.011*	*0.069*	*0.021*	*0.002*
Added: 2-Methoxy-1-propanol										*0.006*	*0.002*	*0.000*	*0.001*	*0.000*	*0.000*
Water-based Ink #W2 – Site 1															
Amides or nitrogenous compounds	0.002	0.000	0.001	0.003	0.001	0.002	0.092	0.028	0.065				0.002	0.001	0.002
Hydrocarbons - high molecular weight	0.001	0.000	0.001	0.002	0.001	0.001	0.015	0.005	0.011				0.001	0.000	0.000
Hydrocarbons - low molecular weight	0.001	0.000	0.000	0.001	0.000	0.001									
Alcohols							0.038	0.011	0.027						
Ethylene glycol ethers							0.038	0.011	0.027						
Added: Isobutanol	*0.001*	*0.000*	*0.000*							*0.001*	*0.000*	*0.001*	*0.001*	*0.000*	*0.001*

3.5 OCCUPATIONAL EXPOSURE ASSESSMENT

This section describes the exposure assessment of flexographic printing plant workers to the chemicals in the flexographic ink formulations. An exposure assessment—the third step in a risk assessment—defines the expected exposures of an identified population to specific chemicals.

Two scenarios were studied for this exposure assessment: workers in the ink preparation room, and workers in the press room during a print run. Prior to a production run, the potential for exposure exists for workers transferring and mixing inks in the ink preparation room. During the production run, inhalation and dermal exposures can occur when workers handle ink cans and operate the press. Inhalation exposures were estimated using the EPA mass balance model; dermal exposures were estimated using an EPA dermal exposure model.

The exposure assessment indicates the relative exposure levels that result from each ink system. It can also indicate whether exposure results from primarily dermal or inhalation pathways, and therefore may indicate whether exposure reduction measures might be effective for a given ink system (e.g., if a facility requires the use of gloves, dermal exposure could be nearly eliminated). The two scenarios of the assessment can also assist in determining the variation of exposure depending on a worker's location in a printing facility.

Occupational Exposure Methodology

The occupational exposure assessment used a model facility approach, in which reasonable and consistent assumptions were used for each ink type. Data to characterize the model facility were aggregated from a number of sources, including flexographic printing facilities and industry suppliers in the United States. The model facility is not entirely representative of any existing facility. Thus, actual exposure (and risk) could vary substantially depending on site-specific operating conditions, end-products, age of pollution control equipment, and other factors.[d]

For a detailed explanation of the method used to calculate occupational exposures, see Appendix 3-E.

Exposure Scenarios

In Scenario I, workers were assumed to be exposed in the ink preparation room while pumping ink from a 55-gallon drum into five-gallon cans, and while mixing inks in the five-gallon cans. Under this scenario, one worker was assumed to be exposed for 48 minutes per formulation per shift.

In Scenario II, workers were assumed to be exposed to fugitive emissions released into the printing room air, both by operating the printing press for a 7.5-hour shift and by adjusting the inks in the five-gallon cans next to the ink press for 1-2.5 hours, depending on the ink

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[d] Many facilities conduct exposure monitoring to measure worker exposure rates. If monitoring data are available, they can be used with other data in this analysis to determine whether facility-specific conditions pose a low, potential, or clear concern for risk according to the scale used in this study. To do this, a reader should compare exposure data to the hazard data reported in Appendix 3-B. By following the procedures outlined in Section 3.7 and Table 3.13, the reader can conduct a site-specific comparative risk assessment.

type. Scenario II used the printing room mass balance model to estimate exposures. The following assumptions were made:

- Only one source (ink can) within the work area emits the chemical.
- The concentrations of the chemicals in a mixture are constant throughout the time of dermal absorption.[12]
- The average surface area of two hands is 1,300 cm^2. After coming into contact with a chemical, the quantity of chemical remaining on the hands is assumed to be 1-3 mg/cm^2. Dermal exposure is modeled assuming that the worker has routine two-hand contact with the inks. Dermal exposures are based on an 8-hour, time-weighted average.[12]
- There are three shifts per day. Each worker works 7.5 hours per day and 250 days per year.
- A total of nine workers are exposed per shift; one worker exposed in Scenario I (one worker per shift) and eight workers exposed in Scenario II (two workers per press per shift, four presses).

Table 3.9 lists the general facility assumptions that were developed for both scenarios. See Appendix 3-E for a more detailed discussion of the model facility parameters.

Table 3.9 Occupational Exposure Methodology Assumptions

Assumption	Value	Source
Temperature of the ink during transfer	25°C	EPA[12]
Average ventilation rate in both rooms	7,000 ft^3/min	Average of Technical Committee responses
Ventilation/room air mixing factor	0.5	EPA[12]
Velocity of the air across the cans	100 fpm	EPA[12]
Press emissions capture rate	70%	Technical Committee response[a]
VOC destruction efficiency of oxidizer	95%	Technical Committee response
Diameter of the five-gallon cans	1 ft	EPA[12]
Press speed	500 fpm	Performance methodology
Exposure time in the ink preparation room	48 min/ formulation	Technical Committee response
Exposure time adjusting five-gallon ink can near the press — solvent-based inks	2.5 hr	Technical Committee response
Exposure time adjusting five-gallon ink can near the press — water-based inks	1.0 hr	Technical Committee response
Exposure time adjusting five-gallon ink can near the press — UV-cured inks	2.0 hr	Technical Committee response

[a] The capture rate for newer or retrofitted presses will be considerably higher (approximately 85%) due to the use of enclosed doctor blades.

Inhalation Exposure

The amount of a chemical in a room was calculated as follows:

> *Amount of chemical in a room = (the amount of chemical entering the room + the amount of chemical generated in the room – the amount of chemical leaving the room.*)

This analysis used a different mass balance model for each scenario.

- Scenario I used an open surface mass balance model to estimate the volatilization of liquids from open surfaces. For chemicals with vapor pressures less than 35 mmHg at 25°C, one vapor generation rate was used.[10] For chemicals with vapor pressures greater than or equal to 35 mmHg at 25°C, a different vapor generation rate was used (see Appendix 3-E).[11]
- Scenario II used a printing room mass balance model to calculate chemical concentrations in the printing room based on fugitive emission and room ventilation rates.
- Inhalation exposures to components with a vapor pressure less than 0.001 mmHg at 25°C were assumed to be negligible.[6]

Dermal Exposure

Dermal exposures may result from contact with the inks during transferring and mixing of the inks both before and after the production runs. A dermal contact model provided upper and lower "bounding" estimates of dermal exposure. Because glove usage is not universal in the printing industry, the data were calculated based on the conditions for a worker who does not use gloves or barrier creams.[12] In situations where the ink formulation was corrosive, dermal exposure to workers was considered negligible, because it was assumed that workers wore gloves when working with corrosive chemicals.

Occupational Exposure Limitations and Uncertainty

Any determination of the occupational exposure levels associated with flexographic printing activities requires making assumptions about the printing process, the workplace environment, and health and safety practices. Occupational exposure levels differ among facilities because of many variables, including the following:

- procedures used in handling the ink formulations
- press speed
- capture efficiency of the press system
- equipment operating time
- temperature conditions (ambient and ink)
- volatility of the chemicals in the inks
- ventilation conditions and shop layout
- number of presses per facility
- use of personal protective equipment and safety procedures

Occupational Exposure Results

The results indicated that workers under Scenario I would have lower exposures than workers exposed in Scenario II. This difference was due to the shorter exposure time in the ink preparation room, and to the lower vapor generation rates resulting from an open can of ink versus those resulting from fugitive emissions in the printing room.

The occupational exposure results indicated that dermal exposure was comparable in the ink preparation room (Scenario I) and the press room (Scenario II). However, inhalation exposure in the ink preparation room was very low compared to that in the press room. For this reason, only the results from Scenario II were used in the risk characterization. The results of both scenarios are presented in Appendix 3-F.

Tables 3-F.1 and 3-F.2 in Appendix 3-F present potential inhalation exposure rates, minimum dermal exposure rates, and maximum dermal exposure rates for both scenarios. Exposure rates are given for each chemical category in each of the five formulations for each of the nine product lines: the higher the value (in mg/day), the greater the exposure to that chemical via the given exposure pathway. The minimum and maximum dermal exposure rates provide a range for the dermal pathway. Press-side solvents and additives were incorporated into the data tables for Scenario II; therefore, Scenario II data were site-specific.

Table 3.10, an excerpt from Table 3-F.1, presents occupational exposure data for Solvent-based Ink #S2 at Site 10 (Scenario II). Table 3.10 is included in the text to show an example of the format of the data and to indicate the magnitude of occupational exposure.

As discussed in the environmental release section, solvent-based formulations exhibited higher volatilization rates and higher fugitive emissions. Solvent-based inks therefore created higher inhalation exposures than did water-based or UV-cured formulations. Water-based and UV-cured formulations resembled each other in levels of volatile emissions and worker inhalation exposures.

Ink consumption rates affected fugitive emissions and therefore affected occupational exposure levels. Because ink consumption rates varied by color, workers were exposed to the greatest amounts of volatile compounds from white inks. Also, the addition of solvents, reducers, extenders, cross-linkers, and other compounds to the printing inks resulted in greater occupational exposures.

Table 3.10 Sample Occupational Exposure Results, Scenario II (Press Room) [a]

Chemical category *(Press-side solvents and additives in italics)*	Blue			Green			White			Cyan			Magenta		
	Inhalation exposure (mg/day)	Dermal exposure (mg/day)		Inhalation exposure (mg/day)	Dermal exposure (mg/day)		Inhalation exposure (mg/day)	Dermal exposure (mg/day)		Inhalation exposure (mg/day)	Dermal exposure (mg/day)		Inhalation exposure (mg/day)	Dermal exposure (mg/day)	
		min.	max.		min.	max.		min.	max.		min.	max.		min.	max.
Solvent-based Ink #S2 – Site 10															
Alcohols	1,310	183	548	1,624	199	597	2,712	140	421	1,324	175	524	1,386	164	492
Alkyl acetates	838	117	350	835	102	307	945	49	147	1,028	135	406	415	49	147
Hydrocarbons - low molecular weight	494	69	206	677	83	249	2,223	115	345	401	53	159	911	108	323
Alcohols	297	41	124	312	38	115	457	24	71	279	37	110	502	59	178
Resins	0	183	550	0	175	525	0	188	565	0	171	514	0	105	316
Hydrocarbons - low molecular weight	25	4	11	18	2	6	95	5	15	25	3	10	32	4	11
Siloxanes	0	7	21	0	7	22	0	8	24	0	7	20	0	6	19
Amides or nitrogenous compounds	0	7	21	0	7	22	0	8	24	0	7	20	0	6	19
Organic acids or salts	0	7	21	0	7	22	0	8	24	0	7	20	0	6	19
Alcohols	4,019	560	1,681	4,387	537	1,612				2,301	303	910	5,274	624	1,871
Polyol derivatives	0	26	78	0	14	41				0	23	68	0	17	50
Amides or nitrogenous compounds	0	7	21	0	7	22				0	7	20	0	6	19
Organophosphorous compounds	0	7	21	0	7	22				0	7	20	0	6	19
Pigments - organometallic	0	53	158	0	13	39				0	84	251			
Pigments - inorganic				0	59	177	0	334	1,003						
Pigments - organometallic	0	29	88												
Pigments - organic				0	29	86									
Pigments - organometallic				0	13	38									
Pigments - inorganic													0	83	249
Added: Propanol							*8,128*	*420*	*1,261*						
Added: Propylene glycol methyl ether										*2,099*	*277*	*830*	*463*	*55*	*164*
Added: 2-Methoxy-1-propanol										*43*	*6*	*17*	*9*	*1*	*3*

[a] Shaded areas indicate where data are not applicable (i.e., the chemical category was not found in the particular formulation).

3.6 GENERAL POPULATION EXPOSURE ASSESSMENT

This section describes the exposure assessment of the general population living near a flexographic printing facility to the chemicals in the flexographic ink formulations. The general population is anyone not directly involved in the flexographic printing process who lives near a printing facility. These people may breathe air containing small amounts of vapors from evaporation of products at the facility.

The amount of exposure to these chemicals by the general population depends on several factors:

- distance from the facility
- the actual route of contact (e.g., inhalation)
- the length of time the chemical has been in the environment
- the way in which the chemical moves through the environment

Therefore, measuring internal facility contaminant levels may not be sufficient to determine significant general population exposure. Certain types of controls may move the chemical from inside the plant to the outdoors. It is also important to note that some chemicals may have a more significant impact on a specific segment of the general population, such as children, than on a typical worker.

Preliminary modeling was performed for both peak and average exposure. Short-term effects, such as eye irritation, are best predicted by peak exposure estimates, since the effect occurs within a short period of exposure. Long-term effects, such as carcinogenicity, are better predicted through average exposures because the effects depend on the cumulative exposure of an individual. The analysis also sought to determine whether the aggregate releases of facilities within a model region result in higher exposures for the general population compared to the releases from a single flexographic facility.

General Population Exposure Methodology

For this exposure assessment, it was assumed that fugitive and stack releases from a flexographic printing facility mixed with outside air. The resulting air concentrations depend on weather conditions. Stagnant conditions will not move vapors away quickly, so local concentrations of the chemical will be higher near the plant. Windy conditions will transport vapors away faster, thereby reducing local concentrations.

This assessment addressed acute and chronic exposure concerns for two exposure scenarios: local and regional. The local scenario considered a single facility in normal operation that has certain releases affecting a specific area and specific local population. The regional scenario considered the cumulative impact of all flexographic printing facilities within a region; in this case, Chicago, Illinois was used to model regional exposure. In both cases a model facility approach was used to calculate generic releases and environmental concentrations.

For the local exposure scenario, two models that were developed as regulatory models by the EPA's Office of Air and Radiation[15] were run to separately model the peak and average exposures. A short-term model, the Industrial Source Complex Short Term (ISCST) model, was initially used to calculate peak exposures in order to determine acute risk. A long-term model, the Industrial Source Complex Long Term (ISCLT) model, was used to determine average exposures and chronic risk. When results for the peak ISCST model were used to develop acute risk values, the results indicated that there is an insignificant likelihood of acute effects within the general population from any of the three ink systems. Therefore, the final analysis only considers chronic risk, which was determined by calculating average exposure with the ISCLT model.

Local Exposure Methodology

A model facility was used to estimate local exposure by determining a chemical's air concentration at a specified distance from the printing facility. San Bernardino, California, was used for the model because the weather conditions there result in the highest average concentrations of pollutants around the model facility of any of the approximately 500 weather stations in the United States.[14] The average concentrations around San Bernardino are within an order of magnitude of concentrations expected anywhere else in the country. That is, if the San Bernardino average concentration were estimated as 10 $\mu g/m^3$, then the average concentration anywhere else in the country would be between 1 and 10 $\mu g/m^3$.

To determine the long-term, local, general population exposure, EPA's Office of Pollution Prevention and Toxics used an implementation of ISCLT in the Graphical Exposure Modeling System (GEMS).[16] Appendix 3-G presents the input parameters used in the model.

The air concentration at 100 meters from a facility is often assumed for exposure modeling, because this is close enough to the release site so that the concentration is conservatively high (concentrations usually lessen with distance), but far enough away that a residential population could reasonably be expected to be present. To obtain the concentration at 100 meters, a special polar grid was entered into the model. Distances from the facility of 100, 200, 300, 400, 500, and 1,000 meters were specified, forming concentric circles (i.e., rings) on the grid. These rings, along with compass points, were then used to define arc-shaped areas, or sectors. The air dispersion model took three calculations per sector to obtain average air concentrations of chemical vapors. Finally, the compass point with the highest cumulative (i.e., stack plus fugitive) concentration at 100 meters was used to determine general population exposure. The model indicates whether a person at this distance would be exposed, but offers no estimate of the number of people that would be exposed.

From the average concentration in the air, estimated inhalation exposures for an individual can be calculated in different ways, depending on the toxicity factor of the modeled chemical. For the flexographic ink chemicals, the toxicity factors indicated the need for Average Daily Dose (ADD) and Average Daily Concentration (ADC) estimates for use in non-cancer chronic risk calculations.

The formulas for ADD and ADC are as follows:

$$\text{ADD (mg/kg-day)} = [(C)(IR)(ED)(1\ \text{mg}/1000\ \mu\text{g})]/[(BW)(AT)]$$

$$\text{ADC (mg/m}^3) = [(C)(ED)(\text{mg}/1000\mu\text{g})]/(AT)$$

where

C = chemical concentration in air from air dispersion modeling ($\mu g/m^3$)
IR = inhalation rate (m^3/day)
ED = exposure duration (days): for residential exposures, the average hours per day spent at the house multiplied by the average years of residency. This factor includes considerations for the average time spent inside, outside, and vacation away from the house.

BW = average body weight (kg)
AT = average time of exposure/residency (days)

Appendix 3-G demonstrates how the parameter values were calculated and presents their underlying assumptions and references.

Regional Exposure Methodology

The regional scenario provides insight into the overall impact of releases from all of the flexographic printing facilities in an area to that area's general population. This approach permits the estimation of the cumulative exposures resulting from all of the flexographic printers in an area. The total residential population exposed to flexographic ink chemicals was not available, because the locations of all the flexographic printing facilities across the country were not known.

The regional scenario was partially modeled using facilities located in the six-county metropolitan area around Chicago, Illinois, to provide an example of cumulative exposures. Within this area, the State of Illinois Environmental Protection Agency reported six companies with a total of 222 flexographic presses in a land area of 3,717 square miles. The 1995 population of the area was approximately 7,500,000.[17] The model assumed that all of these printers used the same printing formulation at the same time. The average concentration of pollutants for the Chicago area was then calculated using local weather data by means of the BOXMOD model, also implemented in GEMS.[16]

Although a region with many facilities of a given industry might have cumulative exposures greater than the local exposure estimate, that was not the case here. Instead, the relatively small number of flexographic printing facilities within the large land area meant that the regional exposure values were uniformly only half to a third of the exposure levels calculated at 100 meters from an isolated facility. Because the risks from the regional results were insignificant, complete regional modeling was deemed unnecessary, and separate results are not reported in this CTSA.

General Population Exposure Limitations and Uncertainty

There is no one value that can be used to describe exposure. Not only is uncertainty inherent in both the parameters and assumptions used in estimating exposure, but the effects possible within a population are variable. Sources of exposure uncertainty include the following:

- the accuracy with which the model facility used in the assessment characterizes an actual facility;
- estimated exposure levels from averaged data and modeling in the absence of measured, site-specific data;
- data limitations in the Environmental Air Release Assessment (the release values are inputs for the general population modeling);
- the accuracy with which the models and assumptions represent the situation being assessed, and the extent to which the models have been validated or verified; and
- parameter value uncertainty, including measurement error, sampling (or survey) error, parameter variability, and professional judgment.

EPA's *Guidelines for Exposure Assessment* document defines and describes how risk (or exposure) descriptors are used to provide information about the position of an exposure estimate in the distribution of possible outcomes.[18] One of four descriptors might be used, depending on the type and quality of data used in the analysis:

- central tendency
- high-end
- bounding
- what-if

In an ideal exposure analysis, all data would have both a value and some information about the associated probability distribution. If all data are based on average or median estimates, the analysis would be termed "central tendency," since it represents exposures that would typically be encountered. If all data are based on an exposure expected to be larger than that experienced by 90 percent of the population, the analysis is described as "high-end." An alternate descriptor is that the data represent "bounding" exposures; i.e., calculated exposures are higher than any expected actual exposures.

In some analyses, however, probability data are not available for each piece of information. In these cases, data are based on a set of circumstances (without indication of how probable that circumstance is). Such analyses are known as "what-if scenarios." Because, along with other factors, the probability of a flexographic facility being similar to that of our model facility could not be determined, the exposure analysis in this CTSA is considered a "what-if scenario."

General Population Exposure Results

Table 3-H.1 in Appendix 3-H presents fugitive and stack chemical concentrations 100 meters from the model facility for each chemical category and press-side solvent or additive. Table 3-H.2 in Appendix 3-H presents the Average Daily Dose (ADD) and Average Daily Concentration (ADC) for the general population (residential, 100 meters from the facility).

Tables 3.11 and 3.12, excerpts from Tables 3-H.1 and 3-H.2, present general population exposure data for Solvent-based Ink #S2 at Site 10. These tables are included in the text to show the format of the data and to indicate the magnitude of general population exposure.

General population exposure quantities depend on many of the same variables affecting environmental releases and occupational exposures. As a result, general population exposure results are affected in the same manner that environmental release and occupational exposure results are affected: by the volatility of the inks, ink consumption, press speed, and the use of press-side solvents and additives.

The general population exposure estimates show solvent-based inks as having the highest ADD/ADC values of the three ink systems. This indicates that the higher fugitive emissions from solvent-based inks outweigh the decrease in stack emissions resulting from the use of oxidizers on solvent-based presses. There is no clear difference between the ADD/ADC values of water-based and UV-cured inks, but they are both significantly lower than those for solvent-based inks.

Table 3.11 Sample General Population Exposure Results for Fugitive and Stack Concentrations[a]

Chemical category *(Press-side solvents and additives in italics)*	Blue		Green		White		Cyan		Magenta	
	Concentration (µg/m³)									
	fugitive	stack	fugitive	stack	fugitive	stack	fugitive	stack	fugitive	stack
Solvent-based Ink #S2 – Site 10										
Alcohols	1.82e+01	2.27e-01	2.25e+01	2.81e-01	3.76e+01	4.70e-01	1.84e+01	2.30e-01	1.92e+01	2.40e-01
Alkyl acetates	1.16e+01	1.45e-01	1.16e+01	1.45e-01	1.31e+01	1.64e-01	1.43e+01	1.78e-01	5.77e+00	7.20e-02
Hydrocarbons - low molecular weight	6.92e+00	8.63e-02	9.49e+00	1.18e-01	3.12e+01	3.89e-01	5.62e+00	7.01e-02	1.28e+01	1.59e-01
Alcohols	4.17e+00	5.15e-02	4.37e+00	5.41e-02	6.41e+00	7.92e-02	3.91e+00	4.84e-02	7.03e+00	8.69e-02
Hydrocarbons - low molecular weight	3.50e-01	4.36e-03	2.45e-01	3.06e-03	1.31e+00	1.64e-02	3.52e-01	4.40e-03	4.49e-01	5.61e-03
Alcohols	5.64e+01	7.03e-01	6.15e+01	7.67e-01			3.23e+01	4.03e-01	7.40e+01	9.23e-01
Added: Propanol					*1.14e+02*	*1.42e+00*				
Added: Propylene glycol methyl ether							*2.91e+01*	*3.64e-01*	*6.43e+00*	*8.03e-02*
Added: 2-Methoxy-1-propanol							*5.95e-01*	*7.43e-03*	*1.31e-01*	*1.64e-03*

[a] Shaded areas indicate where data are not applicable.

Table 3.12 Sample General Population Exposure Results, Average Daily Dose (ADD), and Average Daily Concentration (ADC)[a, b]

Chemical category *(Press-side solvents and additives in italics)*	Blue		Green		White		Cyan		Magenta	
	ADD (mg/kg-d)	ADC (mg/m³)	ADD (mg/kg-d)	ADC (mg/m³)	ADD (mg/kg-d)	ADC (mg/m³)	ADD (mg/kg-d)	ADC (mg/m³)	ADD (mg/kg-d)	ADC (mg/m³)
Solvent-based Ink #S2 – Site 10										
Alcohols	2.53e-03	1.34e-02	3.14e-03	1.66e-02	5.24e-03	2.78e-02	2.56e-03	1.36e-02	2.68e-03	1.42e-02
Alkyl acetates	1.62e-03	8.58e-03	1.61e-03	8.55e-03	1.82e-03	9.68e-03	1.98e-03	1.05e-02	8.02e-04	4.25e-03
Hydrocarbons - low molecular weight	9.62e-04	5.10e-03	1.32e-03	7.00e-03	4.33e-03	2.30e-02	7.82e-04	4.14e-03	1.78e-03	9.42e-03
Alcohols	5.79e-04	3.07e-03	6.08e-04	3.22e-03	8.91e-04	4.73e-03	5.44e-04	2.89e-03	9.78e-04	5.19e-03
Hydrocarbons - low molecular weight	4.86e-05	2.58e-04	3.41e-05	1.81e-04	1.83e-04	9.68e-04	4.90e-05	2.60e-04	6.25e-05	3.31e-04
Alcohols	7.84e-03	4.16e-02	8.55e-03	4.54e-02			4.49e-03	2.38e-02	1.03e-02	5.45e-02
Added: Propanol					*1.58e-02*	*8.40e-02*				
Added: Propylene glycol methyl ether							*4.05e-03*	*2.15e-02*	*8.94e-04*	*4.74e-03*
Added: 2-Methoxy-1-propanol							*8.27e-05*	*4.39e-04*	*1.82e-05*	*9.68e-05*

[a] Residential general population, 100 meters from the model facility

[b] Shaded areas indicate where data are not applicable.

3.7 RISK CHARACTERIZATION

Risk characterization integrates hazard and exposure information into quantitative and qualitative expressions of risk. This final step in a risk assessment enables experts to make a realistic estimate of risks to specific groups of people who are exposed to chemicals analyzed in earlier steps of the risk assessment. The accompanying text box describes how chemicals are grouped into categories of clear, potential, or low/negligible concern for risk.

Defining Risk Levels

Clear concern for risk indicates that for the chemical in question under the assumed exposure conditions, **adverse effects were predicted to occur.** A chemical was placed in this category if it had a Hazard Quotient (HQ) (see Note 1 below) greater than 10, or a Margin of Exposure (MOE) (see Note 2) equal to or less than 10 or 100 (depending on the type of available data). If the chemical did not have a HQ or MOE, but instead was analyzed by the structure activity team (SAT), the chemical was considered to be of clear concern for risk if it had a moderate or high hazard rating and exposure was predicted (see Note 3). Table 3.13 summarizes the HQ, MOE, and SAT criteria.

Potential concern for risk indicates that for the chemical in question under the assumed exposure conditions, **adverse effects may occur**. A chemical was designated as a potential concern for risk if it had a HQ between 1 and 10, or a MOE that either was between 10 and 100 or 100 and 1,000. A SAT-analyzed chemical was evaluated as a potential concern for risk if it posed a low-moderate hazard and exposure was predicted (see Note 3).

Low or negligible concern for risk indicates that for the chemical in question under the assumed exposure conditions, **no adverse effects were expected**. A chemical of low or negligible concern for risk had a HQ less than 1, or a MOE greater than 100 or 1,000. An SAT-analyzed chemical was evaluated as a low or negligible concern for risk if it had a low hazard rating (see Note 3).

Note 1. A Hazard Quotient (HQ) is the ratio of the average daily dose (ADD) to the Reference Dose (RfD) or Reference Concentration (RfC), where RfD and RfC are defined as the lowest daily human exposure that is likely to be without appreciable risk of non-cancer toxic effects during a lifetime. The more the HQ exceeds 1, the greater the level of concern. HQ values below 1 imply that adverse effects are not likely to occur.

Note 2. A Margin of Exposure (MOE) is calculated when a RfD or RfC is not available. It is the ratio of the NOAEL or LOAEL of a chemical to the estimated human dose or exposure level. The NOAEL is the level at which no significant adverse effects are observed. The LOAEL is the lowest concentration at which adverse effects are observed. The MOE indicates the magnitude by which the NOAEL or LOAEL exceeds the estimated human dose or exposure level. High MOE values (e.g., greater than 100 for a NOAEL-based MOE or greater than 1,000 for a LOAEL-based MOE) imply a low level of risk. As the MOE decreases, the level of risk increases.

Note 3. The Structure Activity Team (SAT) determined hazard levels based on analog data and/or structure activity considerations, in which characteristics of the chemicals were estimated in part based on similarities with chemicals that have been studied more thoroughly. SAT-based systemic toxicity concerns were ranked according to the following criteria:

- high concern — evidence of adverse effects in humans, or conclusive evidence of severe effects in animal studies
- moderate concern — suggestive evidence of toxic effects in animals; or close structural, functional, and/or mechanistic analogy to chemicals with known toxicity
- low concern — chemicals not meeting the above criteria.

Table 3.13 Criteria for Risk Levels

Level of concern	Hazard Quotient [a]	Margin of Exposure [b]		SAT Hazard Rating[e]
		NOAEL [c]	LOAEL [d]	
Clear risk	> 10	1 to 10	1 to 100	moderate or high
Potential risk	1 to 10	> 10 to 100	> 100 to 1,000	low-moderate
Low or negligible risk	< 1	> 100	> 1,000	low

[a] Hazard Quotient = ADD / RfD (RfC).
[b] Margin of Exposure = NOAEL (LOAEL) / Dose or Exposure Level.
[c] No Observed Adverse Effect Level.
[d] Lowest Observed Adverse Effect Level.
[e] This column presents the level of risk concern if exposure is expected. If exposure is not expected, the level of risk concern is assumed to be low or negligible.

Risk Characterization Limitations and Uncertainty

Estimated doses assume 100% absorption. The actual absorption rate, however, may be significantly lower, especially for dermal exposures to relatively polar compounds. This assessment used the most relevant toxicological potency factor available for the exposure under consideration.

Dermal exposure values to workers should be regarded as bounding estimates. The inhalation exposure estimates are "what-if" estimates.

Occupational Risk Results

Chemicals of Clear Concern for Risk

Categories with chemicals that present a clear concern for systemic and developmental risks to flexographic plant workers are shown in Tables 3.14 through 3.17. The type of exposure route (inhalation or dermal), the applicable formulation, and the chemical's function in the ink are listed for each formulation. For a presentation of the occupational risk data for systemic and developmental risks via dermal and inhalation pathways, see Appendices 3-I through 3-N.

The alcohols chemical category contained the most chemicals of clear concern for risk in the solvent-based and water-based ink formulations. Several amides or nitrogenous compounds in water-based ink formulations also presented a clear concern for systemic risks to workers. The acrylated polyols category contained many of the chemicals posing a clear concern for risk in the UV-cured formulations, based on toxicological data. Based on SAT reports, several other categories, including acrylated polymers and amides or nitrogenous compounds, contained chemicals that presented a clear concern for developmental effects.

Table 3.14 Clear Occupational Risk Concern: Chemical Categories for Solvent-based Inks #S1 and #S2 [a]

Exposure route	Type of risk	Categories with chemicals of clear concern [b, c]	Color	Function in ink
Solvent-based Ink #S1				
Inhalation	Systemic	Alcohols	All	Solvent
		Alkyl acetates	All but blue	Solvent
Dermal	Systemic	Alcohols	All	Solvent
		Alkyl acetates	Green, cyan, magenta	Solvent
		Inorganics	Magenta	Multiple Function
	Developmental	Alcohols	All	Solvent
		Inorganics	Magenta	Multiple Function
		Organic acids or salts (SAT)[d]	Blue	Additive
		Organometallic pigments (SAT)[d]	Blue, magenta	Colorant
		Organotitanium compounds (SAT)[d]	Blue, white	Additive
Solvent-based Ink #S2				
Inhalation	Systemic	Alcohols	All	Solvent
		Hydrocarbons — low molecular weight	All	Multiple Function
		Propylene glycol ethers	Cyan, magenta	Solvent
	Developmental	Alcohols	Blue	Solvent
Dermal	Systemic	Alcohols	All but white	Solvent
		Propylene glycol ethers	Cyan	Solvent
	Developmental	Alcohols	All	Solvent
		Organometallic pigments (SAT)[d]	Blue, magenta	Colorant

[a] Based on toxicological data, unless noted as an SAT-based concern.
[b] Criteria for clear risk concern are presented in Table 3.13.
[c] Each of these categories contains at least one chemical that was predicted to be of clear concern for risk.
[d] Developmental risks for SAT-evaluated chemicals were evaluated on a "concern/no concern" basis.

Table 3.15 Clear Occupational Risk Concern: Chemical Categories for Water-based Inks #W1 and #W2 [a]

Exposure route	Type of risk	Categories with chemicals of clear concern [b, c]	Color	Function in ink
Water-based Ink #W1				
Inhalation	Systemic	Alcohols	All but magenta	Solvent
		Amides or nitrogenous compounds	All	Multiple Function
		Ethylene glycol ethers	All but white	Solvent
Dermal	Systemic	Alcohols	All but magenta	Solvent
		Amides or nitrogenous compounds	All	Multiple Function
		Ethylene glycol ethers	All but white	Solvent
		Organic pigments	Magenta	Colorant
	Developmental	Alcohols	Blue, green	Solvent
Water-based Ink #W2				
Inhalation	Systemic	Alcohols	All but green	Solvent
		Amides or nitrogenous compounds	Green, white	Multiple Function
		Ethylene glycol ethers	All but green	Solvent
Dermal	Systemic	Alcohols	Blue	Solvent
		Amides or nitrogenous compounds	White, magenta	Multiple Function
		Ethylene glycol ethers (SAT)[d]	All	Solvent

[a] Based on toxicological data, unless noted as an SAT-based concern.

[b] Criteria for clear risk concern are presented in Table 3.13.

[c] Each of these categories contains at least one chemical that was predicted to be of clear concern for risk.

[d] Developmental risks for SAT-evaluated chemicals were evaluated on a “concern/no concern” basis.

Table 3.16 Clear Occupational Risk Concern: Chemical Categories for Water-based Inks #W3 and #W4 [a]

Exposure route	Type of risk	Categories with chemicals of clear concern [b, c]	Color	Function in ink
Water-based Ink #W3				
Inhalation	Systemic	Alcohols	All but cyan	Solvent
		Amides or nitrogenous compounds	All	Multiple Function
		Ethylene glycol ethers	Green	Solvent
Dermal	Systemic	Alcohols	Blue, green, white	Solvent
		Amides or nitrogenous compounds	All	Multiple Function
		Ethylene glycol ethers	Green	Solvent
		Organometallic pigments	Magenta	Colorant
	Developmental	Alcohols	All but cyan	Solvent
Water-based Ink #W4				
Inhalation	Systemic	Alcohols	All	Solvent
		Amides or nitrogenous compounds	All	Multiple Function
	Developmental	Amides or nitrogenous compounds	White	Multiple Function
Dermal	Systemic	Alcohols	All	Solvent
		Amides or nitrogenous compounds	Green, white	Multiple Function
		Organometallic pigments	Magenta	Colorant
	Developmental	Alcohols	All	Solvent
		Amides or nitrogenous compounds	Magenta	Multiple Function

[a] Based on toxicological data, unless noted as an SAT-based concern.
[b] Criteria for clear risk concern are presented in Table 3.13.
[c] Each of these categories contains at least one chemical that was predicted to be of clear concern for risk.

Table 3.17 Clear Occupational Risk Concern: Chemical Categories for UV-cured Inks #U1, #U2, and #U3 [a]

Exposure route	Type of risk	Categories with chemicals of clear concern [b, c]	Color	Function in ink
UV-cured Ink #U1				
Inhalation	Systemic	Acrylated polyols (SAT)	Green	Monomer
		Amides or nitrogenous compounds (SAT)	All	Multiple Function
	Developmental	Amides or nitrogenous compounds (SAT)[d]	All	Multiple Function
Dermal	Systemic	Acrylated polyols (SAT)	Green	Monomer
		Amides or nitrogenous compounds (SAT)	All	Multiple Function
		Organometallic pigments	Magenta	Colorant
	Developmental	Acrylated polymers (SAT)[d]	All	Oligomer
		Amides or nitrogenous compounds (SAT)[d]	All	Multiple Function
		Inorganic pigments (SAT)[d]	White	Colorant
UV-cured Ink #U2				
Inhalation	Systemic	Acrylated polyols	All	Monomer
	Developmental	Acrylated polyols	White	Monomer
Dermal	Systemic	Acrylated polymers	All	Oligomer
		Acrylated polyols	All	Monomer
		Organometallic pigments	Magenta	Colorant
		Organophosphorus compounds	White	Multiple Function
	Developmental	Acrylated polymers (SAT)[d]	All	Oligomer
UV-cured Ink #U3				
Inhalation	Systemic	Acrylated polyols (SAT)	All but white	Monomer
		Amides or nitrogenous compounds (SAT)	All	Multiple Function
	Developmental	Acrylated polyols (SAT)	All but white	Monomer
		Amides or nitrogenous compounds (SAT)	All	Multiple Function
Dermal	Systemic	Acrylated polyols (SAT)	All but white	Monomer
		Amides or nitrogenous compounds (SAT)	All	Multiple Function
	Developmental	Acrylated polymers (SAT)[d]	All	Oligomer
		Acrylated polyols (SAT)[d]	All but white	Monomer
		Amides or nitrogenous compounds (SAT)[d]	All	Multiple Function

[a] Based on toxicological data, unless noted as an SAT-based concern.

[b] Criteria for clear risk concern are presented in Table 3.13.

[c] Each of these categories contains at least one chemical that was predicted to be of clear concern for risk.

[d] Developmental risks for SAT-evaluated chemicals were evaluated on a "concern/no concern" basis.

Most of chemicals presenting a clear occupational risk concern in solvent-based ink formulations are solvents; many chemicals presenting clear risk concern for water-based inks serve as solvents, colorants, and multi-function chemicals. For UV-cured ink formulations, most chemicals presenting a clear occupational risk concern serve as additives, monomers, oligomers, colorants, and the multiple function category.

Range of Occupational Risk Concern Levels by Chemical Category and Ink System

Table 3.18 summarizes the range of occupational risk concern levels (low concern, potential concern, or clear concern) for the three ink systems via dermal and inhalation routes. Because concern levels for systemic and developmental risk were very similar for each chemical category, the ranges for the two types of risk were combined. These ranges were based on toxicological data only, except for two chemical categories found in UV-cured inks: amides or nitrogenous compounds and aromatic esters, which had SAT data.

Each ink system contained chemicals with a clear concern for risk:

- Solvent-based inks had five chemical categories that contained chemicals of clear risk.
- Water-based inks had five chemical categories that contained chemicals of clear risk.
- UV-cured inks had four chemical categories that contained chemicals of clear risk.

Chemical categories within an ink system showed a wide variation in the level of risk concern. For example, ethylene glycol ethers in water-based inks ranged from low concern to clear concern. Variation also occurred among ink systems for certain chemical categories (e.g., certain alcohols in solvent- and water-based inks presented a clear concern, but alcohols in UV-cured inks presented a low concern). Such variations were due to differences in physical properties between chemicals in a category and/or differences in percent composition of an ink formulation.

Summary of Number of Chemicals of Clear Occupational Risk Concern by Product Line and Site

Table 3.19 summarizes of the number of chemicals that were found to be of concern for clear occupational risk. Solvent- and water-based ink product lines each included an average of 16 chemicals with clear risk concern (based on both toxicological and SAT-based data): an average of 29% for water-based inks, and 23% for solvent-based inks. Two of the three UV-cured inks had relatively few chemicals with clear concern; however, UV-cured Ink #U2 had 21 chemicals with clear concern (30%). It should be noted that these tallies do not necessarily give a full picture of risk concerns, because it is not possible to correlate the nature and severity of potential adverse effects on an aggregate product line level.

The total number of chemicals in an ink product line was determined by adding the numbers of base chemical ingredients and press-side solvents and additives for each formulation within a product line, and then summing the totals for all five formulations. Using this method, a chemical was counted more than once if it were found in more than one formulation. For example, ethanol, used in three formulations within a product line, was considered to be three "chemicals." However, if a chemical presented a clear risk concern for both dermal and inhalation pathways in a single formulation, it was counted only once. Similarly, if a chemical presented a clear risk concern for both systemic and developmental effects, it was counted only once.

Table 3.18 Range of Occupational Risk Concern (Combined Systemic and Developmental) [a, b, c]

Chemical category	Solvent-based	Water-based	UV-cured
Acrylated polymers	▨	▨	● ↔ ●●●
Acrylated polyols	▨	▨	● ↔ ●●●
Acrylic acid polymers	▨	●	▨
Alcohols	● ↔ ●●●	● ↔ ●●●	●
Alkyl acetates	● ↔ ●●●	▨	▨
Amides or nitrogenous compounds	●	● ↔ ●●●	moderate concern (SAT)
Aromatic esters	●	▨	low to moderate concern (SAT)
Aromatic ketones	▨	▨	● ↔ ●●
Ethylene glycol ethers	▨	● ↔ ●●●	▨
Hydrocarbons - high molecular weight	●	● ↔ ●●	▨
Hydrocarbons - low molecular weight	● ↔ ●●●	● ↔ ●●	▨
Inorganics	● ↔ ●●●	●	▨
Olefin polymers	▨	●	●
Organic acids or salts	●	● ↔ ●●	▨
Organophosphorous compounds	● ↔ ●●	▨	● ↔ ●●●
Organotitanium compounds	●	▨	▨
Pigments - inorganic	● ↔ ●●	● ↔ ●●	● ↔ ●●
Pigments - organic	●	● ↔ ●●●	●
Pigments - organometallic	●	● ↔ ●●●	● ↔ ●●●
Polyol derivatives	●	▨	●
Propylene glycol ethers	● ↔ ●●●	● ↔ ●●	▨
Resins	●	●	▨
Siloxanes	● ↔ ●●	● ↔ ●●	●

[a] The range of systemic and developmental risk concern levels were very similar for each chemical category and were therefore combined. The range of concern levels presented in this table represent the compounds in each chemical category that presented the lowest and highest risks for prep and press room workers from dermal and/or inhalation routes.

[b] Key: ● = low concern; ●● = potential concern; ●●● = clear concern

[c] Shaded areas indicate where data are not applicable.

Table 3.19 Summary of Number of Chemicals with Clear Occupational Risk Concern, by Product Line and Site

Ink type	Product Line	Site	Number of Chemicals[a]	Toxicological Data[a,b]		SAT Data[a,b]		Total Chemicals of Clear Risk Concern[a,b]		
				Number	Percent	Number	Percent	Number	Percent	Rank[c]
Solvent-based	#S1	9B	63	15	24%	2	3%	17	27%	5
	#S2	5	70	14	20%	0	0%	14	20%	10
		7	71	15	21%	0	0%	15	21%	9
		10	75	18	24%	0	0%	18	24%	7
Water-based	#W1	4	43	16	37%	0	0%	16	37%	1
	#W2	1	48	13	27%	3	6%	16	33%	2
	#W3	2	62	15	24%	0	0%	15	24%	6
		3	56	13	23%	0	0%	13	23%	8
	#W4	9A	66	18	27%	0	0%	18	27%	4
UV-cured	#U1	11	48	1	2%	6	13%	7	15%	12
	#U2	6	70	16	23%	5	7%	21	30%	3
	#U3	8	46	0	0%	9	20%	9	20%	11

[a] Chemicals are counted more than once if found in more than one formulation within the same product line. The number of chemicals may also include site-specific press-side solvents or additives.

[b] Includes clear concern for risk for systemic or developmental effects via inhalation or dermal routes.

[c] The ranking orders the product lines from the highest to lowest percentage of chemicals with clear concern for occupational risk.

Occupational Concern for Risk from Press-side Solvents and Additives

The use of additives increased the occupational risk for many of the solvent- and water-based ink formulations. In particular, propanol and propylene glycol methyl ether in solvent-based inks, and ammonia, propanol, isobutanol, and ethyl carbitol in water-based inks presented potential or clear occupational risk concerns in certain formulations. UV-cured inks typically do not use any press-side additives. In the performance demonstrations, however, one additive was used in UV-cured Ink #U2 (green).

Concern for Cancer Risk

Only a few ink formulations contained chemicals posing a concern for cancer. These included Water-based Ink #W1 (Site 4) and Water-based Ink #W2 (Site 1), which contained chemicals shown to produce tumors in rodents following dermal and/or inhalation exposures. An inorganic pigment found in every solvent-based, water-based, and UV-cured ink system is a possible carcinogen by the inhalation route of exposure. However, this compound, like other possibly carcinogenic compounds used in this project, does not pose significant risk because the exposure pathway for workers is different from that which results in carcinogenic effects.

General Population Risk Results

Categories with Chemicals of Potential General Population Concern for Risk

Categories with chemicals that present a potential risk concern for systemic and developmental effects in the general population are shown in Table 3.20. **No chemicals presented a clear concern for risk to the general population.** For a presentation of the general population risk data for systemic and developmental risks via inhalation, see Appendices 3-O and 3-P.

In the solvent-based and water-based ink product lines, alcohols found in Solvent-based Ink #S2, Water-based Ink #W2, and Water-based Ink #W3 were the only category with chemicals of potential general population risk concern based on toxicological data. (The alcohols served as solvents in these formulations.) For the UV product lines, acrylated polyols in UV-cured Ink #U2, serving as reactive diluents, were the only category with chemicals of potential risk concern based on toxicological data. Based on SAT reports, certain propylene glycol ethers in Solvent-based Ink #S2, amides or nitrogenous compounds in UV-cured Inks #U1 and #U3, and acrylated polyols in UV-cured Ink #U2 may present a risk to the general population.

Range of General Population Risk Concern Levels by Chemical Category and Ink System

Table 3.21 summarizes the range of general population risk levels for each of the three ink systems. The range of concern levels for systemic and developmental risk are very similar for each chemical category and were therefore combined in the table. These ranges are based on toxicological data only, except for two chemical categories in UV-cured inks: amides or nitrogenous compounds, and aromatic esters, which have SAT support.

Most of the chemicals presented a negligible concern for general population risk because the model anticipated little exposure to the general population in the model, and no chemicals presented a clear concern for risk. Each ink system had one category with chemicals that posed a potential risk concern for the general population: alcohols in solvent- and water-based inks, and acrylated polyols in UV-cured inks. Five additional categories in water-based inks, three in solvent-based inks, and one in UV-cured inks contained chemicals of low concern for risk to the general population.

Summary of Number of Chemicals of Potential General Population Risk Concern by Product Line and Site

Table 3.22 summarizes the number of chemicals with a potential risk concern for the general population, by product line and site. **Very few chemical categories include chemicals that carry a potential risk concern for the general population:** alcohols in Solvent-based Ink #2 (Site 5), Water-based Ink #W2 (Site 1), and Water-based Ink #W3 (Sites 2 and 3), and acrylated polyols in UV-cured Ink #U2 (Site 6). The number of chemicals in a product line was determined by the same method used for Table 3.19.

Table 3.20 Categories with Chemicals Having a Potential Systemic and Developmental Risk Concern for the General Population [a]

Exposure route	Type of risk	Chemical categories with potential risk [b]	Color	Function in ink
Solvent-based Ink #S1				
Inhalation	Systemic			
	Developmental			
Solvent-based Ink #S2				
Inhalation	Systemic	Alcohols	White, cyan, magenta	Solvent
	Developmental	Propylene glycol ethers (SAT)	Cyan, magenta	Solvent
Water-based Ink #W1				
Inhalation	Systemic			
	Developmental			
Water-based Ink #W2				
Inhalation	Systemic	Alcohols	White	Solvent
	Developmental			
Water-based Ink #W3				
Inhalation	Systemic	Alcohols	White	Solvent
	Developmental			
Water-based Ink #W4				
Inhalation	Systemic			
	Developmental			
UV-cured Ink #U1				
Inhalation	Systemic			
	Developmental	Amides or nitrogenous compounds (SAT)	All	Multiple Function
UV-cured Ink #U2				
Inhalation	Systemic	Acrylated polyols	White	Monomer
	Developmental			
UV-cured Ink #U3				
Inhalation	Systemic			
	Developmental	Acrylated polyols (SAT)	All but white	Monomer
		Amides or nitrogenous compounds (SAT)	All	Multiple Function

[a] Based on toxicological data, unless noted as an SAT-based concern.

[b] Criteria for potential concern for risk to the general population are presented in Table 3.13. No chemicals presented a clear concern for risk to the general population.

Table 3.21 Range of General Population Risk (Combined Systemic and Developmental) [a, b, c]

Chemical category	Solvent-based ink	Water-based ink	UV-cured ink
Acrylated polymers			○
Acrylated polyols			○ ↔ ●●
Acrylic acid polymers		○	
Alcohols	● ↔ ●●	○ ↔ ●●	○
Alkyl acetates	●		
Amides or nitrogenous compounds	○	●	moderate concern (SAT)
Aromatic esters	○		low to moderate concern (SAT)
Aromatic ketones			○ ↔ ●
Ethylene glycol ethers		○ ↔ ●	
Hydrocarbons - high molecular weight	○	●	
Hydrocarbons - low molecular weight	●	●	
Inorganics	○	○	
Olefin polymers		○	○
Organic acids or salts	○	○	
Organophosphorous compounds	○		○
Organotitanium compounds	○		
Pigments - inorganic	○	○	○
Pigments - organic	○	○	○
Pigments - organometallic	○	○	○
Polyol derivatives	○		○
Propylene glycol ethers	●	○ ↔ ●	
Resins	○	○	
Siloxanes	○	○	○

[a] The ranges of systemic and developmental risk concern levels were very similar for each chemical category and were therefore combined. The range of risk levels presented in this table represent the compounds in each chemical category that presented the lowest and highest risk concern for the general population via inhalation only.

[b] Key: ○ = negligible concern because exposure is not anticipated; ● = low concern; ●● = potential concern; ●●● = clear concern

[c] Shaded areas indicate where data are not applicable.

Table 3.22 Summary of Number of Chemicals with Potential General Population Risk Concern, by Product Line and Site

Ink type	Product Line	Site	Number of Chemicals With Potential Risk Concern[a, b]	Number of Total Chemicals [b]	Percent
Solvent-based	#S1	9B	0	63	0%
	#S2	5	3	70	4%
		7	0	71	0%
		10	0	75	0%
Water-based	#W1	4	0	43	0%
	#W2	1	1	48	2%
	#W3	2	1	62	2%
		3	1	56	2%
	#W4	9A	0	66	0%
UV-cured	#U1	11	0	48	0%
	#U2	6	1	70	1%
	#U3	8	0	46	0%

[a] Includes potential risk concern for systemic or developmental effects via inhalation.
[b] Chemicals are counted more than once if found in more than one formulation within a product line. The number of chemicals includes site-specific press-side solvents and additives used in the performance demonstrations.

General Population Risk Concern from Press-Side Solvents and Additives

The use of press-side solvents and additives was found to increase the concern for risk to the general population for many of the solvent- and water-based inks formulations. In particular, propanol and propylene glycol ethers in solvent-based inks; and ammonia, propanol, isobutanol, and ethyl carbitol in water-based inks, presented low concern for risk to the general population in certain formulations.

Concern for Cancer Risk

Water-based ink #W2 (Site 1) contained one chemical that could expose the general population by the inhalation route; there is evidence of this chemical producing tumors in one species following inhalation exposure. Several of the carcinogenic chemicals identified were found to be of negligible general population risk concern, because incidental exposure of the general population to these chemicals was not expected.

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Chapter 4: Performance

CHAPTER CONTENTS

CHAPTER OVERVIEW

This chapter describes the data collection that was done to evaluate performance of the different ink systems, and presents highlights of the results.

METHODOLOGY: The methodology of the data collection and tests for this CTSA is summarized in Section 4.1. The methodology section describes the performance demonstrations, the laboratory tests that were performed on all the ink/substrate combinations, and the specific sites at which the demonstrations were run. (The complete performance demonstration methodology can be found in Appendix 4-A, and other information relevant to the methodology is in Appendix 4-B through 4-D.) Western Michigan University conducted separate laboratory runs on all substrates using water-based and solvent-based inks. The use of a single press under controlled conditions was intended to provide some consistency and a basis of comparison for the results of the performance demonstrations. Highlights of the tests that were performed for the laboratory runs are discussed in Section 4.2, and more detailed information is provided in many of the appendices to Chapter 4, particularly Appendices 4-A through 4-E.

PERFORMANCE DEMONSTRATION TEST RESULTS: The printed substrates completed at the performance demonstrations were sent to Western Michigan University, which tested each ink/substrate combination. A total of 18 tests were performed to measure a wide range of capabilities for solvent-based, water-based, and UV-cured ink systems. The performance demonstration test results for solvent-based and water-based inks are summarized in Section 4.2 . Because the technology for UV-cured inks was still in a developmental phase at the time of the performance demonstrations (November 1996 — March 1997), the results for UV-cured inks are presented separately in Section 4.3. To provide a more current picture of UV-cured inks, The section also discusses some of the relevant advances that have been made in UV technology since the performance demonstrations were completed.

PERFORMANCE DEMONSTRATION SITE PROFILES: Demonstration runs were done at 11 sites, which are numbered to protect confidentiality. Section 4.4 provides detailed data about each of the volunteer printing facilities. For each facility, the type of ink used, control equipment, annual production, operating hours, and average production run are provided. Details are also provided about the presses on which the demonstrations were run.

HIGHLIGHTS OF RESULTS: At the end of Sections 4.3 and 4.4, readers will find brief summaries of the overall test results. This study was set up to explore a wide range of characteristics and interactions between inks and substrates that can be important in flexographic printing. The demonstrations were all performed by different press operators at different flexographic facilities under widely varying circumstances, and consequently the test scores show considerable variation over both ink systems and substrates, and often between individual ink product lines as well. That is, they show the kinds of differences that are typically encountered in the real world of flexographic printing. Such variances indicate that printers need to give careful consideration to a variety of different factors in determining acceptable quality for their facility. These factors—among them cost, health and environmental risks, energy use, and pollution prevention opportunities—are discussed in other chapters of this CTSA.

CAVEATS

The use of the terms *quality* and *acceptable print* are highly subjective. What one printer finds acceptable and salable in a printed product may be considered scrap by another printer. Thus, caution must always be used when making statements about what constitutes acceptable printing and high quality.

4.1 METHODOLOGY

The Flexography Project Technical Committee (whose members are listed at the front of this CTSA) developed this methodology to investigate the performance of solvent-based, water-based, and UV-cured ink systems on three film substrates. The substrates that were used are low-density polyethylene (LDPE), co-extruded polyethylene/ethyl vinyl acetate (PE/EVA), and oriented polypropylene (OPP). The methodology involved two types of data collection: performance demonstrations at 11 volunteer printing facilities, and laboratory runs conducted at the printing facility of Western Michigan University.

Facility Selection Process

Ten commercial printing facilities in the United States, and a press manufacturer's pilot line in Germany, volunteered to participate in this study. To participate in the project, facilities needed to be proficient with the ink system and the product-substrate combination that they would test. In some cases, this use of "real world" facilities and conditions required modifying the specifications, because all printers do not necessarily have the precise mixture of requirements desired. All facilities that participated donated press time to print the appropriate ink/substrate combinations on wide-web presses.[a]

Each facility that volunteered to participate in the project also contributed a significant amount of technical information via a detailed Facility Background Questionnaire (Appendix 4-B). The Site Profiles in Section 4.4 present much of this information.

Methodology for On-site Performance Demonstrations

Each ink/substrate combination was run on a standardized image in at least two of the facilities. Table 4.1 lists the ink-substrate combinations run at each of the facilities. Four of the 12 sites used a solvent-based ink system, five used water-based, and three used UV-cured. Seven sites ran LDPE, six sites ran PE/EVA, and seven sites ran OPP. Appendix 4-A details the specifications of the printing presses, plates, substrates, and demonstration runs.

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[a] One facility, Site 9, ran two different inks at the same location and was separated into two performance demonstrations (Sites 9A and 9B). This made a total of 12 "sites."

Table 4.1 Ink System and Substrates Tested at Each Site

Ink System	Substrate(s)	Site
Solvent-based	LDPE, PE/EVA	Site 5
	LDPE, PE/EVA	Site 7
	OPP	Site 9B
	OPP	Site 10
Water-based	LDPE, PE/EVA	Site 2
	LDPE, PE/EVA	Site 3
	OPP	Site 4
	OPP	Site 1
	OPP	Site 9A
UV-cured	LDPE, PE/EVA, OPP	Site 6
	LDPE, PE/EVA, OPP	Site 8
	LDPE	Site 11

During each demonstration, the press was run at production speeds (approximately 300 to 500 feet/min) for about two hours to produce up to 60,000 feet of printed product. Flexographic printing experts from Western Michigan University's (WMU) Department of Paper and Printing Science and Engineering were present at all demonstration runs to ensure consistent adherence to the methodology. At the completion of each demonstration, the printed substrate was sent to Western Michigan University for analysis.

These press runs were intended to provide a "snapshot" of performance under actual production conditions, rather than a tightly controlled experiment. The performance demonstrations collected information about the real-world print quality issues associated with different ink systems using different film substrates and printed on wide-web presses. Additionally, information was collected for the cost, environmental and health risk, and energy and natural resources analyses. (These issues are the focus of other chapters of this CTSA.)

The complete performance demonstration methodology and data collection sheets can be found in Appendices 4-A and Appendix 4-C.

Tests Performed on Samples from Performance Demonstrations and Laboratory Runs

All the samples collected in both the performance demonstrations and the laboratory runs were subjected to an extensive series of tests. A total of 18 different tests were conducted to analyze a wide range of ink properties and inks' effects on substrates, focusing on aspects that would be important to many flexographic printers. The purpose, procedure, and interpretive information for each test are provided in Table 4.2. The inclusion of laboratory runs allows comparative analysis about field performance. The results of these tests are described in Sections 4.2 and 4.3, and the details of the laboratory test procedures and performance data can be found in Appendix 4-E.

Table 4.2 Purpose, Procedure, and Interpretation of Tests

Test Name	Purpose	Procedure (detailed demonstration and laboratory procedures described in Appendix 4-E)[a]	Interpretation
Adhesive lamination	Measures bond strength between the adhesive layer of the lamination and the ink. In laminations, the ink needs to bond well to both top and bottom lamination structures.	A laminated sample was attached to a force measurement instrument (an Instron tensile tester). The instrument separated the lamination layer from the substrate. The amount of force in kilograms (kg) necessary to cause the separation was measured and recorded as the delamination force.	Adhesion is influenced by volume of ink applied, chemical composition, and ink-substrate interaction. Each measurement listed is an average of five measurements. Readings above 0.350 kg are considered acceptable.
Block resistance	Measures the bond between ink and substrate when heat and pressure are applied. Ink transfer from a printed substrate to a surface in contact with the print indicates that blocking has occurred.	Folded samples of the printed substrate were layered between sheets of aluminum foil. Pressure was applied to the foil/substrate/foil sandwich using a clamping device. Blocking was measured in the laboratory with samples collected from each site.	There is no industry standard for blocking. The integrity of the ink bond to the substrate is an important performance characteristic of the ink; no blocking (0) reflects good print quality. The results of the test were recorded on a scale from 0 (no blocking) to 5 (complete blocking).
CIE L*a*b*	Measures the reflected light of a printed color and calculates a unique numerical value. The ability to match L*a*b* values is crucial in producing high-quality graphics and meeting customer specifications.	Using a Datacolor Spectraflash 600, measurements were taken for four colors at four locations during each performance demonstration. For laboratory runs, measurements were taken for only one color measured at three locations.	CIE L*a*b* values have no units and are used only for relative consideration and reference. No conclusions can be drawn from the data because the ink systems use different pigments. Only the L* component of the L*a*b* values provides direct information about changes in density. A higher L* value=a lighter color; a lower L* value=a darker color; a higher a* value=a redder (less green) color; a lower a* value=a greener (less red) color; a higher b* value=a more yellow (less blue) color; lower b* value=a bluer (less yellow) color; The a* and b* components are a function of ink pigment, which differs by ink systems.
Coating weight	Measures the weight of the ink film layer on a substrate after drying; affects all final printed properties, both optical and physical.	This test was performed by drying printed samples in a 150°F oven for 1 hour to remove any remaining solvents. The samples were weighed, along with an equal number of unprinted samples of the same film type. The weight of the unprinted samples was subtracted from the weight of the printed samples. The difference was then divided by the total linear footage of the printed samples.	Coating weight is the weight of the ink film layer and is expressed in grams per square centimeter (g/cm^2). There is no industry standard for coating weight; it is only a relative value. Coating weight is a function of anilox roll volume, wettability of the substrate, ink viscosity, and weight of the solids content of the applied ink.

Table 4.2 Purpose, Procedure, and Interpretation of Tests (continued)

Test Name	Purpose	Procedure (detailed demonstration and laboratory procedures described in Appendix 4-E)[a]	Interpretation
Coefficient of friction (COF)	Determines the resistance of a printed object to sliding. High COF is important is some situations, low COF in others.	COF was measured in the laboratory using an Instron tensile tester equipped with a friction sled. The COF values were then converted to angle of inclination.	Results are expressed as the angle of inclination, where high angle values indicate high resistance, or friction, between the ink and film substrate. COF values are relative and are used only as a reference based on the needs of the final product.
Density	Measures the degree of darkness (light-absorption) of a printed solid.	An X-Rite 418 densitometer measured the amount of reflected light from the surface of a printed sample.	Density is primarily a function of anilox roll volume and the resulting thickness of the applied ink film. Density fluctuations may be the result of changes in ink viscosity and impression pressure.
Dimensional stability	Measures how printing conditions distort the linear dimensions of the substrate. Various factors, such as heat from the dryers, can affect stability by changing the physical dimensions of the substrate — in either the cross-web direction (perpendicular to the movement of the web) or the machine direction (the direction in which the web moves).	Measured the length and width of the printed solid blocks, and compared those measurements to the size of the original images on the printing plate.	Any change in the dimensions of the printed areas indicates instability of the substrate due to printing conditions. The average percent change in the width of the sample represents the distortion in the cross-web direction compared with the original plate, and the average percent change in the length represents the distortion in the machine direction. The smallest percent change indicates the least amount of distortion.
Gloss	Measures the reflection from a light source directed at the surface from an angle.	A Gardner Microgloss glossmeter shone a beam of light at a 60° angle onto the sample; the light was reflected back onto a photoelectric cell. On LDPE, gloss was measured for magenta, cyan, blue, and green over a white ink background, and also for white, green, and blue on clear film. On PE/EVA, gloss was measured for magenta, cyan, blue, and green on white film.	The measurements are reported on a scale from 0 to 100 (higher numbers indicating higher reflectivity). These values have no units and are used only for comparison purposes. Gloss is a function of ink composition, ink film thickness, substrate, and, to a lesser extent, how well the ink dries on the substrate. The visual assessment of gloss is subjective.

Table 4.2 Purpose, Procedure, and Interpretation of Tests (continued)

Test Name	Purpose	Procedure (detailed demonstration and laboratory procedures described in Appendix 4-E)[a]	Interpretation
Heat resistance/ heat seal	Measures the degree to which a printed substrate will resist transfer when heated. Many printed products are subjected to extreme heat during handling and storage.	A printed sample was folded on itself and sandwiched between two pieces of aluminum foil. This sandwich was heated to 400°F. After the sample cooled back down, it was peeled apart and checked for ink transfer.	The test results are recorded as “pass” (no ink transfer), or “fail” (transfer of ink). In the case of a failure, the percent of ink transferred is evaluated and recorded.
Ice water crinkle adhesion	Measures the integrity and flexibility of the ink on the substrate when exposed to refrigerator and freezer conditions. Many flexographically printed products, such as those used for frozen foods, are subjected to very cold conditions. The inks must stay flexible and maintain the integrity of their adhesion to the substrate under these conditions so that they don’t rub off or flake off.	A printed strip was submerged in a container of ice water for 30 min. Then it was removed and twisted rapidly 10 times. This was done by grasping the print firmly between the thumb and forefinger of each hand with about one inch of print between the thumbs, bringing the hands almost together, and then rotating the wrists in opposite directions fairly rapidly.	The adhesion results of this test are expressed as a “no” (no ink was removed) or a “yes” (some of the ink was removed). If a “yes” is reported, the approximate amount of ink removed is given as a percentage; the higher the percentage, the lower the print quality. A “no” indicates that the ink maintained the integrity of its adhesion and flexibility when exposed to cold conditions.
Image analysis	Measures how well the image is formed. Good image detail is important for printing, particularly for small type, reverse type, and halftones (single or process color).	The test was performed using high-resolution optics, an RGB digital frame grabber, and a computer with Image ProPlus Analysis software. The average dot area and the average perimeter of the printed dots were measured and analyzed.	There is currently no industry standard for image detail. The data are only relative and can be used for comparing the formation of the tones among ink samples. The dot area and perimeter correspond to the spread of the ink and may indicate dot distortion. The test evaluates screened dot detail as used in process color reproduction. Dot detail information is dependent on the wettability of the substrate, impression pressure, viscosity, and cell volume of the anilox roll.
Jar odor	Measures the type and strength of odor produced by ink film on the substrate. Many flexographically printed products are used for food packaging, so it is important that ink odor does not affect the packaged product.	A printed sample was placed in a glass jar and sealed. The jar was put into a 100°F oven for 2 hours. It was removed, opened, and sniffed immediately. The same procedure was repeated with an unprinted sample of the substrate as a control.	The results of this test are expressed both quantitatively (on a scale from 0 to 5, with 0 signifying no odor and 5 signifying an unpleasant, offensive odor) and qualitatively (a comparative description of the odor).

Table 4.2 Purpose, Procedure, and Interpretation of Tests (continued)

Test Name	Purpose	Procedure (detailed demonstration and laboratory procedures described in Appendix 4-E)[a]	Interpretation
Mottle/lay	Measures spottiness or non-uniformity of an ink film layer. Minimizing mottle is important for high-quality printing.	Multiple density measurement points (250-500) were collected with a Mottle Tester during 20 linear scans over the sample area.	Minimizing mottle is a particular challenge when printing large solid areas, which are typical in line printing. There are no industry standards for “good” or “bad” mottle. The values should be used only for comparative analysis. The higher the Mottle Index, the lower the print quality. Also, the higher the standard deviation, the more variable the print quality.
Opacity	Measures the percentage of light blocked from being transmitted through the ink film and substrate. The opacity values indicate the uniformity of ink coverage of the substrate. Opacity is critical on clear substrates, where an opaque background is needed to provide a backdrop for other color graphics.	Samples were taken using a Datacolor Spectraflash 600 and a Diano-BLN opacity meter. The measurements were averaged to obtain one reading for each location.	Opacity is expressed as the percentage of light blocked. Average values greater than 48% are generally considered desirable. Factors such as anilox roll volume play a greater role in opacity than does ink type. High opacity is best achieved by using inks with high solids content and high application weights as governed by the anilox roll. Opacity is also a function of substrate and plate wettability. When interpreting opacity data, the anilox roll volumes, printing viscosity, and substrates must be evaluated as a complete system.
Rub resistance	Indicates the ink’s ability to resist being rubbed off substrate. Dry rub resistance is critical on products such as retail bags and bread bags, as the exposed ink film is abraded and scuffed during end use. Wet rub resistance is very important on frozen food bags, which can be subjected to abrasion during handling.	The initial density of the ink on the printed sample was measured using a Sutherland Rub Tester. For the dry rub test, a printed sample was mounted on the base of the rub tester, and an unprinted sample of substrate was mounted on a rubbing block. The rubbing block oscillated against the printed sample. Results were expressed as the percent of retained density. For the wet rub resistance test, distilled water was first placed on the printed surface at the start of the test; and a maximum of ten strokes was specified but no number of strokes per cycle was specified.	Both wet and dry rub are a function of ink film integrity and bonding to the substrate. Rub is influenced by volume of ink applied, chemical composition, and ink-substrate interaction. Rub is not considered as critical a factor on laminated OPP products, since the ink will be layered between two polymer substrates. The dry rub test results are reported as percent retained density after 50 strokes. For perfect print quality, the ink retains 100% density. Failure is determined by color transferred from the printed substrate to the unprinted substrate. The higher the number of strokes at which the sample fails, the better the rub resistance.

Table 4.2 Purpose, Procedure, and Interpretation of Tests (continued)

Test Name	Purpose	Procedure (detailed demonstration and laboratory procedures described in Appendix 4-E)[a]	Interpretation
Tape adhesiveness	Measures the bond of the dry ink to the substrate. Adequate ink adhesion is critical; if the ink doesn't adhere well enough, it will not be able to stand up to the normal demands placed on the finished product.	A length of adhesive tape was smoothed over a printed area of the sample, and the tape was pulled off with a smooth, quick movement at a little less than a 180° angle to the surface. The tape was pulled off with one hand while the substrate was held down on a flat surface with the other. This test was conducted on single and multiple layers of ink.	The results of this test are expressed as either "pass" (no ink was removed) or "fail" (some or all of the ink was removed). A "pass" indicates good ink adhesion.
Trap	Measures how well one ink prints on top of another. Good trapping is necessary to ensure adequate overprinting and to produce the desired color hue.	An X-Rite 418 densitometer measured the trap of magenta and cyan. Average trap, given as a percent, was calculated from densitometer readings.	Trap measurement of 100% is considered ideal.
Uncured residue (UV-cured inks only)	Measures whether uncured residue from UV-cured ink remains on the printed substrate after the final UV curing station. Uncured ink may have possible negative results, such as odor, ink transfer to the rollers, and ink contact with food after packaging.	Three jars were filled with enough alcohol to fully immerse one printed sample in each jar. After 24 hours, the first jar was checked for evidence of discoloration of the alcohol, indicating the presence of uncured residue on the sample. After 48 hours, the second jar was evaluated, and after 72 hours, the third jar was evaluated.	The degree of uncured residue is measured by the percent (by weight) of uncured ink removed. This number reflects the amount of uncured ink; the lower the percent, the better the UV cure.

[a] During performance demonstrations, up to four "locations" were marked on the printed test roll, determined by time into the test: w=start of run, x=30 minutes into run, y=60 minutes into run, and z=end of test or 120 minutes into run (whichever came first). These locations were analyzed during the laboratory tests.

Inks Used for the Study

Participation in the study was open to all ink formulators. The ink companies that participated in this study donated all the inks and submitted their formulations to EPA. Two different product lines were used for solvent-based inks, four product lines for water-based inks, and three product lines for UV-cured inks. Both line colors and process colors were printed, to cover the range of flexographic applications. Colors were printed to match colors identified in the Pantone Color Selector/Film Guide. The colors used in the demonstration are listed in Table 4.3.

Table 4.3 Colors Used for the Tests

	Color (as listed in the text)	Specific Color
Line colors	Blue	Reflex Blue
	Green	354 Green
	White (opacity target 48%)	
Process colors	Cyan	Phthalocyanine Blue
	Magenta	Rubine Red

Substrates Used for the Tests

Flexographic printers produce many different products on a variety of substrates. This project selected film substrates so that data could be collected on technical issues related to printing inks on film (e.g., drying times for non-solvent-based inks) and environmental issues (e.g., VOC emissions from solvent-based inks). The DfE team, along with the Technical Committee, chose three commonly used substrates that correspond to particular product segments. The substrates selected were (1) clear low-density polyethylene (LDPE), (2) white polyethylene/ethyl vinyl acetate (PE/EVA), and (3) clear oriented polypropylene (OPP). These three substrates represent a common selection of films to allow a wide range of flexographic printers to benefit from the data analysis. Table 4.4 describes the substrates.

Table 4.4 Substrates Used for the Tests

Substrate	Characteristics	Printing Type	Typical Products
Low-density polyethylene (LDPE)	1.25 mil, medium slip, clear	Surface	Shopping bags and bread bags
Polyethylene / ethyl vinyl acetate (PE/EVA) co-extruded film	2.5 mil, high slip, white, prints on polyethylene side	Surface	Frozen food bags
Oriented polypropylene (OPP)	0.75 mil, slip modified	Reverse	Snack food bags and candy bar wrappers

Film manufacturers donated the substrates used in the study. With two exceptions, all the LDPE was supplied by one manufacturer, all the OPP was supplied by another manufacturer, and all the PE/EVA was supplied by another. One exception was Site 11, where UV-cured ink was printed on an LDPE film that was extruded with no slip additives. The other exception was Site 7, which received a different PE/EVA substrate.

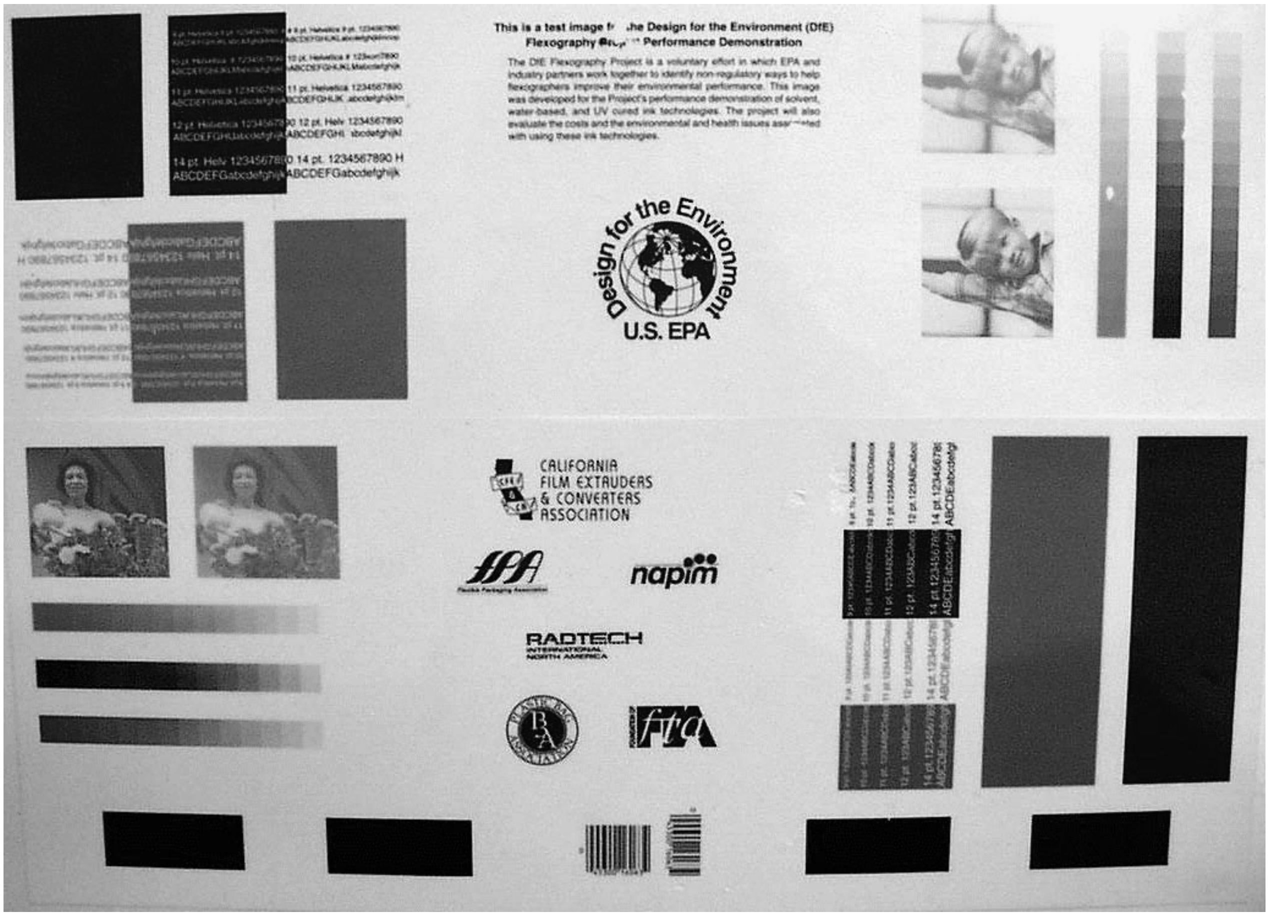
All films used with water-based and UV-cured inks were treated on press with a corona treater to achieve a dyne level specified by each ink manufacturer. The dyne levels of the films treated in the demonstration runs ranged between 40 and 44 dynes. The one exception was Site 4, for which the surface tension was known to be greater than 44 dynes but could not be measured with the available equipment.

Image and Plates Used for the Tests

The methodology specified photopolymer printing plates for the performance demonstration. The volunteer facilities were given the option of using donated plates or plates supplied by their own vendors. The caliper (thickness) of the plates was optimized for each press.

The test image was developed with the intent of covering the technical spectrum of printing on film at the time the project was designed, using recommendations made by the Technical Committee. The image was 20 inches wide and 16 inches long. The image included both process tone printing in various gradations and two-color line printing. A reduced-size copy of the image below and in Appendix 4-D.

Test Image Used in CTSA



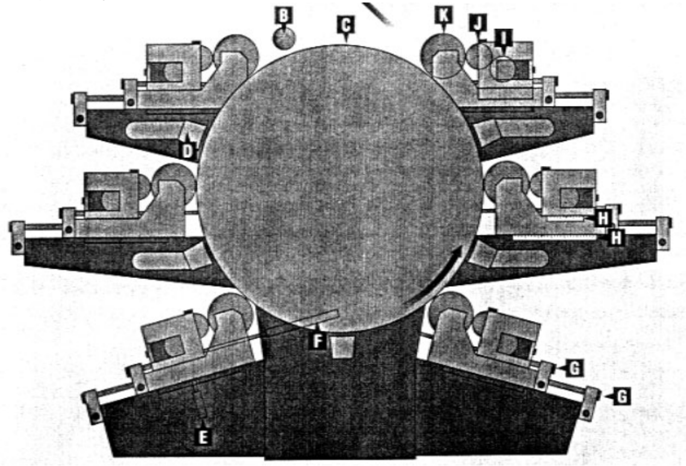
This is a test image for the Design for the Environment (DfE) Flexography Project Performance Demonstration

The DfE Flexography Project is a voluntary effort in which EPA and industry partners work together to identify non-regulatory ways to help flexographers improve their environmental performance. This image was developed for the Project's performance demonstration of solvent, water-based, and UV cured ink technologies. The project will also evaluate the costs and the environmental and health issues associated with using these ink technologies.

Printing Presses Used

There are three major types of flexographic printing presses: in-line, stack, and central impression (CI). The CI press was selected for use in the CTSA performance demonstrations. In many ways the CI press represents the standard for quality in the flexographic printing industry, especially in converting. This type of press has a particular advantage in holding tight register, which allows it to be used for technically demanding multiple-color jobs on many different substrates. The CI press is distinguished and named for its structural configuration, in which different color stations are arranged around a single large (central impression) drum. The number of stations can vary. Most CI presses have six color stations, but presses are now being built with eight and ten stations.

Diagram of Central Impression Press
(from *Flexography: Principles and Practices,* 5th edition, volume 6, page 6)



The performance demonstrations required wide-web CI presses, with a target width of 24 inches, six color stations, and capability of running the film substrates selected for the project. Suggested specifications of the presses chosen for the performance demonstrations are listed in Appendix 4-A. The point of choosing this type of press was to gather data about the three primary ink systems on commonly used presses running film substrates. At the time the project was designed this combination represented some of the most complex printing situations, as well as the anticipated future direction of flexographic printing. Wide-web printing in particular can pose many challenges. As a case in point, at the time this project was being developed, UV-cured inks were making inroads in narrow-web printing but not yet in wide-web printing.

Types of Printing Performed

The test image included process and line printing, to represent a wide range of types of flexographic printing. The performance demonstration runs also included both surface and reverse printing. In surface printing, the dried ink film sits on the surface of the product, so the physical properties of the ink can be extremely important. For example, the printing on food packages must be able to withstand extremes of temperature, wetness, and handling. In reverse printing, the ink is trapped between two layers of film, protecting it from outside physical contact. The chemical properties of the ink film are essential for keeping the substrate layers bound together and ensuring that the ink adheres well to the substrate.

Limitations of the Performance Demonstrations

Close adherence to the performance methodology was attempted throughout the study. Because of the voluntary nature of this project and the manufacturing diversity of the flexographic industry, however, occasional adjustments to the methodology were required. Overall changes, such as ink or substrate substitutions, were evaluated and approved by the Steering Committee, the DfE staff, or the field testing teams as they arose. Specific changes to the methodology made at the individual performance demonstration sites are described in the site profiles. Significant deviations from the methodology included the following:

- Adhering to the full two-hour run time of each ink-substrate combination would have placed an unacceptable burden on the production schedules of the volunteer facilities in six cases (Sites 2, 5, 6, 8, 9, and 10). At these sites, the press crew and DfE team continued the runs only as long as was deemed necessary to get accurate results.

- Some sites experienced shortages of materials, such as substrate, which decreased the run lengths. In addition, the overheating of the chill roller at Site 6 caused the run to be aborted.

- Although target ranges for the anilox roll volumes were specified in the methodology, the volunteer facilities did not all have rolls with these specifications available at the time of the performance demonstration. Again, because of the production needs of the volunteer facilities, changing or acquiring anilox rolls to meet the specified targets was impractical. A summary of the actual anilox roll specifications for all of the demonstration sites, along with the target specifications, can be found in Appendix 4-F.

- Ink type, although the focus of this project, is only one aspect of the very complex printing process. The project was not designed to control for other variables, so caution should be used when reviewing the test results.

- Although every effort was made to match the volunteer facility with the type of ink and type of printing that the facility normally runs, this was not possible at Site 9B, which normally runs water-based inks but ran solvent-based inks for the performance demonstration. This may have had an impact on the performance demonstration results.

In addition, the interpretation of the data is limited by the following caveats:

- Although the performance methodology set forth guidelines and parameters for the on-site printing runs, variable conditions between and within printing facilities, the limited number of facilities, and the relatively short duration of the performance demonstrations do not allow the results to be interpreted as definitive performance testing of the ink systems.

- Press operators' experience with ink systems differs substantially and can affect ink performance. Some of the information recorded was subjective and depended on the perception and previous experiences of the operators and the DfE team.

- Standardization of test protocols within the flexible packaging industries is limited. Some of the tests used in this project were developed at WMU. Other procedures were obtained from ink manufacturers and trade organizations. In addition, during the testing of the printing products, some methods were modified to improve accuracy and efficiency. The test procedures can be found in Appendix 4-E.

- Demonstration facilities were chosen based on their ink technology and relative experience with the system, rather than on their ability to attain a close match to all aspects of the performance test design.

Methodology for Laboratory Runs

Industry representatives decided that collecting data under both production and laboratory conditions would give printers a better sense of the actual capabilities of the ink/substrate combinations under a variety of conditions. Thus, laboratory runs were conducted at Western Michigan University's printing laboratory to collect baseline data. These runs used the same ink/substrate combinations and the same test image.

For all solvent-based and water-based ink formulations, laboratory runs were performed on a flexographic press at Western Michigan University (WMU). This was done to provide consistency of results and a context in which to interpret the performance test data. Due to equipment difficulties, the UV-cured ink combinations were not printed at WMU.

This section presents technical information about the laboratory facility and the press. Section 4.2 includes relevant data from the laboratory runs as well as the performance demonstration sites. (Laboratory site codes begin with an "L".) Appendices 4-E and 4-L provide a narrative description of the laboratory procedures and runs. All the results of the laboratory runs are included in the tables in Appendix 4-E.

Some general information about the facility at Western Michigan University is provided in Table 4.5.

Table 4.5 Summary Facility Background Information for Laboratory Runs

Item	Description
Ink type used	Solvent-based and water-based for education and test runs only
Emission control equipment	None
Annual production	This facility is an educational institution, not a commercial printing facility.
Operating hours	n/a
Avg. production run	n/a

The solvent-based and water-based inks used were provided by the same suppliers and formulators that supplied inks for the performance demonstrations. Table 4.6 lists the ink system, substrate, and product line that correspond to each laboratory run.

Table 4.6 Ink-Substrate Combinations for Laboratory Runs

Site[a]	Ink System	Substrate	Product Line
L1	Water-based	LDPE	W3
L2	Water-based	OPP	W4
L3	Water-based	OPP	W2
L4	Solvent-based	OPP	S2
L5	Solvent-based	LDPE	S2
L6	Water-based	PE/EVA	W3
L7	Solvent-based	PE/EVA	S2

[a] "L" indicates that this was a laboratory run.

The laboratory runs were conducted on a pilot press. The press used in the laboratory runs has an in-line design. Information about the press and configuration is shown in Tables 4.7 and 4.8. All laboratory runs were completed as designed, with no significant deviations from the methodology. A summary of information about the laboratory runs is provided in Table 4.9.

Table 4.7 Press Information for Laboratory Runs

Item	Description
Press	Zerand
Size of press	24 inches wide, two-color
Printing type	Surface
Typical production speed	500 feet/minute
Plates	0.107" Dupont EXL photopolymer: 1) Two process plates (magenta and cyan) mounted using compressible stick back 2) Three line plates (green, blue, and white) mounted using hard stick back
Corona treater	Enercon
Ink metering system	Two-roll with doctor blade
Type of doctor blade	Stainless steel
Ink pumping and mixing system	Electric

Table 4.8 Color Sequence and Anilox Configurations for Laboratory Runs [a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1	White	220	6.4
Deck 2	Green	440	2.8

[a] Deck 1 (white ink) was changed to cyan ink for the PE/EVA substrate.
[b] lines per inch
[c] billion cubic microns per square inch

Table 4.9 Summary Information from Laboratory Runs

	Lab Run #1	Lab Run #2	Lab Run #3	Lab Run #4	Lab Run #5	Lab Run #6	Lab Run #7
Substrate	LDPE	OPP	OPP	OPP	LDPE	PE/ EVA	PE/ EVA
Ink	#W3	#W4	#W2	#S2	#S2	#W3	#S2
Press Speed	343	231	292	324	311	274	305
Total Footage Consumed	41,143	27,732	35,097	38,851	37,263	32,930	36,875

The laboratory runs were optimized for speed, to maximize quality and drying efficiency. Because these tests lasted only a few hours, the press speeds listed in Table 4.9 do not necessarily reflect running speeds that may be more commonly seen in flexographic printing facilities.

The complete results for each test, including the laboratory runs, are provided in the tables in Appendix 4-E, Laboratory Test Procedures and Performance Data.

Impression on an in-line press is not as accurate as a central impression (CI) flexographic press. As a result, more mottle occurred during printing on all laboratory runs. In general, the water-based ink did not wet as well as the solvent-based ink, and more mottle was evident. Excessive foaming of the ink was evident for L3 (Water #2). L1, L2, and L6 (Water #3, #4) also showed some foaming after 15 minutes. Drying on the plates and poor re-wettability was noted in L7 (Solvent #2) after 20 minutes. In all runs, it was necessary to wash the plates during roll changes.

Block resistance scores were fairly consistent between the laboratory runs and the performance demonstrations (slight cling to slight blocking). No test received a score higher than 3, indicating that blocking was not a serious problem in this setting.

For the gloss test, the laboratory readings tended to be quite a bit lower than the site readings, indicating less gloss. This was especially evident with green water-based ink on LDPE, which had gloss readings below 25%.

For the opacity test, the average percent opacity was very high for site L5 (solvent-based ink on LDPE), but fairly low for the other scenarios. A high score indicates better opacity and higher quality of this aspect of the printing.

4.2 RESULTS OF PERFORMANCE DEMONSTRATION AND LABORATORY RUN TESTS — SOLVENT-BASED AND WATER-BASED INKS

This section discusses the results of the performance demonstration tests on solvent-based and water-based inks using all three film substrates. These two ink systems are discussed together to allow printers to compare how the systems perform with different substrates and in different tests.

The 18 tests (listed in alphabetical order) measure many aspects of appearance, odor, and durability of the inks, as well as evidence of interactions between the inks and film substrates. Some of these tests have established quality standards, whereas many do not. For example, the adhesive lamination and opacity tests each have a standard below which results are considered unacceptable by the industry. For CIE L*a*b* and coefficient of fiction tests, on the other hand, acceptability is a relative concept and depends entirely upon the needs of the printing situation. Also, some tests, such as jar odor, which measures the amount and type of odor from the different printed ink samples, are clearly subjective. Tests such as dimensional stability measure how the ink (and the process that applies it) affect the structure of the substrate on which the ink is printed. Table 4.2 describes the purpose, procedure, and interpretation for each test that was performed during the performance demonstrations and laboratory runs.

Data for the laboratory tests were obtained by examining up to four different locations on the printed rolls. The locations from which samples were collected are described in Appendix 4-A. A detailed description of each laboratory test procedure and results for the performance demonstrations can be found in Appendix 4-E. The tests and results for the laboratory runs are included in Appendix 4-I, and particularly interesting results are highlighted in the text.

Adhesive Lamination — Solvent-based and Water-based Inks

OPP was the only substrate that had a lamination layer to be tested. A clear propylene substrate was laminated to the printed sample at Sites 1 and 4, while a metallized propylene substrate was laminated to the printed sample at Site 9. Site 10 did not test for adhesive lamination; although the test substrate was intended to be laminated, the site did not have lamination capabilities.

Table 4.10 presents the adhesive lamination data. All four product lines tested had less than the minimum 0.350 kg that is considered acceptable. However, the solvent-based ink product line displayed a delamination force 16% greater than the average of the three water-based ink product lines.

Table 4.10 Adhesive Lamination Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Average Delamination Force (kg)	Standard Deviation (kg)
Solvent-based	OPP	#S1	9B	0.3040	0.0132
Water-based	OPP	#W1	4	0.2649	0.0012
		#W2	1	0.2631	0.0000
		#W4	9A	0.2575	0.0158

Block Resistance — Solvent-based and Water-based Inks

Table 4.11 summarizes the block resistance test data. The averages are based on four measurements taken from each site sample. The two variables were the location of the sample (e.g., beginning or end of the run) and whether ink transferred to a printed or unprinted substrate. The most successful combinations of ink and substrate were water-based inks on LDPE and PE/EVA. The least successful combinations were water-based inks on OPP, followed by solvent-based inks on LDPE and PE/EVA.

Table 4.11 Block Resistance Results — Solvent-based and Water-based Inks

Ink	Film	Average Rating of Blocking Resistance[a]
Solvent-based	LDPE	2.9
	PE/EVA	2.9
	OPP	1.9
Water-based	LDPE	1.2
	PE/EVA	1.2
	OPP	3.2

[a] The following scale was used to assign a numerical score to the test results: 0 = no blocking. 1 = slight cling. 2 = cling. 3 = slight blocking. 4 = considerable blocking. 5 = complete blocking. Table 4-E.1 in Appendix 4-E provides a detailed description of this scale.

CIE L*a*b* — Solvent-based and Water-based Inks

For most sites, samples were taken at four locations on the substrate during the test run. Due to the aborted run using the PE/EVA substrate at Site 7, however, samples were taken only from the beginning and the end of the run. Sites 8 and 9 also had shorter runs, with samples taken only from the beginning, 30 minutes into run, and the end of the run.

Table 4.12 presents the results of the CIE L*a*b* test. Because this test does not have units and should be used for relative comparisons only, no overall statements can be made about the results of this test.

Table 4.12 CIE L*a*b* Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Color	Average L*	Average a*	Average b*
Solvent-based	LDPE	#S2	5	magenta	47.07	58.41	-4.83
				cyan	59.82	-40.31	-13.65
				green	53.42	-48.59	29.56
				blue	38.07	5.25	-50.33
			7	magenta	50.03	54.48	-6.93
				cyan	61.75	-38.85	-23.90
				green	63.67	-39.34	31.42
				blue	42.43	0.03	-46.95
			L5	green	61.73	-40.73	30.10
	PE/EVA	#S2	5	magenta	54.11	47.73	-0.38
				cyan	62.17	-27.49	-37.61
				green	56.78	-55.08	32.32
				blue	36.84	16.46	-57.24
			L7	green	65.25	-37.46	31.32
				cyan	63.30	-28.79	-37.44
Solvent-based	PE/EVA	#S2	7	magenta	50.98	54.00	-3.89
				cyan	61.22	-31.68	-37.12
				green	67.69	-46.98	32.09
				blue	38.77	13.11	-53.87
	OPP	#S1	9B	magenta	51.98	52.20	-3.96
				cyan	59.97	-37.48	-27.02
				green	64.76	-35.20	30.42
				blue	47.64	-5.21	-39.55
		#S2	10	magenta	67.01	29.98	-5.73
				cyan	70.86	-27.42	-12.67
				green	56.29	-47.18	29.39
				blue	40.01	2.51	-46.11
			L4	green	69.86	-35.62	32.38
Water-based	LDPE	#W3	2	magenta	51.43	50.55	-1.75
				cyan	56.38	-27.94	-35.69
				green	62.31	-51.15	34.34
				blue	34.11	16.01	-49.82
			3	magenta	52.46	51.31	-7.16
				cyan	64.10	-32.03	-21.71
				green	61.77	-54.49	37.65
				blue	33.43	17.90	-50.75
			L1	green	68.39	-44.29	32.33

Table 4.12 CIE L*a*b* Results — Solvent-based and Water-based Inks (continued)

Ink	Film	Product Line	Site	Color	Average L*	Average a*	Average b*
Water-based, cont.	PE/EVA	#W3	2	magenta	55.22	48.52	-1.05
				cyan	58.57	-22.09	-40.29
				green	62.32	-58.16	34.05
				blue	33.87	19.50	-49.27
			3	magenta	54.03	55.08	-2.54
				cyan	62.00	-28.11	-39.06
				green	62.27	-59.70	34.92
				blue	35.01	18.94	-50.39
			L6	green	70.40	-51.59	29.28
				cyan	64.77	-28.94	-37.15
	OPP	#W1	4	magenta	49.22	51.22	-4.05
				cyan	59.46	-32.96	-25.57
				green	53.32	-54.58	31.23
				blue	39.75	1.28	-45.48
		#W2	1	magenta	50.17	47.82	2.44
				cyan	57.40	-30.72	-27.87
				green	64.19	-57.66	44.41
				blue	30.19	15.65	-37.30
			L3	green	72.58	-32.68	25.21
		#W4	9A	magenta	48.53	52.36	4.16
				cyan	57.80	-35.74	-29.96
				green	61.39	-53.33	32.10
				blue	42.17	-1.38	-44.90
			L2	green	66.32	-44.36	28.26

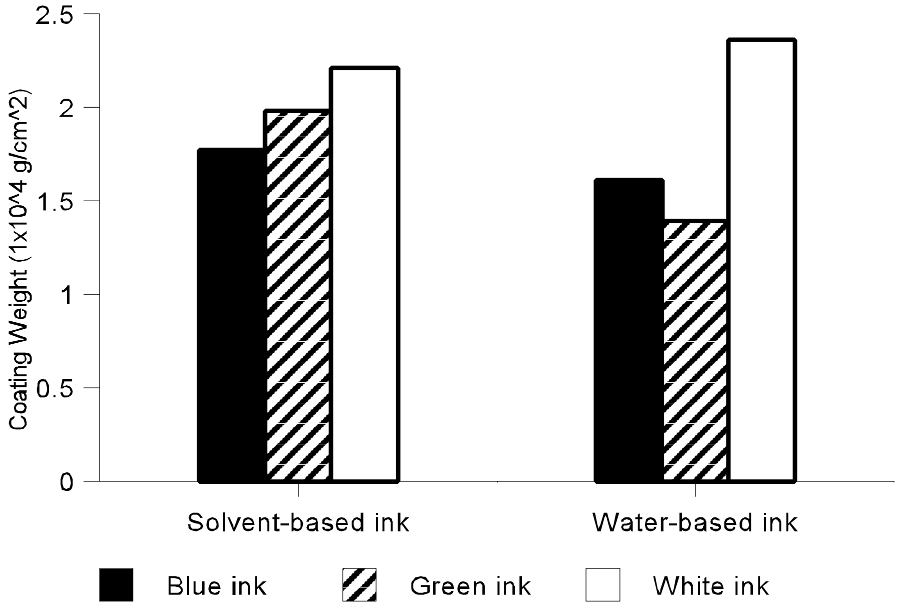
“L” in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

Coating Weight — Solvent-based and Water-based Inks

Coating weight was measured for green, blue, and white printed areas on OPP and LDPE. Only the green and blue inks were tested on PE/EVA because it is a white substrate.

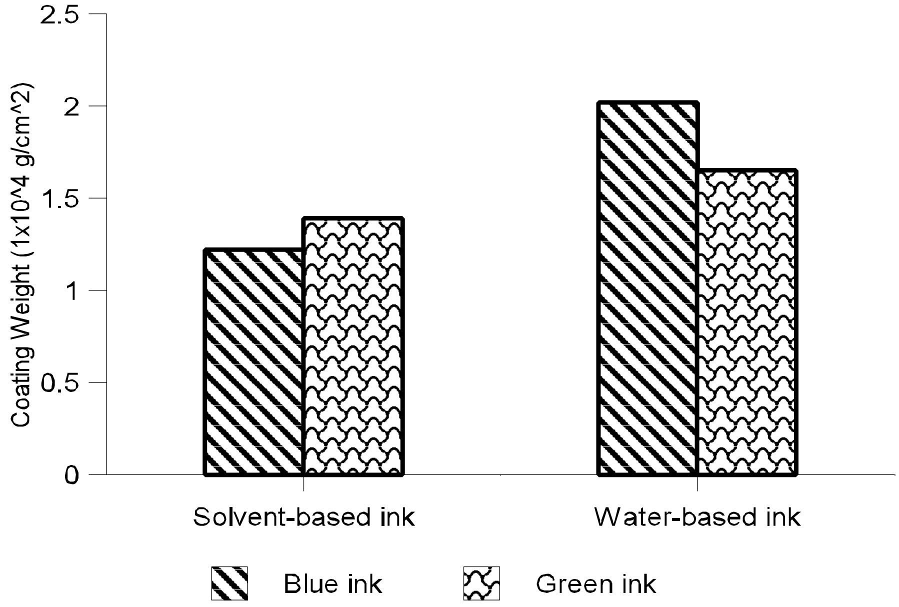
Figures 4.1-4.3 show the average coating weight data. The water-based inks in this study had higher solids content than the solvent-based inks, a typical scenario for these ink types. Therefore, on average, the water-based inks exhibited higher coating weights than the solvent-based inks on PE/EVA and OPP. This difference was most marked in the case of white ink on OPP and for blue and green inks on PE/EVA. For LDPE, on the other hand, the coating weight for water-based green ink was substantially lower than that for solvent-based green ink.

Figure 4.1 Average Coating Weight for LDPE — Solvent-based and Water-based Inks



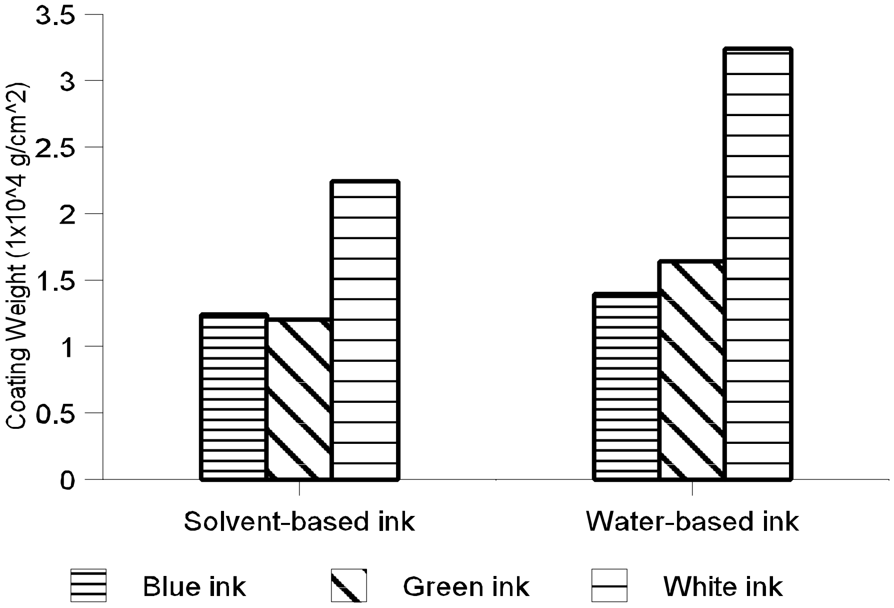
	Solvent-based ink	Water-based ink
Blue ink	1.77	1.61
Green ink	1.98	1.39
White ink	2.21	2.36

Figure 4.2 Average Coating Weight for PE/EVA — Solvent-based and Water-based Inks



	Solvent-based ink	Water-based ink
Blue ink	1.22	2.02
Green ink	1.39	1.65

Figure 4.3 Average Coating Weight for OPP — Solvent-based and Water-based Inks



	Solvent-based ink	Water-based ink
Blue ink	1.24	1.39
Green ink	1.2	1.64
White ink	2.24	3.24

Coefficient of Friction — Solvent-based and Water-based Inks

The coefficient of friction (COF) between two layers of unprinted substrate was measured to provide a control. The COF was then measured between printed substrate and unprinted substrate, as well as between printed substrate and printed substrate. Printed samples from Sites 1, 4, 9, and 10 were not tested in the laboratory because the OPP substrate printed at these sites was laminated to another substrate. The lamination traps the ink between the two substrate layers, making it unnecessary to test for COF.

Table 4.13 summarizes the COF test results. This test does not have a standard, because high COF may be desirable in some printing situations (for instance, if products are stacked on top of one another), whereas a low COF may be equally important in other cases. As would be expected, the unprinted controls had the lowest average COF, the products with only one surface printed (Ink-Un) had a higher average COF, and the products with both surfaces printed (Ink-Ink) had the highest average COF. Beyond this, however, no clear differences emerged between the two ink systems or among the different substrates.

Table 4.13 Coefficient of Friction Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Average Angle of Inclination (degrees)		
				Ink-Un[a]	Ink-Ink[b]	Control[c]
Solvent-based	LDPE	#S2	5	28.4	36.5	22.3
			7	25.2	35.4	23.3
			L5	20.8	30.6	23.3
	PE/EVA	#S2	5	25.6	38.2	16.7
			7	23.5	22.2	16.7
			L7			
Water-based	LDPE	#W3	2	27.6	33.0	23.2
			3	27.8	29.4	23.3
			L1	34.2	34.2	23.3
	PE/EVA	#W3	2	24.8	32.6	16.7
			3	21.6	32.8	17.2
			L6	26.6	40.0	16.7

"L" in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

[a] "Ink-Un" represents the coefficient of friction for printed substrate on unprinted substrate.

[b] "Ink-Ink" represents the coefficient of friction for printed substrate on printed substrate.

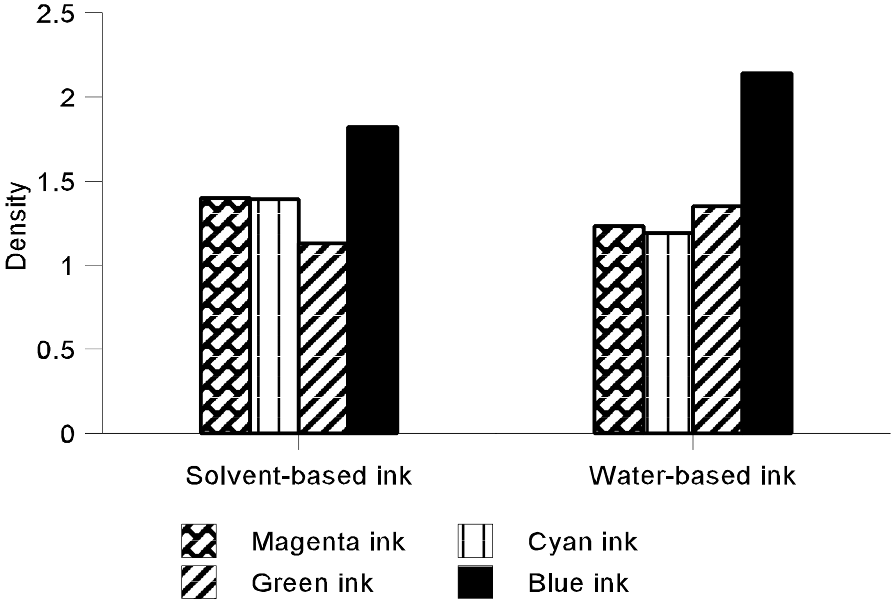
[c] "Control" represents the coefficient of friction for unprinted substrate on unprinted substrate.

Density — Solvent-based and Water-based Inks

Density was measured on areas printed with magenta, cyan, green, and blue inks. Due to shortened runs at Sites 7 and 9, samples were taken only at three of the four planned locations on the runs. Fewer samples than usual were taken for testing from the laboratory runs because they were shorter in duration than the performance demonstration runs.

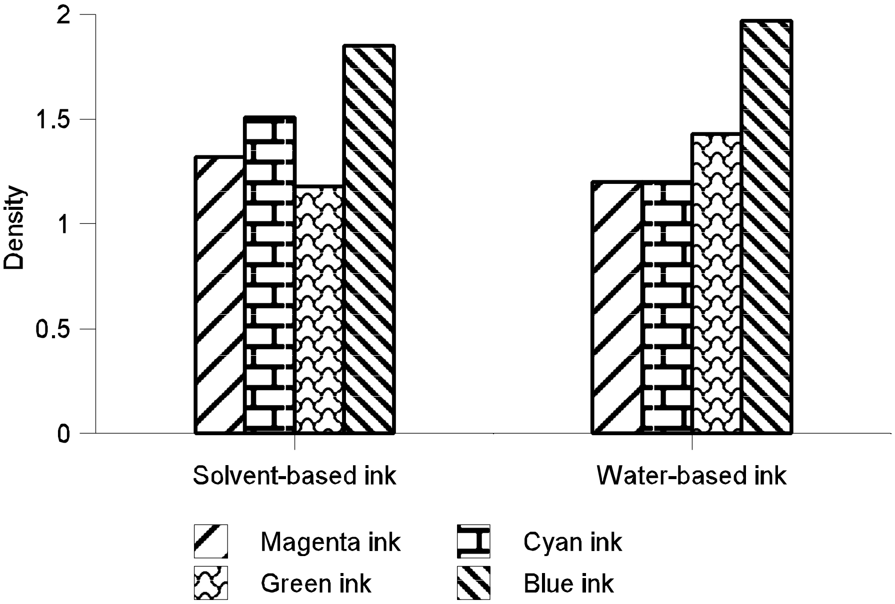
Figures 4.4-4.6 show the average density for these four ink colors on each substrate. Scores were highest for blue ink in all scenarios, and blue ink scores were higher for water-based inks than for solvent-based inks. Scores for the other colors tended to be fairly consistent with each other. On OPP, density was considerably higher on all water-based inks.

Figure 4.4 Average Density for LDPE — Solvent-based and Water-based Inks



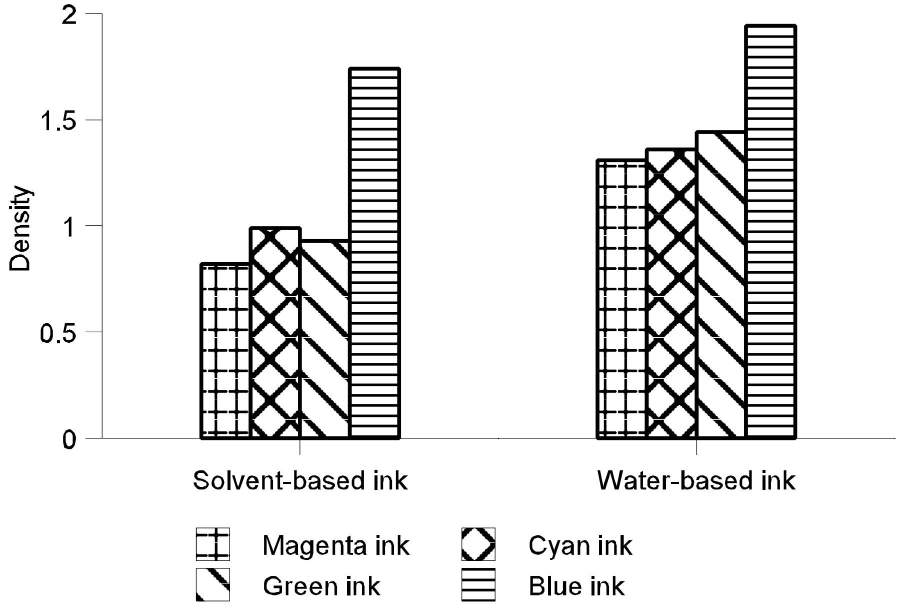
	Solvent-based ink	Water-based ink
Magenta ink	1.4	1.23
Cyan ink	1.39	1.19
Green ink	1.13	1.35
Blue ink	1.82	2.14

Figure 4.5 Average Density for PE/EVA — Solvent-based and Water-based Inks



	Solvent-based ink	Water-based ink
Magenta ink	1.32	1.2
Cyan ink	1.51	1.2
Green ink	1.18	1.43
Blue ink	1.85	1.97

Figure 4.6 Average Density for OPP — Solvent-based and Water-based Inks



	Solvent-based ink	Water-based ink
Magenta ink	0.82	1.31
Cyan ink	0.99	1.36
Green ink	0.93	1.44
Blue ink	1.74	1.94

Dimensional Stability — Solvent-based and Water-based Inks

Due to shortened runs at Sites 7 and 9, samples were taken only from some of the four scheduled locations on the run. Table 4.14 presents the results of the dimensional stability test. No statistically significant differences were evident between solvent-based and water-based ink systems.

Table 4.14 Dimensional Stability Results — Solvent-based and Water-based Inks

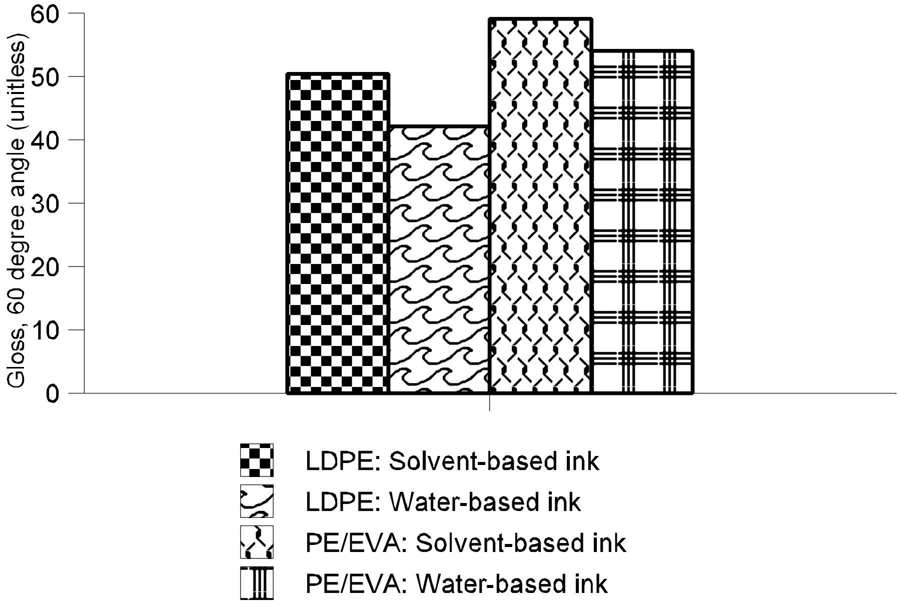
Ink	Film	Product Line	Site	Average Percent Change (Width)	Average Percent Change (Length)
Solvent-based	LDPE	#S2	5	0.5%	2.0%
			7	0.6%	0.4%
	PE/EVA	#S2	5	0.6%	2.4%
			7	0.5%	1.6%
	OPP	#S1	9B	0.7%	1.1%
		#S2	10	0.6%	2.5%
Water-based	LDPE	#W3	2	0.5%	1.0%
			3	0.4%	0.9%
	PE/EVA	#W3	2	0.5%	2.3%
			3	0.5%	1.5%
	OPP	#W1	4	0.5%	1.5%
		#W2	1	0.7%	1.6%
		#W4	9A	0.7%	1.5%

Gloss — Solvent-based and Water-based Inks

Samples from sites 1, 4, 9, and 10 were not subjected to this test because the OPP substrate printed at these sites was laminated. The ink was trapped between the two substrate layers, making it unnecessary to test for gloss. Limited data were available from Site 7 due to the shortened run on PE/EVA. Because the laboratory runs were shorter in duration than the performance demonstration runs, samples for testing were only cut from three locations.

Figure 4.7 shows the average gloss for samples on LDPE and PE/EVA. Overall, inks showed higher gloss on PE/EVA than on LDPE, and solvent-based inks on PE/EVA had the highest gloss.

Figure 4.7 Average Gloss for LDPE and PE/EVA — Solvent-based and Water-based Inks



LDPE: Solvent-based ink	50.4
LDPE: Water-based ink	42.19
PE/EVA: Solvent-based ink	59.08
PE/EVA: Water-based ink	54.09

Heat Resistance/Heat Seal — Solvent-based and Water-based Inks

Only samples printed on OPP and then laminated were tested. Heat resistance/heat seal was measured on blue, green, and/or white printed areas. Table 4.15 presents a summary of the heat seal data. A range of 12 to 24 measurements were taken from each site. The number of measurements depended on where they were taken (e.g., beginning, middle, or end of the run), what ink color was tested, and whether ink transferred to a printed or unprinted substrate.

The solvent-based and water-based inks exhibited mixed results for heat resistance/heat seal. For instance, Solvent-based ink #S2 experienced 100% failure at Site 10 but 100% success at Site L4. These results suggest that other factors, such as the lamination process, might have affected the results.

Table 4.15 Heat Resistance/Heat Seal Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Number of Passes	Number of Failures	Average Percent of Ink Transfer Per Failure
Solvent-based	OPP	#S1	9B	9	9	10%
		#S2	10	0	18	39%
			L4	12	0	—
Water-based	OPP	#W1	4	9	15	21%
		#W2	1	0	24	26%
			L3	1	11	10%
		#W4	9A	6	12	9%
			L2	0	12	22%

"L" in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

Ice Water Crinkle Adhesion — Solvent-based and Water-based Inks

Printed samples from Sites 1, 4, 9, and 10 were not tested because the OPP substrate printed at these sites was laminated. This trapped the ink between the two substrate layers, making it unnecessary to test the ink on the OPP substrate.

Ink adhesion was measured for each color on each substrate. Table 4.16 summarizes the results of this test. The solvent-based ink performed successfully on both the LDPE and PE/EVA substrates. Water-based ink #W3 was evaluated at two sites. At Site 2, the ink performed successfully on both substrates, but at Site 3 the ink failed on both substrates. These results suggest that facility-specific factors other than ink might have affected the results.

Table 4.16 Ice Water Crinkle Adhesion Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Any Ink Removal?
Solvent-based	LDPE	#S2	5	no
			7	no
			L5	no
	PE/EVA	#S2	5	no
			7	no
			L7	no
Water-based	LDPE	#W3	2	no
			3	yes, less than 5%
			L1	no
	PE/EVA	#W3	2	no
			3	no; less than 5%[a]
			L6	yes, about 30% of the green ink and less than 15% of the blue ink

“L” in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

[a] Three of the four samples had complete ink adhesion. The fourth sample had less than 5% removed.

Image Analysis — Solvent-based and Water-based Inks

Due to the shortened run using the PE/EVA substrate at Site 7, samples were taken only from the beginning and 30 minutes into the run. Because Sites 8 and 9 also had shorter runs, samples were taken only from the beginning, 30 minutes into run, and the end of the run.

Table 4.17 presents the image analysis results. Because the purpose of this test was to evaluate screened dot detail as used in process color reproduction, only the magenta and cyan process inks were analyzed. Table 4.17 presents the average dot area and perimeter for these two colors at each performance demonstration site. No statistically significant differences were evident between the two ink systems.

Table 4.17 Image Analysis Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Color	Average Dot Area (micron^2)	Average Dot Perimeter (microns)
Solvent-based	LDPE	#S2	5	magenta	953.28	125.06
				cyan	725.86	104.26
			7	magenta	1049.71	130.64
				cyan	556.95	107.29
	PE/EVA	#S2	5	magenta	912.18	118.81
				cyan	721.00	104.70
			7	magenta	753.80	123.13
				cyan	323.88	103.58
	OPP	#S1	9B	magenta	620.58	102.60
				cyan	499.75	84.20
		#S2	10	magenta	568.41	122.39
				cyan	967.98	263.90
Water-based	LDPE	#W3	2	magenta	608.53	93.30
				cyan	925.17	120.86
			3	magenta	887.76	127.30
				cyan	608.71	97.16
	PE/EVA	#W3	2	magenta	705.83	107.11
				cyan	911.05	118.63
			3	magenta	649.76	96.93
				cyan	840.34	114.19
	OPP	#W1	4	magenta	837.88	116.53
				cyan	781.21	112.03
		#W2	1	magenta	371.59	97.63
				cyan	338.71	81.61
		#W4	9A	magenta	715.59	108.58
				cyan	748.80	95.80

Jar Odor — Solvent-based and Water-based Inks

Jar odor was evaluated for both printed and unprinted substrates. Table 4.18 presents the results of the jar odor test, listing the strength of the odor present and a description of the odor.

Most of the water-based ink samples had a relatively strong ammonia odor (2 to 3 on a scale of 5). Water-based ink #W1 had a strong, unpleasant odor that was not specifically identified as ammonia. The solvent-based inks had a waxy odor of varying strength (1 to 3 on a scale of 5) on all substrates. The one exception was the sample printed with solvent-based ink #S2 on PE/EVA film at Site 7; this sample had no odor for the control or the printed sample.

Table 4.18 Jar Odor Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Relative Score[a]	Description of Printed Area	Description of Unprinted Area (control)
Solvent-based	LDPE	#S2	5	3	unpleasant	very slightly waxy
			7	1	waxy, not a big difference from control	waxy, hydrocarbons
			L5	2	mild waxy	very mild waxy
	PE/EVA	#S2	5	1	not very different from control; slightly like ethyl acetate	mild waxy
			7	0	no odor	no odor
			L7		mild waxy	very mild waxy
	OPP	#S1	9B	3	ethyl acetate	mild waxy
		#S2	10	1	waxy, no difference from control	waxy
			L4	1	mild waxy	very mild waxy
Water-based	LDPE	#W3	2	3	strong ammonia odor	very slight waxy
			3	3	strong ammonia odor	no odor
			L1	3	strong ammonia odor	very mild waxy
	PE/EVA	#W3	2	3	strong ammonia odor	very slight waxy
			3	3	strong ammonia odor	very mild waxy
			L6	1	mild waxy	mild waxy
	OPP	#W1	4	4	unpleasant, strong	mild
		#W2	1	2	ammonia odor	mild
			L3	2	ammonia odor	very mild waxy
		#W4	9A	0	no difference from control	mild waxy
			L2	2	ammonia odor	very mild waxy

"L" in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

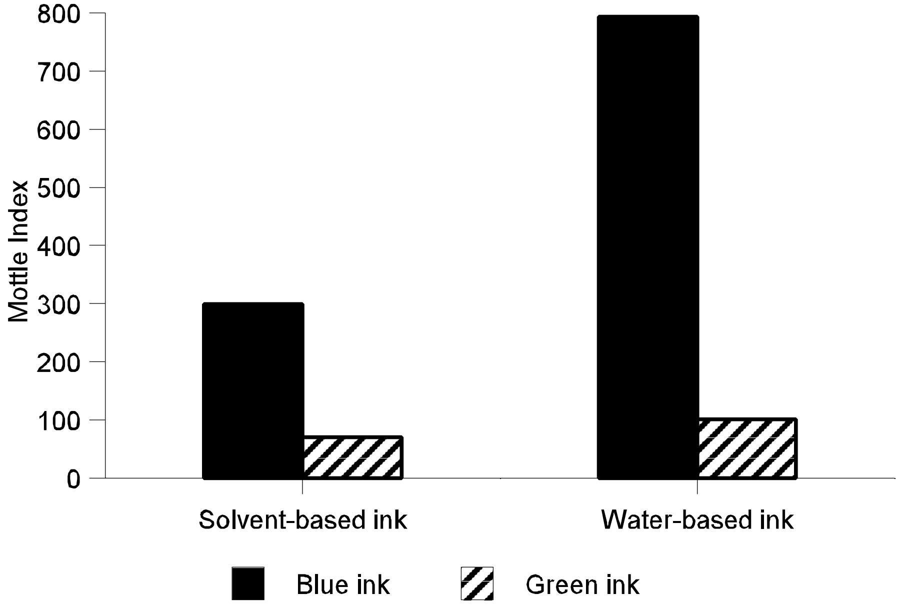
[a] Printed samples were scored on a scale from 0 to 5, with 0 signifying no odor, and 5 signifying an unpleasant, offensive odor.

Mottle/Lay — Solvent-based and Water-based Inks

Mottle was measured on green and blue printed areas. Figures 4.8-4.10 show much higher mottle on the samples printed with water-based inks, especially on LDPE and PE/EVA. Wettability of the substrate plays a role in mottle, and polyethylene substrate surfaces generally do not wet as well as OPP. Corona treatment was employed, however, on all of the LDPE and PE/EVA substrates where water-based inks were used.

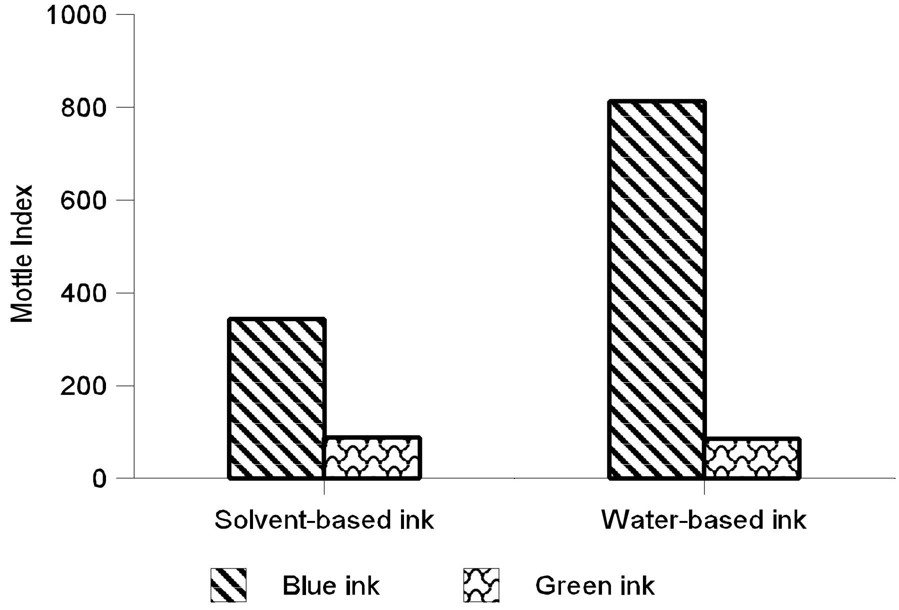
Mottle also was significantly higher on the blue printed areas of all samples tested. None of the variables in this study are thought to account for the differences between the green and blue printed sample results for mottle/lay. Ink formulation and pigment type are most likely the cause for the variations; these variations were evident both ink systems.

Figure 4.8 Average Mottle Index for LDPE — Solvent-based and Water-based Inks



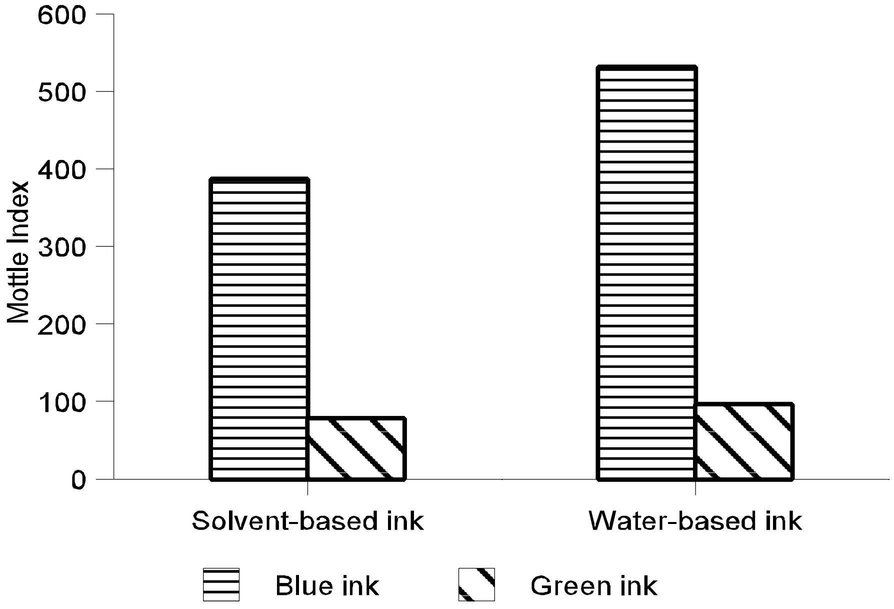
	Solvent-based ink	Water-based ink
Blue ink	298.7	793.75
Green ink	69.8	101

Figure 4.9 Average Mottle Index for PE/EVA — Solvent-based and Water-based Inks



	Solvent-based ink	Water-based ink
Blue ink	343.25	812.25
Green ink	87.5	85

Figure 4.10 Average Mottle Index for OPP — Solvent-based and Water-based Inks



	Solvent-based ink	Water-based ink
Blue ink	386.7	531.5
Green ink	78	96

Opacity — Solvent-based and Water-based Inks

Opacity was measured for samples of white ink on LDPE and OPP. White samples were not printed on PE/EVA because it is a white substrate. The laboratory runs, as well as the runs at Site 9, were shorter in duration than the other demonstration runs; samples were therefore available only from three locations on these runs.

Results for both ink systems were considered acceptable by industry standards (opacity greater than 48%). Results were virtually identical for both ink systems on both substrates.

Rub Resistance — Solvent-based and Water-based Inks

Samples from sites 1, 4, 9, and 10 were not tested in the laboratory, because the OPP substrate printed at these sites was laminated to another substrate. This lamination trapped the ink between the two substrate layers, making it unnecessary to test for rub resistance. Due to the shortened run using the PE/EVA substrate at Site 7, samples were taken only from the beginning and end of the run. Because Site 8 also had a shorter run for the PE/EVA substrate, samples were taken only from the beginning, 30 minutes into the run, and the end of the run.

The blue sample was used for rub testing of the samples taken from the performance demonstration sites. Because blue was not printed during the laboratory runs, the green samples were tested instead.

All inks retained close to 95% of their density after the dry rub test. Table 4.19 presents a summary of the wet rub test results. During the wet rub testing, the water-based ink printed on LDPE performed the best, with “no failure at ten strokes” being reported on the samples from both Sites 3 and L1. The other ink-substrate combinations had mixed results.

Table 4.19 Wet Rub Resistance Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Failure at Number of Strokes (average)[a]
Solvent-based	LDPE	#S2	5	4.2
			7	5.0
			L5	no failure at 10 strokes
	PE/EVA	#S2	5	2.2
			7	5.0
			L7	5.7
Water-based	LDPE	#W3	2	8.0
			3	no failure at 10 strokes
			L1	no failure at 10 strokes
	PE/EVA	#W3	2	2.5
			3	3.2
			L6	two samples had failures at 6 and 7 strokes; one sample had no failure at 10 strokes

"L" in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

[a] A failure represents ink color transferred from the printed substrate to the unprinted substrate. A maximum of 10 strokes were used for the wet rub resistance test. Measurements were taken at four locations and averaged.

Tape Adhesiveness — Solvent-based and Water-based Inks

Tape adhesiveness was measured on LDPE, PE/EVA, and when appropriate, on OPP. The OPP substrates run at the demonstration sites were not tested in the laboratory because these substrates were laminated. Thus, only OPP substrates printed in the laboratory runs were tested for tape adhesiveness. Only the colored inks were tested on the PE/EVA substrate because it is a white substrate.

Table 4.20 presents the results of the tape adhesiveness test. Both inks adhered completely to LDPE. Solvent-based and water-based inks showed good adhesion when printed on OPP during the laboratory runs.

Table 4.20 Tape Adhesiveness Results — Solvent-based and Water-based Inks

Ink	Film	Product Line	Site	Number of Passes	Number of Failures	Comments
Solvent-based	LDPE	#S2	5	4	0	
			7	4	0	
			L5	3	0	
	PE/EVA	#S2	5	2	2	outline of cyan and magenta was removed
			7	0	2	cyan and magenta were slightly removed
			L7	3	0	
	OPP	#S2	L4	3	0	
Water-based	LDPE	#W3	2	4	0	
			3	4	0	
			L1	3	0	
	PE/EVA	#W3	2	2	2	blue was removed
			3	3	1	green was removed
			L6	0	3	all colors were removed
	OPP	#W2	L3	3	0	
		#W4	L2	3	0	

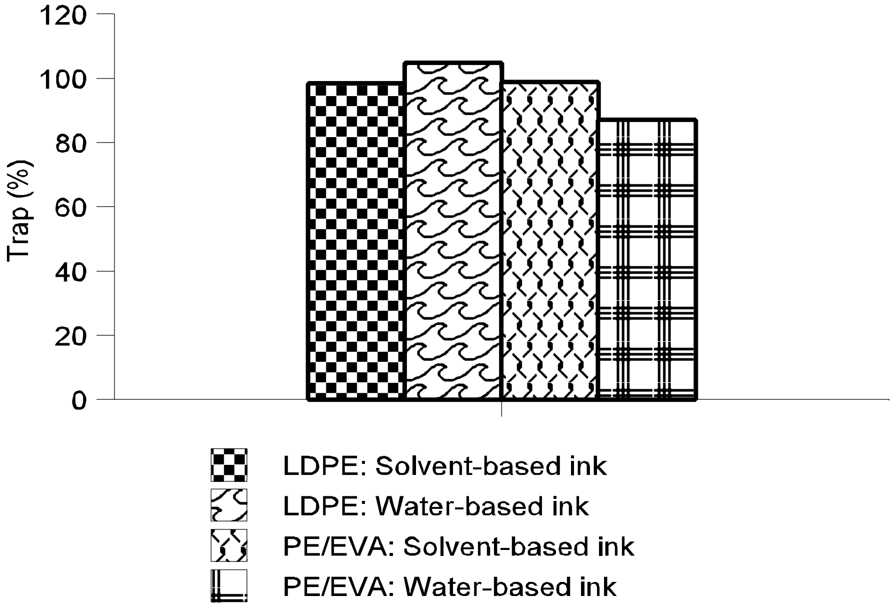
"L" in a site number indicates that the data were taken from a run conducted at Western Michigan University, not from a volunteer printing facility.

Trap — Solvent-based and Water-based Inks

Each site selected its own color sequence for first-down and second-down colors. Trap was measured for both 100% tone (solid) and 80% tone samples printed with magenta and cyan.

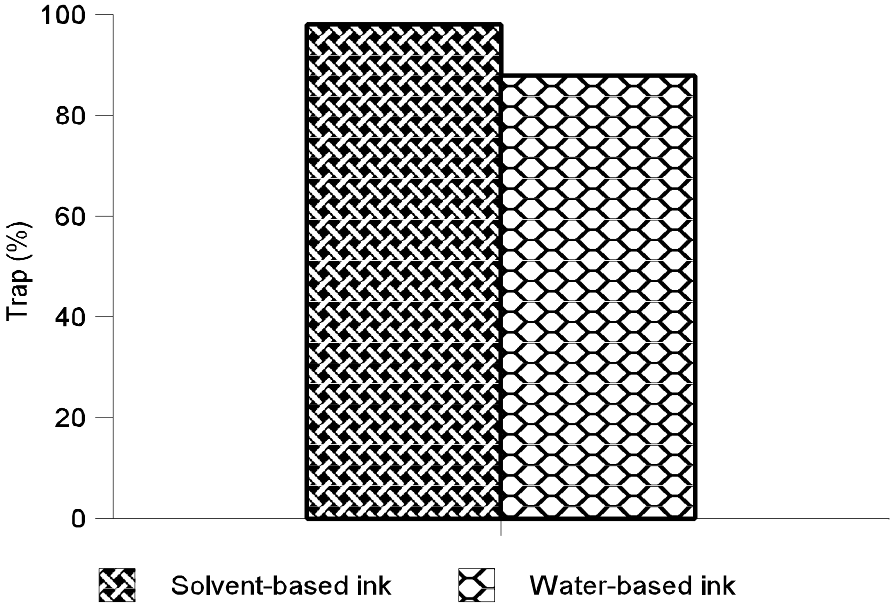
Figure 4.11-4.12 show the average percent trap for these two ink colors on each substrate. The solvent-based inks demonstrated better trap than the water-based inks on the PE/EVA and OPP films. The water-based inks showed slightly better performance than the solvent-based on the LDPE substrate.

Figure 4.11 Average Trap for LDPE and PE/EVA— Solvent-based and Water-based Inks



LDPE: Solvent-based ink	98.4
LDPE: Water-based ink	104.8
PE/EVA: Solvent-based ink	98.7
PE/EVA: Water-based ink	86.9

Figure 4.12 Average Trap for OPP— Solvent-based and Water-based Inks



Solvent-based ink	98
Water-based ink	87.8

Highlights of Performance Results for Solvent-Based and Water-Based Inks

No clear evidence emerged from these tests that either the solvent-based or the water-based system performed better overall. The results of the tests varied widely. On some tests, both ink systems performed comparably well on one substrate and poorly on another. COF, and in most cases density, dimensional stability, image analysis, opacity, and rub resistance, all displayed results that were fairly consistent from substrate to substrate for both ink systems.

On the other hand, other tests showed wide internal variability. Solvent-based inks performed an average of 16% better than water-based inks on the adhesive lamination test. Water-based inks had much better ratings than solvent-based inks on both LDPE and PE/EVA. Gloss was highest for solvent-based inks on PE/EVA. On OPP, heat resistance varied from 9% for one water-based ink to 39% for a solvent-based ink. Odors varied in both strength and type across both ink and substrate type. Mottle was significantly higher for blue inks and water-based inks. Tape adhesiveness and trap varied by substrate and ink system.

These variances point out the importance of a number of factors in the performance of these inks. Substrate type clearly emerged as a critical component of quality. The type and amount of the vehicle (solvent in solvent-based ink and water in water-based ink), as well as press-side solvents and additives, affected the physical properties of ink and substrate. In turn, functional ink-substrate interactions such as wetting and adhesion affected several of the performance results.

The variability of the results indicates that there may not be one best overall choice of an ink system for all performance conditions and applications. One clear conclusion is that a flexographic printer cannot make a simple assumption that any of these ink systems or ink-substrate combinations will be best-suited to the firm’s overall needs. Careful testing of a potential ink system on the various substrates that a printer will be using most often is critical to obtaining desired quality on a consistent basis.

4.3 RESULTS OF PERFORMANCE DEMONSTRATION AND LABORATORY RUN TESTS — UV-CURED INKS

This section focuses separately on the ultraviolet-cured ink system, because flexographic printing technology using this UV inks on wide-web presses, particularly using film substrates, was still in a developmental phase at the time this research was performed (November 1996—March 1997). Therefore, the results using UV-cured inks should be viewed as a snapshot of the technology under field conditions during that time period rather than as representative of the capabilities of UV inks now or in general. Since that time, improvements in UV-cured inks have been made that are described in more detail at the end of this section (Technological Developments in UV-cured Inks). Due to technical limitations, no laboratory runs were performed for UV inks.

For the methodology or for more specific information regarding the performance demonstration tests, please see Section 4.1 of this chapter and Appendix 4-E. Table 4.2, near the start of this chapter, describes the purpose, procedure, and interpretation for each test that was performed.

Substrate type played a major role in the performance of UV-cured inks during the tests, showing that the ink-substrate relationship is very important to the performance of printed products. As is true for the solvent-based and water-based ink systems, the UV-cured ink results also varied widely among tests. Printers need to consider the needs of their clients, the type of substrates and products that they most often print, and the desired aspects of quality that are most critical overall, when determining which type of ink system will be most appropriate for the facility.

Block Resistance — UV-cured Inks

Table 4.21 shows the results of this test. On LDPE the ink showed slight blocking. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no block resistance data were available for this ink-substrate combination.

Table 4.21 Block Resistance Results — UV-cured Inks

Ink	Film	Average Rating of Blocking Resistance[a]
UV	LDPE	2.5
	PE/EVA	1.4
UV (no slip)	LDPE	1.0

[a] The following scale was used to assign a numerical score to the test results: 0 = no blocking. 1 = slight cling. 2 = cling. 3 = slight blocking. 4 = considerable blocking. 5 = complete blocking. Table 4-E.1 in Appendix 4-E provides a detailed description of this scale.

CIE L*a*b* — UV-cured Inks

Results for LDPE and PE/EVA are shown in Table 4.22. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no CIE L*a*b* data were available for this ink-substrate combination.

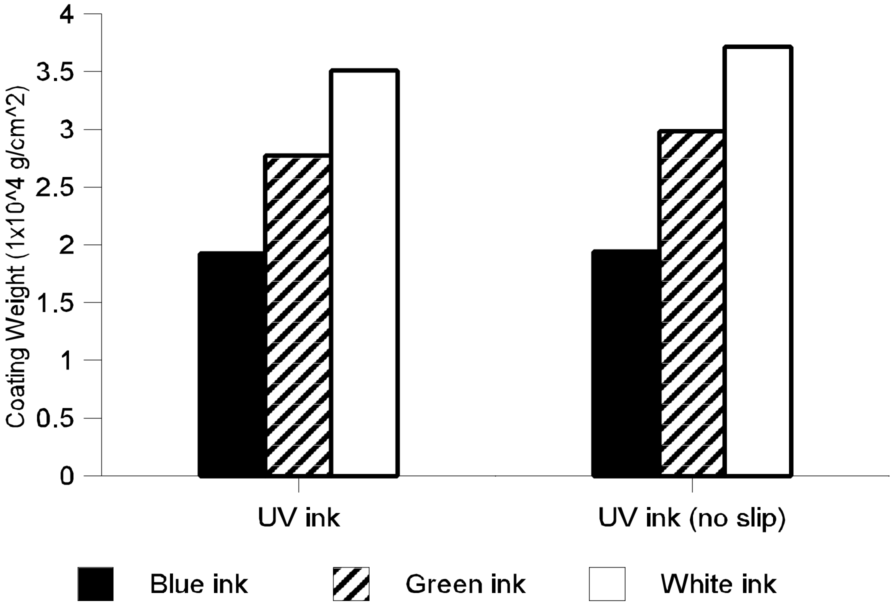
Table 4.22 CIE L*a*b* Results — UV-cured Inks

Ink	Film	Product Line	Site	Color	Average L*	Average a*	Average b*
UV	LDPE	#U2	6	magenta	43.80	49.03	10.90
				cyan	61.17	-37.58	-23.76
				green	65.54	-50.76	32.96
				blue	40.57	2.25	-44.73
	PE/EVA	#U2	6	magenta	47.60	53.85	4.01
				cyan	60.78	-30.65	-38.58
				green	64.47	-57.91	31.73
				blue	38.81	11.30	-50.42
		#U3	8	magenta	53.21	53.50	-2.41
				cyan	62.38	-27.22	-36.98
				green	70.93	-53.83	6.50
				blue	48.64	8.45	-46.77
UV-cured (no slip)	LDPE	#U1	11	magenta	52.71	48.81	-4.70
				cyan	59.88	-33.27	-24.42
				green	63.86	-56.90	10.70
				blue	34.60	15.39	-51.63

Coating Weight — UV-cured Inks

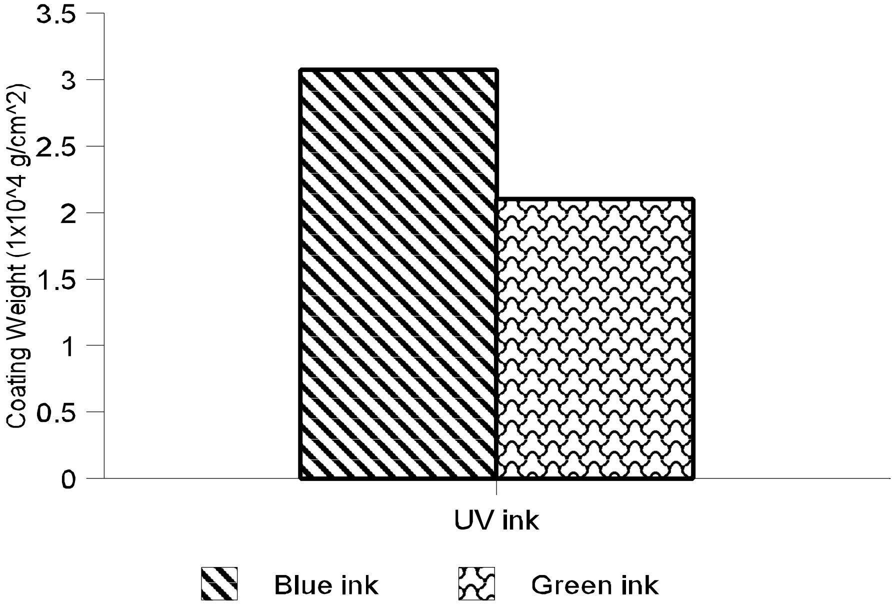
On LDPE, coating weight was lowest for blue and highest for white inks. Figures 4.13 and 4.14 show the results. There were no successful runs of UV-cured ink on OPP, so no coating weight data were available for this ink-substrate combination.

Figure 4.13 Average Coating Weight for LDPE — UV-cured Inks



	UV ink	UV ink (no slip)
Blue ink	1.92	1.94
Green ink	2.77	2.98
White ink	3.51	3.71

Figure 4.14 Average Coating Weight for PE/EVA — UV-cured Inks



	UV ink
Blue ink	3.07
Green ink	2.1

Coefficient of Friction — UV-cured Inks

Results are shown in Table 4.23. UV ink #U3 at Site 11 had the highest COF, as was expected since a no-slip film was used. The COF for UV ink #U2 on LDPE (Site 6) was higher than the other ink-substrate combinations, particularly for two layers of printed substrate. Otherwise, no significant differences between inks tested on the LDPE and PE/EVA substrates existed. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no COF data were available for this ink-substrate combination.

Table 4.23 Coefficient of Friction Results — UV-cured Inks

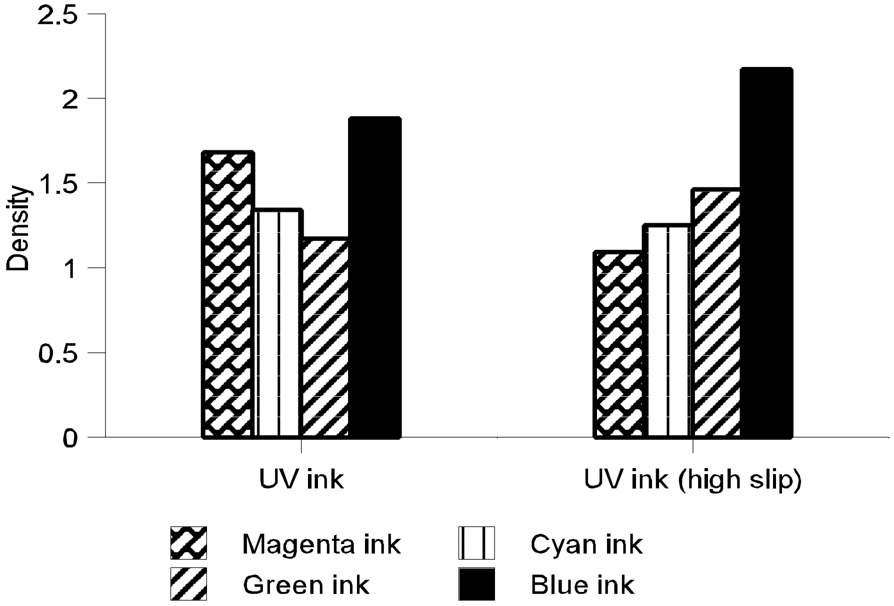
Ink	Film	Product Line	Site	Average Angle of Inclination (degrees)		
				Ink-Un[a]	Ink-Ink[b]	Control[c]
UV	LDPE	#U2	6	31.2	53.8	23.3
	PE/EVA	#U2	6	20.8	21.3	16.7
		#U3	8	25.9	24.7	16.7
UV (no slip)	LDPE	#U1	11	36.9	60+[d]	45.0

[a] "Ink-Un" represents the coefficient of friction for printed substrate on unprinted substrate.
[b] "Ink-Ink" represents the coefficient of friction for printed substrate on printed substrate.
[c] "Control" represents the coefficient of friction for unprinted substrate on unprinted substrate.
[d] The angle of inclination was higher than 60 degrees.

Density — UV-cured Inks

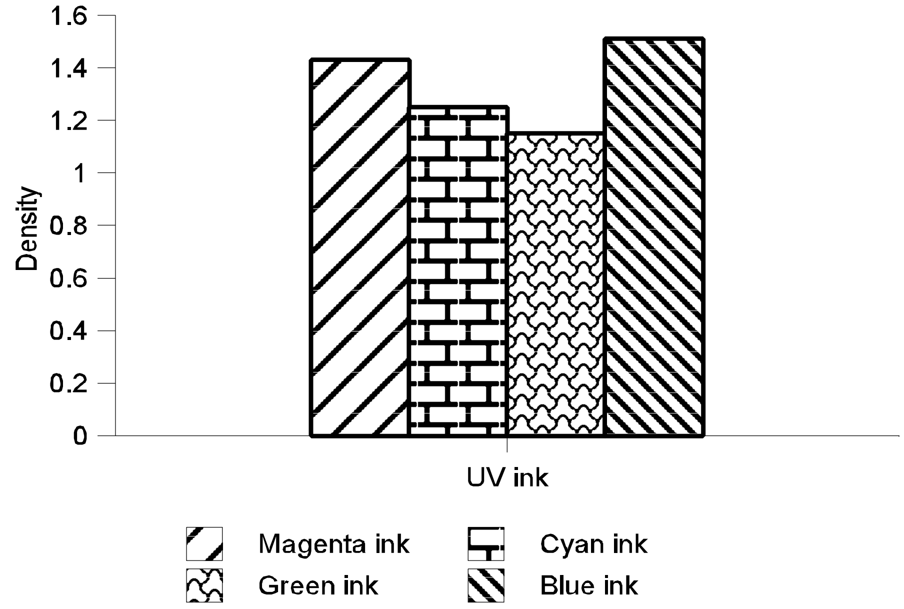
Results are shown in Figures 4.15 and 4.16. On LDPE, the density score for blue ink was substantially higher than that for any other color. Density on LDPE was much lower on the high-slip substrate. Due to a shortened run at site 8, samples were taken only at three of the four planned locations on the runs. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no density data were available for this ink-substrate combination.

Figure 4.15 Average Density for LDPE — UV-cured Inks



	UV ink	UV ink (high slip)
Magenta ink	1.68	1.09
Cyan ink	1.34	1.25
Green ink	1.17	1.46
Blue ink	1.88	2.17

Figure 4.16 Average Density for PE/EVA — UV-cured Inks



	UV ink	UV ink (high slip)
Magenta ink	1.43	n/a
Cyan ink	1.25	n/a
Green ink	1.15	n/a
Blue ink	1.51	n/a

Dimensional Stability — UV-cured Inks

Results are shown in Table 4.24. All three substrates showed similar measurements. Because the run at site 8 was shortened, samples were not taken from all scheduled locations. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no dimensional stability data were available for this ink-substrate combination.

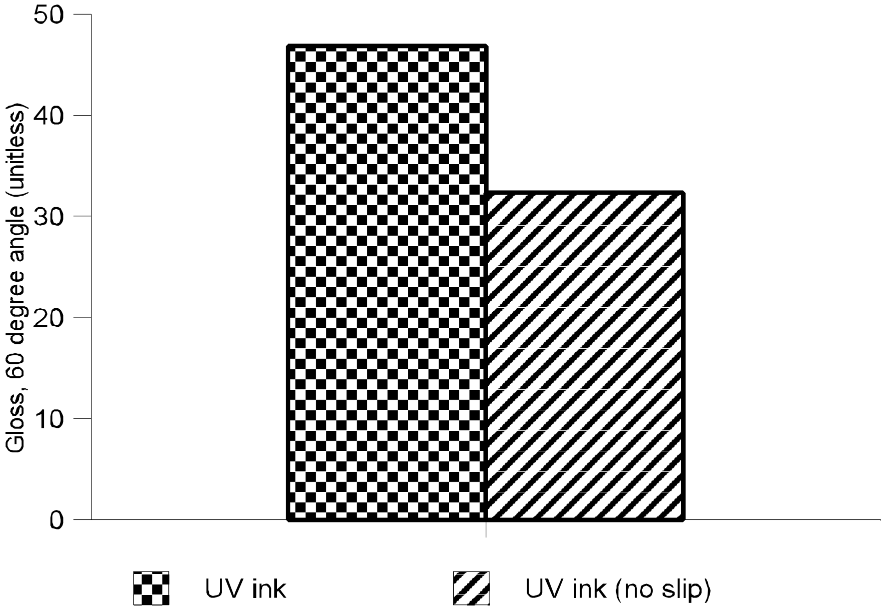
Table 4.24 Dimensional Stability Results — UV-cured Inks

Ink	Film	Product Line	Site	Average Width (mm)	Average Length (mm)
UV	LDPE	#U2	6	54.34	77.24
	PE/EVA	#U2	6	54.24	77.92
		#U3	8	54.08	75.83
UV (no slip)	LDPE	#U1	11	54.25	77.86

Gloss — UV-cured Inks

Figure 4.17 shows the results for UV and UV no slip on LDPE. All readings were below 50%, with UV on LDPE performing the best (46.83%). UV on PE/EVA averaged 42.41%. Limited data were available from Site 8, due to the shortened runs on PE/EVA. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no gloss data were available for this ink-substrate combination.

Figure 4.17 Average Gloss for LDPE — UV-cured Inks



UV ink	46.83
UV ink (no slip)	32.31

Ice Water Crinkle Adhesion — UV-cured Inks

Table 4.25 shows that two of the three UV-cured product lines (UV ink #U1 and UV ink #U3) stayed flexible on both substrates, but UV ink #U2 failed on both substrates.

Table 4.25 Ice Water Crinkle Adhesion Results — UV-cured Inks

Ink	Film	Product Line	Site	Any Ink Removal?
UV	LDPE	#U2	6	yes, less than 15%
	PE/EVA	#U2	6	yes, less than 15%
		#U3	8	no
UV (no slip)	LDPE	#U1	11	no

Image Analysis — UV-cured Inks

Table 4.26 shows the results of the test. Both average dot area and average dot perimeter varied, but not consistently with each other. Dot area showed a range from 384 square microns (cyan on PE/EVA) to 966 square microns (cyan on LDPE). Dot perimeter varied from a low of 80 square microns (cyan and magenta) to a high of almost 139 square microns (cyan). Due to the absence of successful runs of UV-cured ink on the OPP substrate, no image analysis data were available for this ink-substrate combination.

Table 4.26 Image Analysis Results — UV-cured Inks

Ink	Film	Product Line	Site	Color	Average Dot Area (micron^2)	Average Dot Perimeter (microns)
UV	LDPE	#U2	6	magenta	716.28	113.05
				cyan	966.98	134.64
	PE/EVA	#U2	6	magenta	672.38	101.13
				cyan	892.23	138.79
		#U3	8	magenta	480.28	91.78
				cyan	384.78	80.60
UV (no slip)	LDPE	#U1	11	magenta	456.52	80.80
				cyan	571.66	93.08

Jar Odor — UV-cured Inks

Table 4.27 lists the results of this test. The UV-cured inks showed more of a range in scores than did the other ink types. UV ink #U3 had the mildest odor, both in strength (1) and description (mild waxy). The odor from UV ink #U1 was rated 3 in strength and was described as "mild acetic acid." UV ink #U2 had the strongest odors (4 to 5 on a scale of 5) and was described as "very strong bitter almond" on the LDPE substrate, and as "very strong, decayed fish" on the PE/EVA. It should be noted that the controls for these samples were, respectively, "slightly like bitter almond" and "fish." This implies that either the unprinted substrate's odor affected the odor of the ink sample, or that the odor of the ink sample affected the entire roll (both printed and unprinted areas). Due to the absence of successful runs of UV-cured ink on the OPP substrate, no jar odor data were available for this ink-substrate combination.

Table 4.27 Jar Odor Results — UV-cured Inks

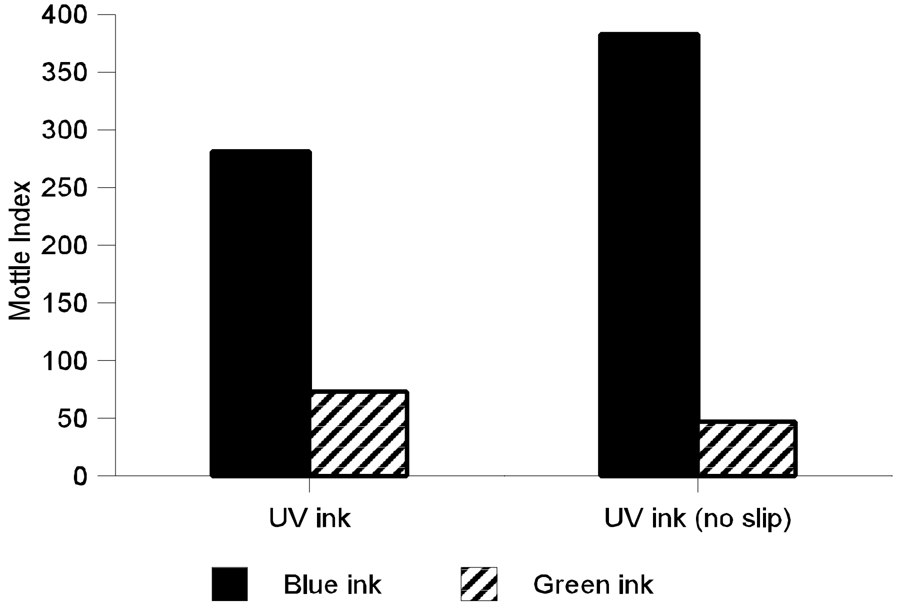
Ink	Film	Product Line	Site	Relative Score[a]	Description of Printed Area	Description of Unprinted Area (control)
UV	LDPE	#U2	6	4	very strong bitter almond	slightly like bitter almond
	PE/EVA	#U2	6	5	very strong, decayed fish	fish
		#U3	8	1	very slight odor	mild waxy
UV (no slip)	LDPE	#U1	11	3	acetic acid, mild	waxy

[a] Printed samples were scored on a scale from 0 to 5, with 0 signifying no odor, and 5 signifying an unpleasant, offensive odor.

Mottle/Lay — UV-cured Inks

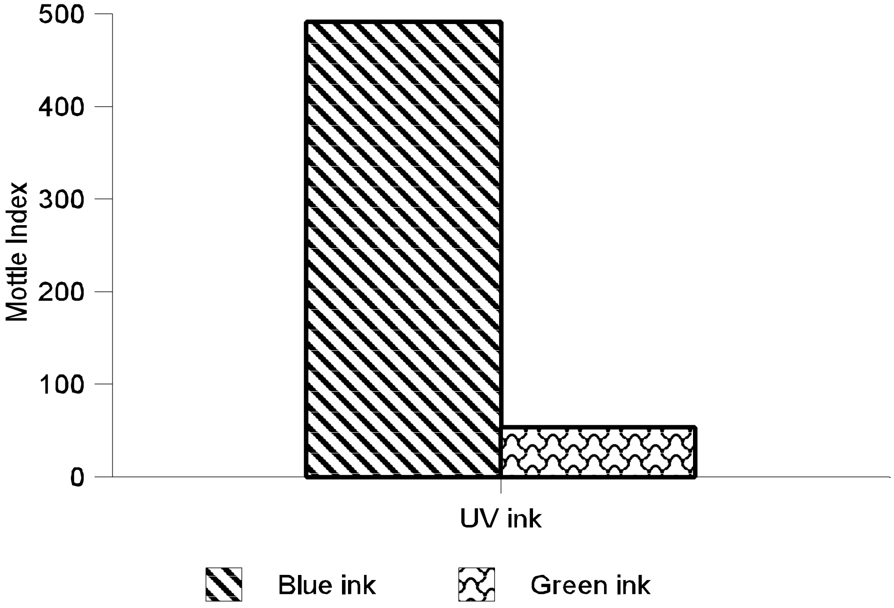
Figures 4.18 and 4.19 display the results of the mottle/lay test. Green ink showed little mottle on either substrate. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no mottle data were available for this ink-substrate combination.

Figure 4.18 Average Mottle Index for LDPE — UV-cured Inks



	UV ink	UV ink (no slip)
Blue ink	281	382.5
Green ink	73	47

Figure 4.19 Average Mottle Index for PE/EVA — UV-cured Inks



	UV ink	UV ink (no slip)
Blue ink	491	n/a
Green ink	53.45	n/a

Opacity — UV-cured Inks

The readings averaged around 55% but showed high standard deviation values, which may indicate poor uniformity of substrate coverage. Only LDPE data were collected for this test. The opacity test was not run on PE/EVA because it is a white substrate, and there were no successful runs of UV-cured ink on OPP.

Rub Resistance — UV-cured Inks

Table 4.28 shows the results of wet rub resistance tests. UV on LDPE performed the best, with failure at an average of 5.2 strokes. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no rub resistance data were available for this ink-substrate combination. For dry rub resistance, the ink used on no-slip LDPE (Site 11) received the only score below 90%.

Table 4.28 Wet Rub Resistance Results — UV-cured Inks

Ink	Film	Product Line	Site	Failure at Number of Strokes (average)[a]
UV	LDPE	#U2	6	5.2
	PE/EVA	#U2	6	4.2
		#U3	8	2.3
UV (no slip)	LDPE	#U1	11	2.2

[a] A failure represents ink color transferred from the printed substrate to the unprinted substrate. A maximum of 10 strokes were used for the wet rub resistance test. Measurements were taken at four locations and averaged. See Appendix 4-E for specifics.

Tape Adhesiveness — UV-cured Inks

Table 4.29 shows the results of the test. Results were mixed. UV no slip on LDPE had no failures and 4 passes, whereas UV on PE/EVA had the reverse showing. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no tape adhesiveness data were available for this ink-substrate combination.

Table 4.29 Tape Adhesiveness Results — UV-cured Inks

Ink	Film	Product Line	Site	Number of Passes	Number of Failures	Comments
UV	LDPE	#U2	6	2	2	white and magenta were removed
	PE/EVA	#U2	6	0	4	blue, green, and magenta were removed
		#U3	8	1	2	cyan was slightly removed
UV (no slip)	LDPE	#U1	11	4	0	

Trap — UV-cured Inks

This system averaged approximately 90% for trapping. UV inks on PE/EVA scored an average of 93%, whereas on LDPE the inks scored an average of 87%. Due to the absence of successful runs of UV-cured ink on the OPP substrate, no trap data were available for this ink-substrate combination.

Uncured Residue — UV-cured Inks

The uncured residue test was performed only for UV-cured inks. The uncured residue test was measured in the laboratory with samples collected from Sites 6, 8 and 11. UV ink was not run at any other sites.

Uncured residue was measured only for green, blue, and white ink, since these colors had the largest areas of coverage. Results are presented in Table 4.30 as average percent (by weight) of ink removed. The averages are based on four measurements taken at different locations from each site sample. Uncured residue was found only on the blue ink samples. Due to the absence of successful runs of UV ink on the OPP substrate, no uncured residue data were available for this ink-substrate combination.

Table 4.30 Average Uncured Residue Results — UV-cured Inks

Ink	Film	Product Line	Site	Average Percent of Ink Removed (by weight)[a]
UV	LDPE	#U2	6	0.00
	PE/EVA	#U2	6	0.00
		#U3	8	6.97
UV (no slip)	LDPE	#U1	11	10.42

[a] Uncured residue was found on the blue ink samples only.

Summary of Performance Test Results for UV-Cured Inks

These performance demonstrations were completed in 1997, since which time flexographic printing technology for UV-cured inks has made significant advances. The test results recorded in this CTSA provide a snapshot of UV technology early in its technical development but do not necessarily lead to any conclusions about current or potential abilities of UV inks. In fact, just as for solvent-based and water-based inks, no one test can provide a reliable or accurate indicator of overall quality for any printer. Printers need to consider a variety of different factors in determining acceptable quality. These factors — among them cost, health and environmental risks, energy use, and pollution prevention opportunities — are discussed in other chapters of this CTSA.

UV-cured inks performed well on some tests. The inks displayed good resistance to blocking, particularly on PE/EVA and no-slip LDPE. The inks displayed relatively good trapping. Mottle was better than that of the water-based inks and comparable to that of the solvent-based inks. For the ice water crinkle test, only one UV-cured ink (#U2) displayed evidence of removal. Also, the coating weight was greater than that for solvent- and water-based inks, despite lower ink consumption as measured in Chapter 6.

The test results on these particular UV product lines also showed a need for improvement, particularly some physical adherence tests. The rub resistance and tape adhesiveness results were unimpressive for inks #U1 and #U3; these results may have been caused by the incomplete curing observed with these two product lines. The opacity level (measured for white inks only) showed a high standard deviation, which indicated a lack of uniformity. In addition, gloss was low, despite the fact that high gloss is considered to be a strength of UV finishes.

Technological Development in UV-cured Inks

With any new technology, changes can occur rapidly, and UV-cured inks are no exception. Recent formulation and equipment improvements are addressing some of the limitations for UV-cured inks seen in the performance demonstrations for this CTSA. For example, cationic inks (as opposed to the free-radical UV inks in the CTSA) may have lower shrinkage rates and improved flexibility, which may help with adherence. Other adjustments in chemistry are being made to reduce viscosity and improve the curing rate of UV inks. Furthermore, improvements in equipment may lead to overall better coatings. This section describes significant developments and the improvements they could yield, and discusses aspects of the technology that continue to pose difficulties.

Many advances have been made in the past few years that improve the quality of UV inks for wide-web flexography. New cationic inks might offer an alternative for printers who use porous substrates, need a more thoroughly cured ink, or print items for which odor must be minimized. Improvements have been made with free-radical UV-cured inks; some inks can be used on several substrates, the viscosity has been reduced, and the ink is more durable when applied. Equipment improvements have led to better heat management, which in turn has provided printers with better energy efficiency, improved equipment durability, and high-quality products. Furthermore, technologies such as improved UV bulbs are improving curing rates while at the same time requiring that less photoinitiator be included in the ink.
Although UV wide-web flexography still faces obstacles, technological developments indicate that UV will continue to improve and grow in the future.

Cationic Inks

Currently, most UV-cured ink is based on free radical curing, which involves acrylate monomers that, when exposed to high-energy ultraviolet light, undergo a chain reaction to bind together in a large polymer. (For more information on the free-radical curing process, see Chapter 2.) This free radical reaction is beneficial in several ways, most prominently that the reaction (or “drying”) is almost instantaneous when the polymer is exposed to the UV light. Early concerns with cationic inks included 1) that the reaction process causes the ink to shrink, which can affect the ability of the ink to bind to the substrate, 2) the reaction can be inhibited by the presence of oxygen for some applications, and 3) unreacted epoxide molecules can have an unpleasant odor.[1] These concerns have largely been addressed through formulation and equipment improvements.[2]

The evolution of cationic inks is one of the most significant recent developments in UV-cured ink technology. Cationic inks work in a similar fashion to free-radical inks, in that small monomers react to form a cohesive polymer in the presence of UV rays. This process differs from free radical curing in that the monomer in the ink is usually an epoxide rather than an acrylate, and that the reaction occurs due to the reaction of electron-deficient ions, rather than the binding of electronically-neutral but unstable radicals.

One benefit of the cationic system over the free radical system is that the reaction is not inhibited by oxygen; therefore, the curing is usually more complete. However, the reaction can be limited if bases, such as amines, are present in the ink or substrate.[3]

Cationic inks have several other advantages. The epoxide shrinks less than acrylate when it polymerizes, and therefore adheres to the substrate better. Cationic inks have less odor, because the material dries more thoroughly and because epoxides are inherently less odorous than acrylics. Furthermore, cationic inks are less viscous. As a result, they flow well without heating, they require corona treatment less frequently, and the applied layer is more evenly spread for solid colors. Ink densities are also stronger for cationic inks than they might be for free radical inks.[4] In addition, cationic inks can produce a high gloss and good adhesiveness, and thus can prevent the need for costly lamination on certain products.[5]

Several disadvantages, however, currently make cationic inks a less popular option than the more established free radical system. Even though cationic inks may dry more thoroughly, the drying process takes longer. This has implications for press speed, because additional colors cannot be added until the first color cures.[6] The final product printed with cationic inks does not have as much solvent resistance as free radical inks.[7] The drying of cationic inks are can be affected by moisture and high humidity, so that until the problem is resolved, cationic inks cannot be used universally in all geographic locations.[8] Finally, cationic inks might not cure effectively on high-pH substrates, such as paper.

Other Ink Developments

Significant advances have been made in adjusting the properties of both free radical and cationic inks. One such property is the ability to be printed on more than one substrate. Early UV-cured inks were specially formulated for a given substrate, and several sets of UV ink chemistries had to be stored on-site if a printer worked with multiple substrates. This practice was inconvenient and increased inventory costs. Newer UV-cured inks are more universal and perform consistently on most substrates. However, these inks may damage the photopolymer plates, which then require more frequent changing.[9]

Ink suppliers are now developing UV-cured inks that have less odor, either by reducing the amount of photoinitiator and monomer needed, or modifying the chemical structure of the monomer so that it is less pungent.[10] Skin irritation sometimes caused by UV-cured inks has been mitigated by using water to reduce the viscosity of the inks rather than traditional diluents.[11] Also, the resistance of inks to water damage has been improved by developing additives that make the ink more durable.[12]

Temperature Control

Temperature management with central impression drum presses (which include most wide-web presses) equipped with UV curing equipment has been a challenge. If the conditions are not managed properly by the press manufacturer, some UV rays reflect off of the drum and heat it in the process. When the press temperature is raised above the standard 32°C, the drum is vulnerable to warping. In addition, heat can damage some substrates, including films.

Adjusting the energy input to the curing lamps has been one approach to reducing press temperatures. One study found that with most UV-cured inks, smaller diameter bulbs cured the inks at the same rate but used significantly less energy and thus generated less heat. In addition, specialized bulbs (e.g., D bulbs containing iron for pigmented inks and V bulbs containing gallium for white inks) can reduce the required energy.[13]

Lowering ink viscosity also helps lower temperatures. Viscous inks often require heating in order to make the ink flow well. Cationic inks, which generally are less viscous and do not require heating, are a possible solution for printers faced with difficulties in heat management.

Equipment suppliers are also improving power supply and ventilation systems used in curing UV inks. Devices can be installed that allow for variable power supply; the press operator can adjust the power so that only the minimum amount of energy is used to cure the ink. Heat can be removed more efficiently from the bulb and substrate surface by making improvements in ventilation, such as improved lamp housing aerodynamics and variable-speed blowers.[14] Another recent improvement has been the development of special dichroic reflectors, which absorb infrared energy while directing UV rays to the desired coating.[15]

Ultraviolet/Electron Beam (UV/EB) Hybrid Press

A combination of a UV press with a final electron beam (EB) curing station is still considered experimental, but might improve drying and reduce energy demands. An EB curing station emits a higher energy wave than UV lamps, and therefore penetrates thicker layers better. Because EB lamps cure so much more thoroughly at the end, the intermediate UV lamps do not have to be as powerful, and fewer photoinitiator are needed in the inks.[16] It has been estimated that a UV/EB hybrid press consumes 35 percent less energy and produces less heat.[17] In addition, the UV/EB technology can be used with porous substrates, which standard UV technology cannot since it does not thoroughly cure ink on such substrates. Currently, the major limitation for UV/EB technology is the large capital expenditure required for equipment. In addition, performance properties of the ink might be altered.[18]

Remaining Technical Challenges

Despite the advances made during the past few years, several difficulties still remain with UV technology. One that is particularly evident in film applications is inadequate adhesion. Much of the difficulty stems from the shrinkage that free radical UV-cured inks undergo as they cure. Because shrinkage is less of an issue with cationic inks, further development of cationic inks may help solve this problem. Ink suppliers are also developing free radical UV-cured inks with improved adhesion.

Another issue is the application of even ink layers. Historically, the thick viscosity of UV-cured inks has created discontinuous ink layers and pinholing. The reduced viscosity of current UV inks reduces pinholing but could affect dot gain.[19, 20, 21]

4.4 SITE PROFILES

The site profiles provide background information for each of the volunteer printing facilities that participated in the performance demonstrations. This section provides information about each facility, as well as technical information about each press.

Table 4.31 summarizes the press speed, run time, and run length for each of the performance demonstration sites.

Table 4.31 Summary Information about the Performance Demonstration Sites

Site	Ink	Substrate	Average press speed (ft/min)[b]	Run time (minutes)[a]	Run length (feet)
1	Water-based	OPP	430	129	51,000
2	Water-based	LDPE	403	93	37,053
		PE/EVA	403	102	37,868
3	Water-based	LDPE	218	126	26,927
		PE/EVA	430	131	47,884
4	Water-based	OPP	450	123	13,160
5	Solvent-based	LDPE	400	57	21,924
		PE/EVA	400	56	20,858
6	UV	LDPE	344	92	32,431
		PE/EVA	354	95	27,691
		OPP	344	38	6,853
7	Solvent-based	LDPE	450	148	42,000
		PE/EVA	—	—	8,069
8	UV	LDPE	262	65	2,559
		PE/EVA	262	63	15,912
		OPP	262	15	4,265
9A	Water-based	OPP	425	66	34,434
9B	Solvent-based	OPP	415	80	33,641
10	Solvent-based	OPP	600	90	56,700
11	UV	LDPE	400	153	38,400

[a] Run time included changing of substrate rolls and getting the press back up to speed.

[b] Based on the maximum speed attained during the run.

Site 1: Water-based Ink #W2 on OPP

Table 4.32 Facility Background Information for Site 1

Item	Description
Ink type used	100% water-based
Control equipment	None
Annual production	1.5 million pounds of clear and metallized polypropylene, polyethylene, and polyester; cellophane and paper flexographic-printed products
Operating hours	24 hours per day, 363 days per year
Avg. production run	Four hours

Table 4.33 Press Information for the Performance Demonstration at Site 1

Item	Description
Press	Amber Press, Central Impression
Size of press	55 inches wide, eight-color
Printing type	Reverse
Typical production speed	500 feet/minute
Plates	0.067” Dupont EXL photopolymer: 1) Two process plates (magenta and cyan) mounted using 0.020 hard stick back 2) Three line plates (green, blue, and white) mounted using 0.020 hard stick back
Corona treater (yes / no)	Pillar, Model DB5673-16
Ink metering system	Chambered
Type of doctor blade	Steel
Ink pumping and mixing system	Peristaltic air pump, pumping from semi-covered five-gallon buckets

Table 4.34 Color Sequence and Anilox Configurations for Site 1

Sequence	Color	Anilox lpi[a]	Anilox BCM[b]
Deck 1	Blue	280	7.0
Deck 2 — Not Used	—	—	—
Deck 3	Cyan	800	1.7
Deck 4	Green	280	6.4
Deck 5 — Not Used	—	—	—
Deck 6	Magenta	800	1.7
Deck 7 — Not Used	—	—	—
Deck 8	White	280	7.5

[a] lines per inch
[b] billion cubic microns per square inch

Table 4.35 Summary Information from the Performance Demonstration at Site 1

Substrate	Press speed	Run time	Run length
OPP	430 ft/min	129 minutes	51,000 feet

Observations and Comments

Due to site-specific circumstances, a surface ink was used for the blue in place of a reverse ink at the start of the run. The correct reverse ink was added to the surface ink in the ink pan after approximately 38,000 impressions. While a press speed of 500 ft/min might have been possible with this press and ink, bounce on the white plate limited the maximum obtainable speed to 430 ft/min. The bounce on the white plate occurred due to mounting.

Overall, the makeready and demonstration run were completed with no uncontrollable complications. The printing problems encountered were considered normal and the press operators were easily able to adjust the printing environment to obtain the desired quality result and achieve production printing speeds and conditions.

Site 2: Water-based Ink #W3 on LDPE and PE/EVA

Table 4.36 Facility Background Information for Site 2

Item	Description
Ink type used	100% water-based
Control equipment	None
Annual production	10,465,000 pounds of polyethylene flexographic-printed products
Operating hours	24 hours per day, 363 days per year
Avg. production run	Five hours, including makeready

Table 4.37 Press Information for the Performance Demonstration at Site 2

Item	Description
Press	UTECO, Quarz 140
Size of press	54 inches wide, six-color
Printing type	Surface
Typical production speed	500 feet/minute
Plates	0.107" Dupont EXL photopolymer: 1) Two process plates (magenta and cyan) mounted using Tessa hard stick back 2) Three line plates (green, blue, and white) mounted using Tessa hard stick back
Corona treater	Enercon
Ink metering system	Chamber
Type of doctor blade	Daetwyler 0.006
Ink pumping and mixing system	Peristaltic pump with air monitors in each five-gallon bucket

Table 4.38 Color Sequence and Anilox Configurations for Site 2[a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1	White	360	5.05
Deck 2	Green	300	6.90
Deck 3 — Not Used	—	—	—
Deck 4	Magenta	360	5.13
Deck 5	Blue	280	6.00
Deck 6	Cyan	360	4.90

[a] Deck 1 (white ink) not used for the PE/EVA substrate
[b] lines per inch
[c] billion cubic microns per square inch

Table 4.39 Summary Information from the Performance Demonstration at Site 2

Substrate	Press speed	Run time	Run length
LDPE	403 ft/min	93 minutes	37,053 feet
PE/EVA	403 ft/min	102 minutes	37,868 feet

Observations and Comments

LDPE

Pinholing occurred in all colors, and the trap was poor. No blocking or apparent problems with dimensional stability occurred. The pinholing and poor trap were considered acceptable and typical for this site. The press operator made minor impression adjustments in an effort to compensate for the pinholing.

PE/EVA

The green and blue samples taken at the beginning of the run failed the adhesiveness test, while the magenta and cyan passed. The printing quality of all colors was poor, and the printing appeared dirty, but the lay was acceptable with no blocking. The trap was variable depending on position across the web and impression. There appeared to be no dimensional stability concerns.

At the end of the run, the green and blue samples continued to fail the adhesiveness test, but the magenta and cyan samples passed with no failure or ink removed. The printing still appeared to look dirty. Trap was acceptable and lay was improved.

Overall, the makeready and run were completed with no serious complications. The printing problems encountered were considered normal for this site.

Site 3: Water-based Ink #W3 on LDPE and PE/EVA

Table 4.40 Facility Background Information for Site 3

Item	Description
Ink type used	100% water-based
Control equipment	None
Annual production	10 million pounds of flexographic-printed flexible packaging products
Operating hours	24 hours per day, seven days per week
Avg. production run	Eight hours including makeready

Table 4.41 Press Information for the Performance Demonstration at Site 3

Item	Description
Press	Faustel
Size of press	50 inches wide, six-color
Printing type	Surface
Typical production speed	Not given
Plates	0.067” Polyfibron photopolymer plates: 1) Two process plates (magenta and cyan) mounted using compressible stick back 2) Three line plates (green, blue, and white) mounted using hard stick back
Corona treater	Enercon
Ink metering system	Chambered doctor blade, except for white, which is a two-roll without doctor blade
Type of doctor blade	Not given
Ink pumping and mixing system	Peristaltic air pump in five-gallon bucket

Table 4.42 Color Sequence and Anilox Configurations for Site 3[a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1	White	300	5.2
Deck 2	Magenta	500	3.2
Deck 3	Cyan	500	3.2
Deck 4	Green	240	7.8
Deck 5	Blue	240	7.8
Deck 6 — Not Used	—	—	—

[a] Deck 1 (white ink) not used for the PE/EVA substrate
[b] lines per inch
[c] billion cubic microns per square inch

Table 4.43 Summary Information from the Performance Demonstration at Site 3

Substrate	Press speed	Run time	Run length
LDPE	218 ft/min	126 minutes	26,927 feet
PE/EVA	430 ft/min	131 minutes	47,884 feet

Observations and Comments

LDPE

Toward the end of the run, pinholing was evident in the blue and the green samples. Also, there was indication of ink drying on the edge of the magenta plate. The pinholing was considered minimal and typical. The press operator made minor impression adjustments to compensate. Trap and dimensional stability were not considered to be a factor in overall quality.

PE/EVA

The samples taken at the beginning of the run passed the adhesiveness test, although some light dusting occurred in the green and blue. No trap or dimensional problems occurred. Poor wetting of the green on white, and pinholing of the blue on white, were evident.

At the end of the run, the cyan and magenta samples passed the adhesiveness test with no ink removed, but the green and blue failed. The demonstration team noted that these two colors should be tested again later after they had more time to dry. When tested again, the blue passed the adhesiveness test, but the green still failed. Increased pinholing was noted for both the green and the blue. Trap and dimensional stability were not considered to be a factor in overall quality.

Overall, the makeready and demonstration run were completed with no uncontrollable complications. The printing problems encountered were considered normal for this site.

Site 4: Water-based Ink #W1 on OPP

Table 4.44 Facility Background Information for Site 4

Item	Description
Ink type	100% water-based
Control equipment	None
Annual production	3 million pounds of polyethylene and polypropylene flexographic-printed products
Operating hours	24 hours per day, five days per week
Avg. production run	One week

Table 4.45 Press Information for the Performance Demonstration at Site 4

Item	Description
Press	Kidder Stacey
Size of press	46 inches wide, six-color
Printing type	Reverse
Typical production speed	400 feet/minute
Plates	0.067" Dupont EXL photopolymer plates: 1) Two process plates (magenta and cyan) mounted using Foam NY20 stick back with foam lining 2) Three line plates (green, blue, and white) mounted using Foam NY20 stick back with foam lining
Corona treater	Enercon
Ink metering system	Chambered
Type of doctor blade	Unknown
Ink pumping and mixing system	Air powered pump from five-gallon buckets covered with cardboard

Table 4.46 Color Sequence and Anilox Configurations for Site 4

Sequence	Color	Anilox lpi[a]	Anilox BCM[b]
Deck 1	Blue	250	6.1
Deck 2	Cyan	800	2.2
Deck 3	Green	250	6.8
Deck 4	Magenta	600	2.7
Deck 5 — Not Used	—	—	—
Deck 6	White	250	6.3

[a] lines per inch

[b] billion cubic microns per square inch

Table 4.47 Summary Information from the Performance Demonstration at Site 4

Substrate	Press speed	Run time	Run length
OPP	450 ft/min[a]	123 minutes	13,160 feet

[a] The press speed varied between 400 ft/min and 450 ft/min.

Observations and Comments

The press was initially ramped to 400 ft/min for the demonstration run. The speed was then increased to 450 ft/min, after 7,500 feet of film had been consumed. Press speed was later slowed to 435 ft/min, and then to 415 ft/min for the last roll of substrate due to drying concerns.

During the run, the pinholing became worse for the green sample, and was also appearing in all the other colors. Both pinholing and plugging occurred in the blue. The pinholing and contamination were considered minimal and typical for this site. The press operator made minor impression adjustments to compensate during the run. Trap and dimensional stability were not considered to be factors in overall quality.

Site 5: Solvent-based Ink #S2 on LDPE and PE/EVA

Table 4.48 Facility Background Information for Site 5

Item	Description
Ink type used	100% solvent-based
Control equipment	Four catalytic oxidizers for nine presses
Annual production	14 million pounds of polyethylene and polypropylene flexographic-printed products
Operating hours	24 hours per day, six days per week
Avg. production run	Two hours

Table 4.49 Press Information for the Performance Demonstration at Site 5

Item	Description
Press	Windmöller & Hölscher, Central Impression
Size of press	24 inches wide, six-color
Printing type	Surface
Typical production speed	400 feet/minute
Plates	0.107” Dupont EXL photopolymer: 1) Two process plates (magenta and cyan) mounted using compressible stick back 2) Three line plates (green, blue, and white) mounted using hard stick back
Corona treater	None
Ink metering system	Enclosed doctor blade
Type of doctor blade	Stainless steel
Ink pumping and mixing system	Closed-loop, air-powered

Table 4.50 Color Sequence and Anilox Configurations for Site 5[a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1	White	300	6.2
Deck 2 — Not Used	—	—	—
Deck 3	Green	240	4.2
Deck 4	Blue	240	4.2
Deck 5	Magenta	550	2.0
Deck 6	Cyan	550	2.0

[a] Deck 1 (white ink) was not used for the PE/EVA substrate.

[b] lines per inch

[c] billion cubic microns per square inch

Table 4.51 Summary Information from the Performance Demonstration at Site 5

Substrate	Press speed	Run time	Run length
LDPE	400 ft/min	57 minutes	21,924 feet
PE/EVA	400 ft/min	56 minutes	20,858 feet

Observations and Comments

LDPE

Some slight plate contamination was evident in the blue sample. Minor pinholing was apparent in the green sample. The pinholing and contamination were considered minimal and typical. The press operator made minor impression adjustments to compensate. Trap and dimensional stability were not considered to be a factor in overall quality.

PE/EVA

The samples taken at the beginning of the run passed the adhesiveness test, with no trap or dimensional problems. The lay was acceptable and tones appeared clean and open in the light end highlights. At the end of the run, the samples passed the adhesiveness test with no failure of ink removed. There were, however, some slight problems with solid formation, which may have been related to impression. The tones were beginning to plug in the light end highlights. The press team suggested that the ink drying speed was fast. Trap and dimensional stability were not considered to be a factor in overall quality.

Overall, the makeready and demonstration run were completed with no uncontrollable complications. The printing problems encountered were considered normal and the press operators were easily able to adjust the printing environment to obtain the desired quality result.

Site 6: UV Ink #U2 on LDPE, PE/EVA, and OPP

Table 4.52 Facility Background Information for Site 6

Item	Description
Ink type used	60% solvent-based inks, 35% water-based inks, and 5% UV inks
Control equipment	Charcoal adsorption
Annual production	8 million pounds of polyethylene, polypropylene, and paper flexographic-printed products
Operating hours	24 hours per day, 4.5 days per week
Avg. production run	Six to eight hours

Table 4.53 Press Information for the Performance Demonstration at Site 6

Item	Description
Press	Cobden Chadwick
Size of press	32 inches wide, six-color
Printing type	Surface and reverse
Production speed	250 to 350 feet/minute
Plates	0.107” Dupont EXL photopolymer: 1) Two process plates (magenta and cyan) mounted using 0.020 compressible stick back 2) Three line plates (green, blue, and white) mounted using 0.020 hard stick back
Corona treater	Q.C. Electronics
Ink metering system	Chambered
Type of doctor blade	Unknown
Ink pumping and mixing system	ARO, model 65736-003, air-powered, with diaphragm

Table 4.54 Color Sequence and Anilox Configurations for Site 6[a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1	White	250	7.5
Deck 2	Magenta	600	2.8
Deck 3	Cyan	600	2.8
Deck 4	Green	360	4.7
Deck 5	Blue	360	4.7
Deck 6 — Not Used	—	—	—

[a] Deck 1 (white ink) not used for the PE/EVA substrate
[b] lines per inch
[c] billion cubic microns per square inch

Table 4.55 Summary Information from the Performance Demonstration at Site 6

Substrate	Press speed	Run time	Run length
LDPE	344 ft/min[a]	92 minutes	32,431 feet
PE/EVA	354 ft/min	95 minutes	27,691 feet
OPP[b]	344 ft/min	38 minutes	6,853 feet

[a] Press speed was averaged between the two rolls (337 ft/min and 351 ft/min).
[b] The run was aborted due to sample failure of the adhesiveness test and overheating of the chill roller.

Observations and Comments

LDPE

Some slight plate contamination and minor pinholing were evident in the white. The pinholing and contamination were considered minimal and typical. The press operator made minor impression adjustments to compensate. Although there was still some wrinkling of the substrate noted, trap was not considered to be a factor in overall quality.

PE/EVA

The samples taken at the beginning of the run revealed that the ink lay was good, but the print quality appeared dirty. These problems were also noted on the samples taken at the end of the run. It was also noted that the density of the magenta had increased during the run, and the attempts to reduce it were unsuccessful. Trap and dimensional stability were not considered to be a factor in overall quality.

Samples taken at the beginning of the run failed the adhesiveness test in all colors. Adhesiveness tests were performed on samples taken mid-run, at which time the green and blue both passed, but the other colors failed. By the end of the run, all colors again failed the adhesiveness test except cyan.

OPP

The samples taken at the beginning of the run failed the adhesiveness test. The white appeared to have low opacity, evidence of pinholing, and the print quality appeared dirty. The other colors appeared to have good printability with fair trap. No major problems with dimensional stability or blocking were noted; however, heat from the lamps caused wrinkles to form.

The main (final) UV lamp was overheating the chill roller during the run, and the demonstration team decided that the chill roller was not functioning properly. The temperature of the chill roller was 155°F, and the chill roller was smoking. The decision was made to abort the run, and no samples were taken for measurement or analysis.

Site 7: Solvent-based Ink #S2 on LDPE and PE/EVA

Table 4.56 Facility Background Information for Site 7

Item	Description
Ink type used	100% solvent-based
Control equipment	Two-unit catalytic oxidation
Annual production	10 million pounds of oriented polypropylene flexographic-printed products
Operating hours	24 hours per day, five days per week plus every other weekend
Avg. production run	60 to 60,000 pounds

Table 4.57 Press Information for the Performance Demonstration at Site 7

Item	Description
Press	Kidder
Size of press	45.5 inches wide, six-color
Printing type	Surface
Typical production speed	500 feet/minute
Plates	0.067” Dupont FAH photopolymer: 1) Two process plates (magenta and cyan) mounted using 0.20 compressible stick back 2) Three line plates (green, blue, and white) mounted using 0.20 compressible stick back
Corona treater	None
Ink metering system	Chamber
Type of doctor blade	Unknown
Ink pumping and mixing system	Greymill, electric

Table 4.58 Color Sequence and Anilox Configurations for Site 7[a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1	White	200	8.5
Deck 2 — Not Used	—	—	—
Deck 3	Cyan	700	2.0
Deck 4	Magenta	700	2.0
Deck 5	Green	500	4.0
Deck 6	Blue	500	4.0

[a] Deck 1 (white ink) was not used for the PE/EVA substrate

[b] lines per inch

[c] billion cubic microns per square inch

Table 4.59 Summary Information from the Performance Demonstration at Site 7

Substrate	Press speed	Run time	Run length
LDPE	450 ft/min	148 minutes	42,000 feet
PE/EVA[a]	—	—	8,069 feet

[a] The run was aborted due to problems with the substrate.

Observations and Comments

LDPE

The printing quality of the tones and the lay of the inks were acceptable. The trap was very good, and no blocking occurred. No problems with dimensional stability were noted.

PE/EVA

It was intended that the PE/EVA substrate also be run at this location. The substrate was mounted on the press, and the "makeready check" was begun. After only 8,069 feet of film were consumed, the run was aborted. The demonstration team decided that the roll of substrate they were running was not the correct project control film, due to a supplier mix-up. In addition, the substrate had wrinkles from poor extrusion, the cores were not the correct size, and the cores were crushed.

No samples were taken from the PE/EVA run, and no measurements were made.

Site 8: UV Ink #U3 on LDPE, PE/EVA, and OPP

Table 4.60 Facility Background Information for Site 8

Item	Description
Ink type used	This facility is a press manufacturing facility in Germany; it is not a commercial printing facility. Therefore, no production data are available.
Control equipment	
Annual production	
Operating hours	
Avg. production run	

Table 4.61 Press Information for the Performance Demonstration at Site 8

Item	Description
Press	Windmöller & Hölscher, Soloflex 2
Size of press	25 inches wide, four-color
Printing type	Surface and reverse
Production speed	450 feet/minute
Plates	0.067" Dupont photopolymer: 1) Two process plates (magenta and cyan), mounting unknown 2) Three line plates (green, blue, and white), mounting unknown
Corona treater	Kalwar
Ink metering system	Chambered
Type of doctor blade	Steel
Ink pumping and mixing system	Air-powered

Table 4.62 Color Sequence and Anilox Configurations for Site 8[a]

Sequence	Color	Anilox lpi[b]	Anilox BCM[c]
Deck 1 — PE/EVA	Magenta	724	4.5
Deck 1 — LDPE, OPP	White	200	8.4
Deck 2	Green	724	4.5
Deck 3	Blue	724	4.5
Deck 4	Cyan	724	4.5

[a] Deck 1 changed between PE/EVA and LDPE because this site used only a four-color press.
[b] lines per inch
[c] billion cubic microns per square inch

Table 4.63 Summary Information from the Performance Demonstration at Site 8

Substrate	Press speed	Run time	Run length
LDPE	262 ft/min	65 minutes	16,643 feet
PE/EVA	262 ft/min	63 minutes	15,908 feet
OPP[a]	262 ft/min	15 minutes	4,264 feet

[a] The run was aborted due to sample failure of the adhesiveness test and the discoloration of the OPP to a greenish tint.

Observations and Comments

The performance demonstration at Site 8 was conducted on a press manufacturer's pilot line, which was not a commercial printing press.

LDPE

The samples taken at the end of the run failed the adhesiveness test. The printing appeared dirty in the solid areas of the blue ink, but the other colors had good printability. The trap was good. No problems with dimensional stability were noted, and there was no evidence of blocking.

PE/EVA

Dirty printing was more evident in the blue solid area on the end of run samples, and the green was also starting to appear dirty. The tones were inspected for cleanliness and transfer. Trap and dimensional stability were not considered to be a factor in overall quality.

OPP

At the end of the run, the samples failed the adhesiveness test. The printing appeared dirty in the blue solid area, and was beginning to appear dirty in the green as well. The visual quality of the other colors was good. Trap was acceptable, there was no blocking, and there were no problems with dimensional stability. During this run, the OPP substrate turned a greenish tint. It is believed that the UV lamps caused a photo-reaction in the substrate.

Site 9A: Water-based Ink #W4 on OPP

Table 4.64 Facility Background Information for Site 9A

Item	Description
Ink type used	100% water-based
Control equipment	None
Annual production	300 million linear feet
Operating hours	Two 12-hour shifts per day
Avg. production run	8 to 12 hours

Table 4.65 Press Information for the Performance Demonstration at Site 9A

Item	Description
Press	Kidder Stacey
Size of press	45.5 inches wide, eight-color
Printing type	Reverse
Typical production speed	500 feet/min
Plates	0.067” Dupont PQS photopolymer: 1) Two process plates (magenta and cyan) mounted using 3M 1020, 0.020 compressible stick back 2) Three line plates (green, blue, and white) mounted using 3M 1020, 0.020 compressible stick back
Corona treater	Enercon
Ink metering system	Chamber
Type of doctor blade	White steel
Ink pumping and mixing system	Powerwise, air-powered

Table 4.66 Color Sequence and Anilox Configurations for Site 9A

Sequence	Color	Anilox lpi[a]	Anilox BCM[b]
Deck 1 — Not Used	—	—	—
Deck 2	Blue	400	4.0
Deck 3	Cyan	550	2.7
Deck 4 — Not Used	—	—	—
Deck 5	Magenta	550	2.7
Deck 6	Green	400	4.0
Deck 7 — Not Used	—	—	—
Deck 8	White	300	5.5

[a] lines per inch

Table 4.67 Summary Information from the Performance Demonstration at Site 9A

Substrate	Press speed	Run time	Run length
OPP	425 ft/min	66 minutes	34,434 feet

Observations and Comments

The samples taken at the end of the run revealed good printability, good trap, no problems with dimensional stability, and no blocking. Overall, the makeready and demonstration run were completed with no uncontrollable complications.

Site 9B: Solvent-based Ink #S1 on OPP

Table 4.68 Facility Background Information for Site 9B

Item	Description
Ink type used	100% water-based
Control equipment	None
Annual production	300 million linear feet
Operating hours	Two 12-hour shifts per day
Avg. production run	8 to 12 hours

Table 4.69 Press Information for the Performance Demonstration at Site 9B

Item	Description
Press	Kidder Stacey
Size of press	45.5 inches wide, eight-color
Printing type	Reverse
Typical production speed	500 feet/min
Plates	0.067” Dupont PQS photopolymer: 1) Two process plates (magenta and cyan) mounted using 3M 1020, 0.020 compressible stick back 2) Three line plates (green, blue, and white) mounted using 3M 1020, 0.020 compressible stick back
Corona treater	None
Ink metering system	Chamber
Type of doctor blade	White steel
Ink pumping and mixing system	Powerwise, air-powered

Table 4.70 Color Sequence and Anilox Configurations for Site 9B

Sequence	Color	Anilox lpi[a]	Anilox BCM[b]
Deck 1 — Not Used	—	—	—
Deck 2	Blue	400	4.0
Deck 3	Cyan	550	2.7
Deck 4 — Not Used	—	—	—
Deck 5	Magenta	550	2.7
Deck 6	Green	400	4.0
Deck 7 — Not Used	—	—	
Deck 8	White	300	5.5

[a] lines per inch
[b] billion cubic microns per square inch

Table 4.71 Summary Information from the Performance Demonstration at Site 9B

Substrate	Press speed	Run time	Run length
OPP	415 ft/min	80 minutes	33,641 feet

Observations and Comments

Site 9B is normally a 100% water-based ink facility. Facility staff agreed to do a demonstration run with solvent-based inks on OPP for this project. Overall, the makeready and demonstration run were completed with no uncontrollable complications. The samples taken at the end of the run revealed good printability, good trap, no problems with dimensional stability, and no blocking.

Site 10: Solvent-based Ink #S2 on OPP

Table 4.72 Facility Background Information for Site 10

Item	Description
Ink type used	100% solvent-based
Control equipment	One thermal oxidizer for three presses
Annual production	10.5 million pounds — 95% medium-density polyethylene (MDPE), 5% low-density polyethylene (LDPE)
Operating hours	24 hours per day, 5 days per week, plus 25 Saturdays
Avg. production run	24 hours

Table 4.73 Press Information for the Performance Demonstration at Site 10

Item	Description
Press	Paper Converting Machine Company, model 7067
Size of press	61 inches wide, eight-color
Printing type	Reverse
Typical production speed	750 to 850 feet/minute
Plates	0.107” BASF photopolymer: 1) Two process plates (magenta and cyan) mounted using 3M 1120 compressible stick back 2) Three line plates (green, blue, and white) mounted using 3M 939 hard stick back
Corona treater	None
Ink metering system	Chambered — two-blade
Type of doctor blade	Unknown
Ink pumping and mixing system	Powerwise, Underwriters Laboratory, electric, 5 hp, 3450 rpm, 115 to 230 volts

Table 4.74 Color Sequence and Anilox Configurations for Site 10

Sequence	Color	Anilox lpi[a]	Anilox BCM[b]
Deck 1 — Not Used	—	—	—
Deck 2	Green	250	9.8
Deck 3	Blue	250	10.1
Deck 4	Cyan	800	1.75
Deck 5 — Not Used	—	—	—
Deck 6	Magenta	800	1.6
Deck 7 — Not Used	—	—	—
Deck 8	White	250	9.0

[a] lines per inch

[b] billion cubic microns per square inch

Table 4.75 Summary Information from the Performance Demonstration at Site 10

Substrate	Press speed	Run time	Run length
OPP	600 ft/min	90 minutes	56,700 feet

Observations and Comments

This site normally prints LDPE, but agreed to print the OPP with a reverse ink system. The samples taken at the end of the run showed poor solid formation in the magenta, with all other colors having good printability. The magenta also appeared weak, attributed to high anilox line count and low volume. Trap and dimensional stability were not considered to be factors in overall quality.

Overall, the makeready and demonstration run were completed with no uncontrollable complications. The printing problems encountered were considered normal and the press operators were easily able to adjust the printing environment to obtain the desired quality result.

Site 11: UV Ink #U1 on LDPE (no slip)

Table 4.76 Facility Background Information for Site 11

Item	Description
Ink type used	80 to 85% water-based, 15 to 20% UV
Control equipment	None
Annual production	50 million pounds of polyethylene flexographic-printed products
Operating hours	24 hours per day, five days per week
Avg. production run	Three hours to two weeks

Table 4.77 Press Information for the Performance Demonstration at Site 11

Item	Description
Press	UTECO, Amber 808
Size of press	61 inches wide, ten-color
Printing type	Surface
Production speed	820 feet/minute
Plates	0.107” Dupont EXL photopolymer: 1) Two process plates (magenta and cyan) mounted using compressible stick back 2) Three line plates (green, blue, and white) mounted using hard stick back
Corona treater	None
Ink metering system	Chambered
Type of doctor blade	Unknown
Ink pumping and mixing system	Arrow, air-powered, diaphragm

Table 4.78 Color Sequence and Anilox Configurations for Site 11

Sequence	Color	Anilox lpi[a]	Anilox BCM[b]
Deck 1	White	300	6.0
Deck 2	Magenta	500	2.7
Deck 3 — Not Used	—	—	—
Deck 4 — Not Used	—	—	—
Deck 5	Cyan	500	2.7
Deck 6	Green	360	5.6
Deck 7 — Not Used	—	—	—
Deck 8	Blue	360	5.6
Deck 9 — Not Used	—	—	—
Deck 10 — Not Used	—	—	—

[a] lines per inch
[b] billion cubic microns per square inch

Table 4.79 Summary Information from the Performance Demonstration at Site 11

Substrate	Press speed	Run time	Run length
LDPE[a]	400 ft/min	153 minutes	38,400 feet

[a] The LDPE was extruded with no-slip additives.

Observations and Comments

This site chose to print its normal production LDPE substrate instead of the DfE-control LDPE. This site-standard LDPE substrate was extruded with no slip additives. Overall, the makeready and demonstration run were completed with no uncontrollable complications. The printing problems encountered were considered normal and the press operators were easily able to adjust the printing environment to obtain the desired quality result.

The samples taken at the end of the run continued to show good printability in all colors, with continued blade streaking in the cyan. Dry ink was continually evident on the blue anilox roll. Trap and dimensional stability were not considered to be factors in overall quality.

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Chapter 5: Cost

CHAPTER CONTENTS

CHAPTER OVERVIEW

This chapter presents a comparative cost analysis of solvent-based, water-based, and UV-cured ink systems. The costs evaluated include material, labor, capital, and energy costs. These elements were chosen because of their importance to facility profitability, their potential to highlight differences among ink systems, and the availability of data. Because this analysis averages industry information, it may not reflect the actual experience of any given printing facility.

Printers who are considering switching ink systems also should evaluate other hidden costs such as regulatory compliance, insurance, storage, clean-up, waste disposal, and permitting. Although estimating these cost factors is beyond the scope of this analysis, this chapter provides a qualitative discussion of these costs.

DEVELOPMENT OF COSTS: Section 5.1 discusses the data sources and methodology used to determine the costs of the four expense categories studied: material, labor, capital, and energy. Because each of these costs were derived quite differently, they are discussed separately. In general, data were collected from three types of sources: performance demonstration observations, industry surveys, and estimates by industry contacts. Some of the costs are highly sensitive to press speed; as a result, some of the figures are calculated based on both the press speeds observed during the performance demonstrations and the speed specified in the project's methodology. Uncertainties of the cost analysis are also presented. A detailed methodology of the cost analysis is located in Appendix 5-A.

COST ANALYSIS RESULTS: Section 5.2 summarizes the overall costs based on the expense categories. Costs are presented by ink system and by ink-substrate combination. The analysis shows the relative costs of each ink system, and also indicates the cost drivers within each system. Detailed results of the cost analysis are provided in Appendix 5-B.

DISCUSSION OF ADDITIONAL COSTS: Section 5.3 discusses costs that often are often hidden from typical accounting analyses but that can affect company profits. These include regulatory costs, insurance and storage costs, and costs related to worker health and natural resource use.

HIGHLIGHTS OF RESULTS

- **Material costs (ink and additives) and capital costs were the two most significant expense categories**. Each accounted for approximately 40% of the costs considered in this analysis.
- **Water-based inks had the lowest material costs**. Water-based inks were consumed at a lower rate than solvent-based ink and had a lower per-pound cost than UV-cured inks.
- **Labor costs were lowest for solvent-based inks at the observed press speeds**, primarily because solvent-based inks were printed at the fastest speeds. When labor costs were calculated for the methodology speed, labor costs were equal across the three ink systems.
- **Water-based inks had the lowest per-hour capital costs**, because the presses did not require pollution control equipment or UV curing lamps. However, **solvent-based inks had the lowest per-image capital costs** because of the higher observed press speeds.
- **Water-based inks had the lowest energy costs**. The primary reason for these lower costs is that water-based inks did not require pollution control equipment or UV curing lamps.
- **Overall, water-based inks were the least expensive to use.** Solvent-based inks were the next least expensive, followed by UV-cured inks.

CAVEATS

- Costs were calculated based on both the observed press speeds and the methodology press speed of 500 feet per minute. Press speed is crucial to cost estimates because if more product can be printed in a given time, then fixed costs (e.g., capital and labor) are distributed across more salable product. If customary press speeds at a facility are significantly different from those used for this analysis, actual costs may be different.
- The costs presented in this analysis do not represent all expenses encountered at a flexographic printing facility. One significant factor that was excluded was substrate (the material, such as film, that is printed). Substrates are a major expense, but because their costs are independent of the ink system, they were not included in the analysis. Other costs, such as those discussed qualitatively in Environmental and Regulatory Costs, also are not included in the quantitative results.
- Assumptions in this analysis may not apply to all facilities. For example, it was assumed that pollution control equipment is not necessary with water-based ink systems. In some locations, oxidizers in fact may be required if inks exceed regulatory minimum VOC content thresholds.

5.1 DEVELOPMENT OF COSTS

This section discusses the categories of costs that were analyzed for the different ink systems, formulas that were used in calculations, and assumptions that were made. This information will allow the reader to understand the basis for the results that are described in the next section.

The primary sources of data were the performance demonstrations and estimates provided by flexographic printers and suppliers. The model facility used in the risk assessment section was also used for the cost analysis. Model facility assumptions were based on averages of the information reported in the questionnaire completed by each performance demonstration site. A detailed methodology of the cost analysis is in Appendix 5-A.

Material Costs

The material costs estimated in this analysis are inks and additives. Representative substrate costs are also presented in this section to give a fuller picture of printing costs, but substrate is not included in the rest of the analysis because during production, its costs do not vary among ink systems. The specific prices that any given printer pays for materials are expected to vary with the volume purchased and the relationship between printer and supplier.

Ink Costs

Ink prices vary with the type of ink (solvent-based, water-based, or UV-cured) and color. Generally speaking, white inks are least expensive, primary colors are slightly more expensive, and other colors or custom colors are most expensive.

For this analysis, one price was estimated for white ink and one for the other four colors. These ink prices are listed in Table 5.1. It is important to note that these are average prices, and the price that a printer pays may be either higher or lower than those presented here.

Table 5.1 Average Ink Prices[a]

	Solvent-based ($/lb)	Water-based ($/lb)	UV-cured ($/lb)
White	$1.40	$1.60	$7.25
Other colors	$2.80	$3.00	$10.00

[a] Based on November 1998 prices.
Source: References 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13.

To determine ink consumption costs, the ink prices were multiplied by the amount of ink used for each performance demonstration run. In addition, the test image dimensions and repeat length were used in the calculations. Information about the test image is presented below. The repeat length indicates the distance from the beginning of an image to the beginning of the first repetition of the image.

Test Image Information
Line colors: blue, green, and white
Process colors: cyan and magenta
Image dimensions: 16 inches x 20 inches (320 sq. inches or 2.22 sq. feet)
Repeat length: 16 inches (1.33 feet)

The ink costs per 6,000 images and per 6,000 ft^2 of image were calculated using the following formulas:

$$\text{Ink cost per 6,000 images} = I \times 2.22\ ft^2/\text{image} \times 6{,}000\ \text{images}$$
$$\text{Ink cost per 6,000 } ft^2 \text{ of image} = I \times 6{,}000\ ft^2$$

where

$$\begin{aligned} I &= \text{ink price (\$/lb)} \times \text{amount of ink used (lb)} / \text{amount of substrate used } (ft^2) \\ &= \text{ink cost per } ft^2\ (\$/ft^2) \end{aligned}$$

Tables 5.2 and 5.3 present the average ink costs for each ink-substrate combination per 6,000 images and per 6,000 ft^2 of image, respectively. The site-specific ink costs and a sample calculation are provided in Appendix 5-B. Both ink and ink additives are included in the average costs, and a detailed table providing site-specific consumption data is provided in Appendix 6-A.

Additive Costs

In most of the performance demonstration runs, additives were mixed with the inks to achieve and maintain desired viscosity and performance. Specifically, extenders, solvents, and/or water were added to the solvent-based and water-based inks. Also, ammonia, reducers, cross-linkers, and/or defoamers were added to the water-based inks, and acetate was added to one solvent-based ink (Site 10). No additives were used in the UV-cured ink performance demonstrations, with the exception of a low-viscosity monomer added to the green ink at one site (Site 11).

The methodology for estimating ink additive costs was similar to that for inks. Based on input from printers and suppliers, the DfE team determined average prices for each additive.[1,3,13,14] Extender was \$2.00/lb, solvent was \$1.00/lb, water was given no charge, and other solvent- and water-based ink additives were \$0.45/lb. A price for the UV additive (monomer) was not determined, because ink manufacturers state that extra monomer is not typically added to UV ink at press side.

The additive costs per 6,000 images and per 6,000 ft^2 of image were calculated using the same formulas as for the normalized ink costs.

The estimated average ink additive costs for each ink-substrate combination also are presented in Tables 5.2 and 5.3. The site-specific ink additive costs are provided in Appendix 5-B.

Table 5.2 Average Ink and Additive Consumption and Costs from the Performance Demonstrations (per 6,000 Images)

	White ink			Colored ink			Extender			Solvent			Other Additives			TOTALS	
	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Avg. cost
Solvent-based ink																	
LDPE	7.37	$1.40	$10.31	10.66	$2.80	$29.83				5.61	$1.00	$5.61				23.63	$45.76
PE/EVA[c]				10.66	$2.80	$29.83				3.78	$1.00	$3.78				14.43	$33.61
OPP	7.86	$1.40	$11.00	5.54	$2.80	$15.51	0.16	$2.00	$0.32	4.44	$1.00	$4.44	0.78	$0.45	$0.35	18.78	$31.62
Water-based ink																	
LDPE	6.53	$1.60	$10.44	4.26	$3.00	$12.78	0.16	$2.00	$0.32	0.26	$1.00	$0.26	0.64	$0.45	$0.29	11.84	$24.09
PE/EVA[c]				4.26	$3.00	$12.78				0.07	$1.00	$0.07	0.37	$0.45	$0.45	4.70	$13.01
OPP	6.78	$1.60	$10.85	3.58	$3.00	$10.73	0.19	$2.00	$0.38	0.17	$1.00	$0.17	0.08	$0.45	$0.04	10.80	$22.17
UV-cured ink																	
LDPE	5.19	$7.25	$37.59	2.52	$10.00	$25.20							[e]			7.72	$62.80
PE/EVA[c]				1.89	$10.00	$18.85										1.89	$18.85
OPP	n/a[d]	n/a	n/a	n/a	n/a	n/a										n/a	n/a

[a] Ink prices may vary from the stated average, so pounds of ink are reported here to allow readers to customize the results to apply to their own situation.

[b] Ink prices are for November, 1998.

[c] PE/EVA is a white substrate, so white ink is not used with it.

[d] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

[e] UV ink manufacturers state that extra monomer is typically not added to UV ink; the printer for this demonstration run did add monomer. The cost of this monomer is not known.

Table 5.3 Average Ink and Additive Consumption and Costs from the Performance Demonstrations (per 6,000 ft^2)

	White ink			Colored ink			Extender			Solvent			Other Additives			TOTALS	
	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Price ($/lb)[b]	Avg. cost	Avg. lbs.[a]	Avg. cost
Solvent-based ink																	
LDPE	3.32	$1.40	$4.64	4.80	$2.80	$13.44			$0.00	2.53	$1.00	$2.53				10.65	$20.61
PE/EVA[c]				4.80	$2.80	$13.44			$0.00	1.70	$1.00	$1.70				6.50	$15.14
OPP	3.54	$1.40	$4.95	2.49	$2.80	$6.97	0.08	$2.00	$0.15	2.00	$1.00	$2.00	0.35	$0.45	$0.16	8.45	$14.23
Water-based ink																	
LDPE	2.94	$1.60	$4.70	1.91	$3.00	$5.72	0.07	$2.00	$0.14	0.12	$1.00	$0.12	0.29	$0.45	$0.13	5.32	$10.80
PE/EVA[c]				1.91	$3.00	$5.72				0.03	$1.00	$0.03	0.17	$0.45	$0.07	2.10	$5.82
OPP	3.05	$1.60	$4.89	1.60	$3.00	$4.81	0.09	$2.00	$0.18	0.08	$1.00	$0.08	0.04	$0.45	$0.02	4.86	$9.97
UV-cured ink																	
LDPE	2.33	$7.25	$16.89	1.14	$10.00	$11.35							[e]			3.47	$28.24
PE/EVA[c]				0.85	$10.00	$8.50										0.85	$8.50
OPP	n/a[d]	n/a	n/a	n/a	n/a	n/a										n/a	n/a

[a] Ink prices may vary from the stated average, so pounds of ink are reported here to allow readers to customize the results to apply to their own situation.

[b] Ink prices are for November, 1998.

[c] PE/EVA is a white substrate, so white ink is not used with it.

[d] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

[e] UV ink manufacturers state that extra monomer is typically not added to UV ink; the printer for this demonstration run did add monomer. The cost of this monomer is not known.

Substrate Costs

Substrate costs are a function of the price of the substrate and the amount of substrate used. Based on input from printers and suppliers, an average price was determined for the three types of substrate used in the performance demonstrations — LDPE, PE/EVA, and OPP. Table 5.4 presents the substrate prices, the conversion factors used to convert square feet of substrate to pounds, and the substrate costs. The substrate costs per 6,000 images and per 6,000 ft^2 of image were calculated using the following formulas:

$$\text{Substrate cost per 6,000 images} = S \times 2.22\ ft^2/\text{image} \times 6{,}000\ \text{images}$$
$$\text{Substrate cost per 6,000 } ft^2 \text{ of image} = S \times 6{,}000\ ft^2$$

where

$$S = \text{substrate price (\$/lb)} \times \text{conversion rate } (lb/ft^2)$$
$$= \text{substrate cost per } ft^2\ (\$/ft^2)$$

Table 5.4 Average Substrate Costs and Conversion Rates (ft^2 to lbs)

Substrate	Price ($/lb)	Conversion rate (lb/ft^2)	Substrate cost per ft^2 ($\$/ft^2$)	Average cost per 6,000 images	Average cost per 6,000 ft^2 of image
LDPE	$0.77	0.0134	$0.01	$138	$62
PE/EVA	$0.82	0.0258	$0.02	$282	$127
OPP	$1.50	0.0072	$0.01	$144	$65

Sources: References 2, 3, 5, 7, 9, 10, 11, 12, 13, 15, 16.

Substrate costs are not included in the cost analysis. The price of substrate can be quite variable and therefore would introduce additional uncertainty to the analysis. Also, because substrate consumption does not vary by ink system, it does not need to be included in comparisons between systems. Average substrate costs are supplied above, however, to provide a more complete tally of total costs a printer might encounter.

Labor Costs

For this cost analysis, labor costs are primarily a function of printers' compensation rates and the time it takes to print the product. Labor rates include the wage rate of a press operator and one assistant, the fringe rate, and the overhead rate. This cost analysis assumes that labor rates do not vary with the ink system or the substrate.

Wage Rate

Industry sector-specific wage rates are typically available from the U.S. Department of Labor; however, obtaining an average flexographic industry labor rate was complicated by the fact that the flexographic industry sector is combined with other printing sectors in SIC 2759. To obtain a wage rate indicative of the industry sector, an average hourly wage rate for the industry of $11.49[17] was used as a baseline and confirmed by performance demonstration site contacts in 1997.[2,4,5,7,11,12,15,18]

Fringe Rate

The average press operator or assistant received fringe benefits of holidays, vacations, sick leave, supplemental pay (premium pay for overtime work on weekends and holidays, shift differentials, and non-production bonuses such as lump-sum payments provided in lieu of wage increases), insurance benefits (life, health, sickness, and accident), and legally required benefits (Social Security). In private industry, blue-collar workers had an average fringe rate of 26.5% of total compensation.[19] Total compensation of $15.63 per hour includes a fringe rate of $4.14 per hour.

Overhead Rate

The overhead factor for the flexographic industry was calculated using the following formula:

Overhead factor = (overhead costs) / (direct labor)

Overhead costs = Rent and heat + fire and sprinkler insurance + indirect labor + direct supplies + repair to equipment + general factory + administrative and selling overhead

Using data from the flexographic industry and the above formula, the average industry overhead factor was 0.41, or an overhead rate of $6.41/hour. For a detailed look at how the overhead rate was calculated, see Appendix 5-A.

Based on the wage, fringe, and overhead rates listed in Table 5.5, the overall labor rate for each worker was $22.04 per hour, or $44.08 per hour for both a press operator and assistant.

Table 5.5 Summary of Labor Rate Calculations

Labor cost component	Calculation	Rate ($/hr)
Wage rate	from industry estimates	$11.49
Fringe rate	26.5% of total compensation[a]	$4.14
Overhead rate	0.41 times total compensation[a]	$6.41
Total per-worker labor rate		**$22.04**

[a] Total compensation equals wage plus fringe.

Total Labor Cost

To calculate the total labor cost, the labor rate was multiplied by the average amount of time generally needed to print 6,000 images and 6,000 ft^2 of image (based on press speed). This simplified calculation omits makeready and clean-up costs. The labor cost estimates were calculated using the following formulas:

Labor cost per 6,000 images = $L \times 2.22\ ft^2/image \times 6{,}000$ images

Labor cost per 6,000 ft^2 of image = $L \times 6{,}000\ ft^2$

where

L = labor rate (\$/hour) × repeat length per ft^2 of image (ft/ft^2) / press speed (ft/hour)
= labor cost per ft^2 (\$/ft^2)

Assuming an average press speed for a flexographic press was extremely difficult. Variables such as the test image, the age of the press, the desired quality of the product, and the skill of the press operator affect the press speed considerably. The performance demonstration methodology dictated a press speed of 300 to 500 feet per minute (fpm). Therefore, the site demonstrations were not illustrative of the potential of a press for a specific ink system. Presses may have been held back from or pushed beyond their optimal running speeds. Using the typical production speed of the press reported by the facility was not realistic because of the variety of product quality. For example, one site ran at 700 fpm and produced a low quality product whereas another site ran at 350 fpm and produced a very high quality product. Finally, few data exist that support an industry average press speed for each ink system.

The cost analysis used the average press speed from the performance demonstrations (Table 5.6) for each ink type to determine labor and capital costs. The parenthetical numbers in the first row indicate the number of demonstration runs on which the data are based.

Table 5.6 Average Press Speed Data from the Performance Demonstrations

	Solvent-based	Water-based	UV-cured
Average feet per minute	453 (6)	394 (7)	340 (4)
Average feet per hour	27,200	23,600	20,400

Table 5.7 presents average labor costs for each ink system using the average observed press speed and the methodology press speed (500 feet per minute). When the methodology press speed is used, the labor costs were neutralized for the three ink systems. When the average observed press speeds are used, the labor cost is lowest for solvent-based inks (i.e., these ran at the fastest press speeds during the demonstrations). Compared to solvent-based inks, the labor cost for water-based inks was 15% higher, and the labor rate for UV-curable inks was 33% higher. The site-specific labor costs and a sample calculation are provided in Appendix 5-B.

Table 5.7 Labor Costs Based on Press Speeds

Ink	Labor rate ($/hr)	Press speed (ft^2/hr)	Labor cost per ft^2 ($/$ft^2$)	Average cost per 6,000 images	Average cost per 6,000 ft^2 of image
Based on Observed Performance Demonstration Press Speeds					
Solvent-based	$44.08	45,300	$0.000973	$12.96	$5.84
Water-based	$44.08	39,400	$0.00112	$14.90	$6.71
UV-cured	$44.08	34,000	$0.00130	$17.27	$7.78
Based on Methodology Press Speed – 500 Feet per Minute					
Solvent-based	$44.08	50,000	$0.000882	$11.74	$5.29
Water-based	$44.08	50,000	$0.000882	$11.74	$5.29
UV-cured	$44.08	50,000	$0.000882	$11.74	$5.29

Capital Costs for New Presses

Capital costs are those costs associated with purchasing or modifying the equipment. Two scenarios were examined: buying a new press outfitted for a specific ink technology and retrofitting an existing press from one ink technology to another.

The data used for capital costs were acquired from press manufacturers, suppliers, and flexographic printers. The capital costs were not gathered at the performance demonstration sites due to the variances in the ages of the presses and, therefore, in the representativeness of the costs.

The capital cost of a new press included the cost of a base press plus any modifications required for each ink system. The base press was assumed to be an eight-color, 48-inch press. The cost for a base press also included installation. The cost of a new base press ranged from $600,000 to $5 million, with an average cost of about $2.5 million.[9,10,13,14,16,17,20] The base press cost included the cost of the following:

- chambered doctor blades
- peristaltic ink pumps
- chill rollers
- covered ink/water rollers
- forced hot air dryers (between-color and overhead final)
- electrical drive
- in-feed devices
- ink agitators
- rewind unit
- roll stands/reels
- water union
- web break detectors
- press installation
- one-week training

The exception to the above list is that a UV press will not require hot air dryers; the base price for a UV press therefore would be reduced to reflect the absence of this approximately $100,000 equipment.[21] All other equipment modifications specific to the ink systems were added to the base press cost. These costs included the cost of pollution control devices which might have been required if solvent-based inks were used, the cost of UV lamps, etc. A summary of the capital costs is presented in Table 5.8, followed by a more detailed discussion of each ink system.

Table 5.8 Summary of Capital Costs for New Presses

Ink	Base press cost ($)	Additional Components	Additional cost ($)	Total capital cost ($)
Solvent-based	$2.5 million	pollution control	$128,000	$2.6 million
Water-based	$2.5 million	corona treater	$25,000	$2.5 million
UV-cured	$2.4 million	corona treater, UV lamps, power supplies, and cooling units	$200,000	$2.6 million

Solvent-based Ink Presses

The primary additional equipment expense in running solvent-based ink is an oxidizer needed for pollution control. The analysis assumed that an "average" wide web facility has four 48" presses and two catalytic oxidizers, with an air flow of 5,800 cubic feet per minute (cfm) to each oxidizer. The cost estimates, based on these characteristics, are shown in Table 5.9.

Table 5.9 Catalytic Oxidizer Costs[a]

Component	Cost
Oxidizer	$200,000
Installation	$50,000
Testing	$5,000-$6,000
Total	**$255,000**

[a]These costs represent an oxidizer serving two presses. The per-press costs used in the analysis are half of these amounts.
Source: References 22 and 23.

Because each oxidizer is assumed in this analysis to control the emissions from two presses, this cost is spread over two presses. Therefore, the cost of a pollution control system per press is expected to be $128,000. This cost may vary depending on facility-specific variables, such as the location of the oxidizer, duct runs, location in the country, and whether the duct is insulated.[14]

An alternative type of oxidizer is the regenerative thermal oxidizer (see Chapter 7 for details). The cost of purchasing, installing, and testing this system is similar to that of a catalytic oxidizer. During operation, it may result in lower costs because the catalyst does not need to be replaced. Including the cost of either type of oxidizer, a press using a solvent-based ink system was estimated to cost $2.6 million.

Water-based Ink Presses

A new water-based press will come equipped with all necessary equipment, with the exception of a corona treater. A corona treater costs approximately $25,000,[24] resulting in a total cost estimate of $2.5 million for a press using a water-based ink system.

UV-cured Ink Presses

The primary cost for UV-cured ink presses is the UV curing system. The equipment consists of lamps, power supplies, cooling units, and a corona treater. According to a press manufacturer, this equipment costs approximately $200,000 for a wide web flexographic printing press.[20] This resulted in an estimate of $2.6 million for a press using a UV-cured ink system.

Total Capital Costs for New Presses

To incorporate capital costs into this cost analysis, the capital costs were annualized (and calculated on an hourly basis) per 6,000 images and per 6,000 ft^2 of image. The annual expense can be translated into an hourly expense by dividing by the annual operating hours.

The annual cost was determined by a present-worth-to-annuity calculation, as follows:

$$A = T * \frac{i(1+i)^n}{(1+i)^n - 1}$$

A = annual capital cost
T = total cost (price of press)
i = interest or depreciation rate
n = lifetime of equipment

The average annual industry depreciation rate was 15% per year,[25] and the estimated lifetime of a press not subject to a substantial modification or upgrade is 20 years.[21] The hourly capital cost estimates were based on the following calculation:

Capital cost per 6,000 images = C × 2.22 ft^2/image × 6,000 images
Capital cost per 6,000 ft^2 of image = C × 6,000 ft^2

where

C = capital cost per ft^2 (\$/ft^2)
= hourly capital cost (\$/hr) × repeat length per ft^2 of image (ft/ft^2) / average press speed (ft/hr)

and

Depreciation rate = 15%
Annual operating hours = 4,200 hours per year
Hourly capital cost ($/hr) = A ($/yr) / annual operating hours (hr/yr)
= A ($/yr) / 4,200 hours per year

Table 5.10 presents the hourly capital costs of each ink system.

Table 5.10 Capital Costs for New Presses

	Capital cost ($)	Hourly capital cost ($)	Cost per ft^2 of image	Cost per 6,000 images	Cost per 6,000 ft^2 of image
Based on Observed Performance Demonstration Press Speeds					
Solvent-based	$2.6 million	$98.90	$0.00218	$29.08	$13.10
Water-based	$2.5 million	$95.10	$0.00241	$32.15	$14.18
UV-cured	$2.6 million	$98.90	$0.00291	$38.75	$17.45
Based on Methodology Press Speed – 500 Feet per Minute					
Solvent-based	$2.6 million	$98.90	$0.00198	$26.35	$11.87
Water-based	$2.5 million	$95.10	$0.00190	$25.33	$11.41
UV-cured	$2.6 million	$98.90	$0.00198	$26.35	$11.87

Capital Costs for Retrofitting a Press

Alternatively a printer may retrofit an existing press for a new technology rather than purchase a new press. The feasibility and costs of a retrofit need to be addressed on a case-by-case basis, because retrofitting costs can vary considerably depending on the age and type of press. The newer the press, the fewer and easier the changes. For example, most newer presses come equipped with diaphragm or peristaltic ink pumping systems and chambered doctor blades. This analysis presents *possible* capital costs that may be incurred for a retrofit; if newer equipment such as that mentioned above were present, the retrofit process would be less expensive.

In this analysis, retrofit costs included only the additional costs of equipment. The labor, training, and downtime costs associated with a retrofit were not included because these costs are highly variable and situation-specific. This analysis assumed a retrofit on an older, six-color, 48-inch press. The following cost estimate of the equipment necessary for the change to a new ink system was developed from discussions with printers who have changed ink systems and from discussions with manufacturers and suppliers who are familiar with the changes.

Solvent-based to Water-based Ink System

A retrofit from an older solvent-based ink system to a water-based ink system may require some of the following equipment changes depending on the age of the press:[16]

- reconfiguring anilox rolls
- adding chambered doctor blades
- adding diaphragm or peristaltic ink pumping systems
- adding a corona treater and auxiliary corona treating material
- adding or retrofitting existing blowers to increase the blowing capacity
- changing plate materials and mounting

Estimates to retrofit from a solvent-based to water-based ink system on a 48-inch press are in the range of $60,000 to $100,000.[9] While a solvent-based ink system press can run water-based ink on well-treated film and at much lower speeds without a retrofit, retrofitting improves substrate wettability and/or increases drying capability.[3]

Solvent-based to UV-cured Ink System

A retrofit from a solvent-based to a UV-cured ink system requires similar equipment changes to those required for a retrofit from a solvent-based ink system to a water-based ink system. The changes required for this retrofit may include the following:[16]

- buying and installing UV-cured lamps and the power units to support the lamps
- purchasing and installing chillers to cool the equipment
- reconfiguring anilox rolls
- adding chambered doctor blades
- adding diaphragm or peristaltic ink pumping systems
- adding a corona treater and auxiliary corona treating material
- changing plate materials and mounting

Retrofits from a solvent-based to UV-cured ink system are estimated to be in the range of $400,000 to $500,000.[9] Given this cost, most printers would probably purchase a new press rather than retrofit an existing one. In addition, many older flexographic printing presses cannot be retrofitted for UV production.[9,14] While the major equipment requirements are listed above, additional engineering or "tinkering" may be necessary to obtain the product quality required. Many flexographic printers, manufacturers, and suppliers do not believe this kind of retrofit can produce a saleable product.[1,3,10,13,26]

Water-based to UV-cured Ink System

In retrofitting a press from a water-based to UV-cured ink system, the following equipment changes are necessary:[16]

- adding UV lamps and power units
- removing blowers
- adding chillers
- possibly adding plate materials

On a six-deck press, retrofit costs are expected to be roughly $30,000 per deck, or $180,000.[5] Water-based ink systems cannot always be retrofitted for UV production. Many flexographic printers, manufacturers, and suppliers do not believe this kind of retrofit can produce a saleable product with an older press, although many new presses are being manufactured with retrofits in mind.[1,3,10,13,26]

UV-cured to Water-based Ink System

Although retrofitting from a UV-cured to a water-based ink system is not common, one site using UV decided to return to a water-based system. The equipment changes included removing the UV lamps, power equipment, and chillers, and adding blowers. If the press had originally been a solvent- or water-based press, then the blowers would simply need to be re-installed, at a cost of approximately \$32,000.[5] If the press had been purchased for a UV-cured ink system, it would be necessary to purchase and install a dryer system, which is estimated to cost approximately \$100,000.[21]

Energy Costs

The energy use for four types of flexographic printing equipment—hot air drying systems, catalytic oxidizers, corona treaters, and UV curing systems—was estimated for the three ink systems (see Chapter 6: Energy and Resource Consumption). Energy costs were calculated using the energy consumption rates for this equipment and national averages of electricity and natural gas costs. Given the typical size and total sales of a flexographic printing facility, an average electricity cost of \$0.0448/kWh[27] and an average gas cost of \$3.14/million Btu[28] were used; however, these figures can vary substantially depending on the location and size of the facility.

To calculate energy costs, electricity and natural gas consumption figures were taken from Chapter 6. Energy costs per 6,000 images and 6,000 ft^2 were then calculated with the following equations:

$$\text{Energy cost per 6,000 images} = (E + G) \times 2.22 \text{ ft}^2/\text{image} \times 6{,}000 \text{ images}$$
$$\text{Energy cost per 6,000 ft}^2 \text{ of image} = (E + G) \times 6{,}000 \text{ ft}^2$$

where

$$E = \text{electricity cost (\$/kWh)} \times [\text{electricity consumption (kWh/hour)} / \text{press speed (ft/hour)}] \times \text{repeat length per ft}^2 \text{ of image (ft/ft}^2)$$
$$= \text{electricity cost per ft}^2 \text{ (\$/ft}^2)$$

$$G = \text{natural gas cost (\$/Btu)} \times [\text{natural gas consumption (Btu/hour)} / \text{press speed (ft/hour)}] \times \text{repeat length per ft}^2 \text{ of image (ft/ft}^2)$$
$$= \text{natural gas cost per ft}^2 \text{ (\$/ft}^2)$$

Uncertainties

Efforts were made to obtain data as representative of the industry as possible. However, differences in the ink systems may have had further cost implications that were not captured in the data. Some of the differences may have been difficult to capture in the time span of a two-hour run, may not have been easily quantifiable, or may have been too minute to identify given the methodology and testing. When interpreting the results of this analysis and applying them to a particular operation, the following uncertainties should be considered.

Ink Maintenance

The print run conditions may affect the level of ink maintenance more significantly than was demonstrated at the volunteer sites. UV inks do not dry on anilox rolls or other rolls and hence the color strength remains constant; in addition, during multi-day runs the number of cleanups can be reduced. Using solvent-based inks and water-based inks can increase the amount of labor, run time, clean-up, and waste because of the need to add or remove ink multiple times during a run. These differences, which make UV more competitive, are not reflected in the cost figures due to difficulties in their quantification. Also, industry feedback suggests that UV-cured inks can operate with smaller-volume anilox rolls than were used in the study, the use of smaller-volume rolls would reduce ink consumption for this system relative to the other ink systems.

Productivity

Productivity was another area that was not effectively captured in the performance demonstrations. The performance demonstration methodology specified a printing run at the rate of 300 to 500 fpm. Some sites, however, had to slow down their runs to increase drying times, whereas other sites increased their press speeds for some runs. For example, at Site 10, the press speed was 600 fpm due to the facility's standard operating procedures. The data do not shed light on the controversial issue of whether one ink can be run faster than the others while producing a product quality that is better or comparable to that of the other inks.

Makeready Variables

The experience of the press operators and the type and age of the press have a greater influence on the makeready time than does the type of ink. This is because the main concerns in makeready are registration and the print impression. The amount of substrate used in makeready and the time required for makeready are based on the ability of the press operator to adjust color and viscosity. However, industry experience indicates that proper color strength can be achieved fastest with UV inks.

Clean-up and Waste Disposal Costs

Clean-up and disposal practices were observed qualitatively for the three ink systems at the performance demonstration sites. During the performance demonstrations, the following cleaning agents were used for each ink type:

- Solvent-based ink: alcohol or alcohol/acetate blend
- Water-based ink: water, or water/ammonia/alcohol blend
- UV-cured ink: alcohol, alcohol/acetate blend, or alcohol/water/soap blend

Appendix 6-A presents more detailed information for each site, and Section 6.5, Clean-up and Waste Disposal Procedures, provides more information on these procedures.

Differences in the clean-up components among the three ink systems include the following:

- The materials are least expensive for water-based inks.
- The type of press is a major factor in how long it takes to clean.
- UV presses can be shut down overnight or for extended periods of time without clean-up procedures. If covered, the inks will not cure in the wells, so the press can be started up with minimal ink preparation.

- Solvent-based ink waste is the most expensive to dispose of because it is often characterized as hazardous waste. Water may or may not require the same costs, depending on the solvent content of the ink and location of the facility. UV waste disposal costs may be substantially lower for two reasons: the wastes often are not designated as hazardous under RCRA, and less waste is generated by UV.

Clean-up and waste disposal costs were not included in the quantitative analysis, however, because it was not possible to calculate reliably the costs associated with these procedures.

Site-Specific Limitations

Each printing site was unique, which created some challenges for the performance demonstration. For some of the sites, specific questions or data points were not applicable because of the ink system, the type of site, insufficient data, or the failure of a test run. For these situations, inconsistencies were identified, the data were omitted, or reliable follow-up information was substituted from phone interviews with printers.

Although most of the sites were actual printing facilities, one UV site was a press manufacturer in Germany. The press used at this site was a demonstration version and was not used to print saleable product. As a result, the data from this site did not contain annual or plant-wide costs. Information on clean-up, waste disposal, and ink and substrate costs also was not available. In addition, the makeready at this site was completed before the observation team arrived at the site. Therefore, the makeready data for the time and feet run were not observed by the team.

Another performance demonstration site (Site 11) used a different substrate than specified in the methodology. Demonstrations run at this site used LDPE that was extruded with no slip additives, in accordance with the facility's standard procedure.

5.2 COST ANALYSIS RESULTS

This section presents the results of the cost analysis for each ink-substrate combination. This analysis can help the reader to compare costs among solvent-based, water-based, and UV-cured ink systems. Site-specific cost information is shown in Appendix 5-B.

Summary of Cost Analysis Results

Table 5.11 presents an overall summary of the costs per 6,000 images and per 6,000 ft^2 of image, broken out by substrate and ink type. Table 5.12 provides an average cost breakdown of four major cost elements (materials, excluding substrate; labor; capital for a new press; and energy costs). Table 5.13 presents cost summaries for each performance demonstration site. These costs do not include substrate, makeready or clean-up.

For each substrate, water-based inks were the least expensive. Solvent-based inks were slightly more expensive than water-based inks (1% more for LDPE, 36% more for PE/EVA, and 9% for OPP), and UV-cured inks were the most expensive (29% more than water-based inks on LDPE, 46% more for PE/EVA). When the figures are calculated based on the methodology press speed, water would again be the least expensive. Solvent-based inks would cost 24% more, and UV 38% more than water-based inks. The numbers in parentheses in

Table 5.11 indicates the number of performance demonstration runs on which the data are based.

Table 5.11 Cost Summary for Ink-Substrate Combinations

	Solvent-based		Water-based		UV-cured	
	Cost per 6,000 images	Cost per 6,000 ft^2 of image	Cost per 6,000 images	Cost per 6,000 ft^2 of image	Cost per 6,000 images	Cost per 6,000 ft^2 of image
Based on Observed Performance Demonstration Press Speeds						
LDPE	$92 (2)	$42 (2)	$91 (2)	$41 (2)	$117 (2)	$53 (2)
PE/EVA	$80 (1)	$36 (1)	$59 (2)	$26 (2)	$86 (2)	$39 (2)
OPP	$72 (2)	$32 (2)	$66 (3)	$30 (3)	n/a[a]	
Based on Methodology Press Speed – 500 Feet per Minute						
LDPE	$85	$38	$62	$28	$103	$46
PE/EVA	$72	$33	$52	$24	$57	$26
OPP	$72	$32	$59	$27	n/a[a]	

[a] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

As shown in Table 5.12, material and capital costs (excluding substrate) accounted for the majority of costs. Averaged across the eight ink-substrate combinations, materials (ink and additives) represented 38% of the costs, and capital costs were 41% of the total. Labor accounted for 14% to 24% of the total cost, and energy accounted for 1% to 4%.

Several factors affect press speed, including labor, equipment, and handling. However, because the differing press speeds observed during the performance demonstrations may cause a misrepresentation of the comparative costs associated with the different ink systems, the costs were also calculated based on the methodology speed of 500 fpm. If all three ink systems had been run at the methodology speed, the labor cost differences and some capital cost differences would have been neutralized. Water-based inks would still have been the least expensive. Solvent-based inks would have been more expensive than water-based inks (39% more for LDPE, 38% more for PE/EVA, and 22% for OPP). UV-cured inks would have been the most expensive on LDPE (66% more than water-based inks on LDPE), but would no longer have been the most expensive on PE/EVA (10% more than water-based inks, but 21% less than solvent-based inks).

Table 5.13 presents a cost summary for each performance demonstration site. A detailed breakdown of costs for each site is provided in Appendix 5-B.

Table 5.12 Cost Breakdown for Ink-Substrate Combinations

Substrate	Ink	Component	Average cost per 6,000 images	Average cost per 6,000 ft^2 of image	Percent of total
LDPE	Solvent-based (2 sites)	materials	$46	$21	49%
		labor	$14	$6	15%
		capital	$31	$14	34%
		energy	$1	$1	2%
		total	**$93**	**$42**	**100%**
	Water-based (2 sites)	materials	$24	$11	26%
		labor	$21	$9	23%
		capital	$45	$20	49%
		energy	$1	$1	2%
		total	**$91**	**$41**	**100%**
	UV-cured (2 sites)	materials	$63	$28	53%
		labor	$16	$7	14%
		capital	$36	$16	30%
		energy	$3	$1	3%
		total	**$117**	**$53**	**100%**
PE/EVA	Solvent-based (1 site)	materials	$34	$15	42%
		labor	$14	$6	17%
		capital	$31	$14	39%
		energy	$1	$1	2%
		total	**$81**	**$37**	**100%**
	Water-based (2 sites)	materials	$13	$6	22%
		labor	$14	$6	24%
		capital	$30	$14	52%
		energy	$1	<$1	2%
		total	**$59**	**$26**	**100%**
	UV-cured (2 sites)	materials	$19	$8	22%
		labor	$20	$9	23%
		capital	$44	$20	51%
		energy	$4	$2	4%
		total	**$86**	**$39**	**100%**
OPP	Solvent-based (2 sites)	materials	$32	$14	44%
		labor	$12	$5	17%
		capital	$27	$12	37%
		energy	$1	$1	2%
		total	**$73**	**$33**	**100%**
	Water-based (3 sites)	materials	$22	$10	34%
		labor	$14	$6	21%
		capital	$29	$13	44%
		energy	$1	<$1	1%
		total	**$66**	**$30**	**100%**
	UV-cured	n/a[a]			

[a] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

Table 5.13 Cost Summary for Each Performance Demonstration Site

Substrate	Ink	Product Line	Site	Cost per 6,000 images	Cost per 6,000 ft^2 of image
LDPE	Solvent-based	#S2	5	$102	$46
			7	$82	$37
	Water-based	#W3	2	$73	$33
			3	$109	$49
	UV-cured	#U1	11	$123	$56
		#U2	6	$111	$50
PE/EVA	Solvent-based	#S2	5	$89	$40
			7	$106	$26
	Water-based	#W3	2	$64	$29
			3	$53	$24
	UV-cured	#U2	6	$83	$37
		#U3	8	$89	$40
OPP	Solvent-based	#S1	9B	$76	$36
		#S2	10	$67	$31
	Water-based	#W1	4	$71	$32
		#W2	1	$66	$30
		#W4	9A	$61	$27
	UV-cured	n/a[a]			

[a] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

Discussion of Cost Analysis Results

Material Costs

Material costs comprised ink and additive costs. Table 5.14 presents these costs. Because no white ink was used on PE/EVA (a white substrate), ink costs for PE/EVA were the lowest.

A significant difference among the three ink systems was the cost of ink. For example, for the performance demonstration runs on LDPE, water-based inks cost an average of $19.19 per 6,000 images, whereas solvent-based inks cost an average of $32.16 (68% more than water-based inks) and UV-cured inks cost an average of $40.82 (113% more than water-based inks). The high price per pound of UV inks contributed to their higher cost, in spite of their lower rate of use per unit of substrate.

Differing ink consumption rates also affected costs. Several factors could have affected consumption rates. Solvent-based ink evaporates more readily, thereby requiring the periodic addition of press-side solvent. (An average of 4.61 pounds ($4.61) of press-side solvent were required per 6,000 images during the performance demonstrations). Solvent-based inks also have a lower solids content; therefore, to deliver an equivalent amount of pigment to the substrate, a greater volume of ink is required. The surface tension of solvent-based inks is lower, and therefore more ink is transferred from the anilox roll given similar anilox roll volumes. Finally, the anilox rolls can dictate the amount of ink consumed; rolls with more volume than necessary may lead to artificially high ink consumption rates.

Table 5.14 Summary of Average Material Costs from the Performance Demonstrations

		Average ink costs			Average additive costs			Total	
Substrate	**Ink**	**per 6,000 images**	**per 6,000 ft^2 of image**	**% of total**	**per 6,000 images**	**per 6,000 ft^2 of image**	**% of total**	**per 6,000 images**	**per 6,000 ft^2 of image**
LDPE	Solvent-based	$40.15	$18.08	88%	$5.61	$2.53	12%	$45.76	$20.61
	Water-based	$23.22	$10.41	96%	$0.86	$0.39	4%	$24.09	$10.80
	UV-cured	$62.79	$28.24	100%	a	a	0%	$62.80	$28.24
PE/EVA	Solvent-based	$29.83	$13.44	89%	$3.78	$1.70	1%	$33.61	$15.14
	Water-based	$12.78	$5.72	98%	$0.23	$0.10	2%	$13.01	$5.82
	UV-cured	$18.85	$8.50	100%	$0.00	$0.00	0%	$18.85	$8.50
OPP	Solvent-based	$26.51	$11.92	84%	$5.11	$2.31	2%	$31.62	$14.23
	Water-based	$21.58	$9.70	97%	$0.58	$0.27	3%	$22.16	$9.97
	UV-cured	There were no successful runs of UV-cured ink on OPP in the performance demonstrations.							

[a] UV ink manufacturers state that extra monomer is typically not added to UV ink; the printer for this demonstration run did add monomer. The cost of this monomer is not known.

Labor Costs

The differences in labor costs among the three ink systems were inversely proportional to press speed (i.e., the higher the press speed, the lower the cost). Table 5.15 presents a summary of average labor costs from the performance demonstrations. Site-specific labor costs and press speeds can be found in Appendix 5-B. Because most of the demonstrations were run between 340 and 450 fpm, the labor costs do not vary much among the demonstration sites. The sites that ran at slower press speeds (Site 3 at 218 fpm and Site 8 at 262 fpm) had higher labor costs for their respective ink-substrate combinations (water-based ink on LDPE and UV-cured on PE/EVA). Conversely, solvent-based ink on OPP had the lowest average labor cost, because Site 10 ran at 600 fpm. These data do not reflect qualitative issues, such as the fact that UV typically requires less press-side adjustment and monitoring. These issues may also affect press availability.

Table 5.15 Summary of Average Labor Costs from the Performance Demonstrations

Substrate	Solvent-based		Water-based		UV-cured	
	per 6,000 images	per 6,000 ft^2 of image	per 6,000 images	per 6,000 ft^2 of image	per 6,000 images	per 6,000 ft^2 of image
LDPE	$13.88	$6.25	$20.77	$9.35	$15.89	$7.15
PE/EVA	$13.88	$6.25	$14.13	$6.36	$19.52	$8.78
OPP	$11.98	$5.39	$13.52	$6.08	n/a[a]	

[a] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

Capital Costs

Table 5.16 presents capital costs for each ink system. Capital cost data from the performance demonstrations were not used, due to the variety and ages of the presses. Instead, the capital costs used in this analysis were based on estimates from suppliers and printers, and also based on average press speeds from the performance demonstrations. A sample calculation is provided in Appendix 5-A.

The differences in capital costs were primarily due to the press speeds (i.e., the higher the press speed, the lower the cost). As a result, the solvent-based press was the least expensive ($29.08 per 6,000 images). The water-based and UV presses were 11% and 33% more expensive, respectively, than the solvent-based press. At the methodology speed, capital costs for a water-based press would be the least expensive. A UV press would be approximately 4% more expensive and a solvent press would be approximately 8% more expensive.

While both new press and retrofit scenarios are presented in this chapter, only the new press scenario was used in the aggregate cost analysis. However, capital costs would be reduced if existing equipment were retrofitted. If a water-based ink press were retrofitted from a solvent-based ink press, instead of purchasing a new press, the total cost for using water-based inks (per 6,000 images or per 6,000 sq. feet of image) could be reduced approximately 12%. If a UV press were retrofitted from a solvent-based or water-based press, the total cost for using UV-cured inks could be reduced approximately 10%.

Table 5.16 Estimated Capital Costs for New Presses

Ink	Cost per 6,000 images	Cost per 6,000 ft^2 of image
Based on Observed Performance Demonstration Press Speeds		
Solvent-based (5 sites)	$29.08	$13.10
Water-based (7 sites)	$32.15	$14.48
UV-cured (4 sites)	$38.75	$17.45
Based on Methodology Press Speed – 500 Feet per Minute		
Solvent-based (5 sites)	$26.35	$11.87
Water-based (7 sites)	$25.33	$11.41
UV-cured (4 sites)	$26.35	$11.87

Energy Costs

Table 5.17 presents energy costs for each ink system. Energy data from the performance demonstrations were not used due to the lack of data. The energy costs used in this analysis were based on estimates from suppliers and printers, as well as average press speeds from the performance demonstrations. A sample calculation is provided in Appendix 5-B, and details about energy consumption are included in Chapter 6, Resource and Energy Conservation. Energy costs were a minor factor in overall costs, averaging 4.7% of the total cost across the eight ink-substrate combinations. Water-based inks were the least expensive; energy costs were 24% and 220% higher for solvent and UV, respectively. At the methodology speed, water-based inks again would have the lowest energy costs. Solvent-based inks would be 52% higher, and UV-cured inks would be 190% higher than water-based inks. Energy costs for UV are particularly high both because the curing lamps require substantial levels of energy, and because all energy is required in the form of electricity. For water- and solvent-based inks, the dryers can be fueled by natural gas, which is considerably less expensive on a per energy unit basis.

Table 5.17 Estimated Energy Costs for Each Ink System

		Average electricity costs			Average natural gas costs			Total	
Substrate	Ink	per 6,000 images	per 6,000 ft^2 of image	% of total	per 6,000 images	per 6,000 ft^2 of image	% of total	per 6,000 images	per 6,000 ft^2 of image
Based on Observed Performance Demonstration Press Speeds									
LDPE	Solvent-based	$0.77	$0.35	55%	$0.64	$0.29	45%	$1.41	$0.64
	Water-based	$0.67	$0.30	47%	$0.74	$0.33	53%	$1.40	$0.63
	UV-cured	$3.09	$1.39	100%	$0.00	$0.00	0%	$3.09	$1.39
PE/EVA	Solvent-based	$0.77	$0.35	55%	$0.64	$0.29	45%	$1.41	$0.64
	Water-based	$0.45	$0.20	47%	$0.50	$0.23	53%	$0.95	$0.43
	UV-cured	$3.80	$1.71	100%	$0.00	$0.00	0%	$3.80	$1.71
OPP	Solvent-based	$0.67	$0.30	55%	$0.55	$0.25	45%	$1.22	$0.55
	Water-based	$0.43	$0.19	47%	$0.48	$0.22	53%	$0.91	$0.41
	UV-cured	There were no successful runs of UV-cured ink on OPP in the performance demonstrations.							
Based on Methodology Press Speed – 500 Feet per Minute									
	Solvent-based	$0.66	$0.30	55%	$0.53	$0.24	45%	$1.19	$0.53
	Water-based	$0.38	$0.17	48%	$0.41	$0.18	52%	$0.78	$0.35
	UV-cured	$2.29	$1.03	100%	$0.00	$0.00	0%	$2.29	$1.03

5.3 DISCUSSION OF ADDITIONAL COSTS

This section discusses major categories of financial costs and benefits that are associated with environmental regulations, pollution prevention opportunities, and environmental practices – items that are often not projected or tracked in conventional accounting measures. It is intended to help the reader focus on additional types of costs that could be useful in an environmental analysis of a flexographic printing operation.

Many environmental costs are obvious, such as purchasing an oxidizer to reduce VOC emissions to levels dictated by air regulations. There are also less obvious costs; for example, an inefficient process that creates waste means that a company is paying for excess raw materials.

Regulatory Costs

As indicated in Chapter 2, several regulations may impact costs for flexographic printers. Compliance may require a capital investment in equipment, such as treatment and control systems, monitoring devices, laboratory facilities, safety equipment, or ongoing monitoring of a system. Regulated wastes may require additional expenditures for on-site storage, hauling, and off-site treatment and disposal. New systems may require additional personnel and may increase energy use. Additional personnel may be needed to run the equipment, analyze wastes, label and handle the wastes, and maintain the paperwork for permitting and reporting. Some of the relevant federal laws and requirements are discussed in Chapter 2.

Also, various state and local regulations may increase flexographic printing costs. For example, printing facilities using water-based inks may be required to install an oxidizer in some states, whereas in other states they may not be required to do so. Also, wastes from water-based inks may or may not be regulated as hazardous material, depending on the formulation.

Non-compliance with environmental regulations may lead to additional costs. Companies that are not in compliance may face the following direct and indirect costs.

- fines levied by regulatory agencies
- legal costs
- property damage and remediation costs
- increased workers' health insurance and compensation
- decreased sales due to negative publicity

Insurance and Storage Requirements

Concrete insurance costs could not be quantified in the performance demonstration runs. However, solvent-based inks, in general, require additional insurance due to their explosive potential and additional storage requirements.

Anecdotally, in a project to reduce ink and cleaning waste for flexographic printers, one facility reported savings in insurance premiums from switching to water-based inks and an aqueous cleaner. The project compared the volume and toxicity of air emissions and liquid wastes produced by the printing processes before and after switching to water-based inks and an aqueous cleaner, and then determined the economics of such processing changes. The facility saved about $500 per year due to lowered insurance premiums based on improved working conditions.[29]

Other Environmental Costs and Benefits

Benefits from sound environmental practices can often impact areas other than production and the environment. Sick days taken by employees may be decreased (and morale improved) by reducing or eliminating hazardous compounds in the workplace. The company's relationships with customers, insurers, investors, and the community can be improved by gaining a reputation as a firm that is dedicated to environmental commitment beyond minimal regulatory compliance.

Many environmental costs and benefits are not solely environmental; utility costs may be categorized as overhead or production costs, and greater profits may result from increased efficiency and improved morale. More efficient use of raw materials will also lead to greater profits. An analysis of the environmental costs may yield a more accurate accounting of a company's expenses and reveal opportunities for cost reduction.

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Chapter 6: Resource and Energy Conservation

CHAPTER CONTENTS

CHAPTER OVERVIEW

This chapter discusses resource and energy use in flexographic printing and identifies opportunities for conservation. By minimizing resource and energy use, companies can improve the environment as well as their bottom line. Data presented in this chapter are based on information collected during the on-site performance demonstration runs and information from equipment vendors. Ink and energy consumption data presented in this chapter are used in the cost analysis (Chapter 5) to calculate ink and energy costs. Ink consumption data are also used to estimate environmental releases for the risk characterization (Chapter 3).

INK AND PRESS-SIDE SOLVENT AND ADDITIVE CONSUMPTION: Section 6.1 presents the comparative ink and press-side solvent and additive consumption rates for solvent-based, water-based, and UV-cured ink systems. This analysis is based on the weights of inks, solvents, and additives, and on the substrate usage recorded by an on-site observer from Western Michigan University (WMU) at each demonstration site.

ENERGY CONSUMPTION: Section 6.2 discusses the energy requirements of the drying systems, corona treaters, and pollution control equipment (catalytic oxidizers) typically used with the different ink systems. Electrical power and/or gas consumption data were collected by WMU and supplemented by energy estimates from equipment vendors. Due to the variability among equipment and operating procedures at the different test sites, equipment vendor estimates, rather than site-specific data, are used in the cost analysis to calculate energy costs.

ENVIRONMENTAL IMPACTS OF ENERGY REQUIREMENTS: Section 6.3 presents the environmental impacts of electricity generation and natural gas combustion, using software that quantifies emissions. The results are calculated for each ink system based on the rate of energy consumption at the methodology press speed (500 feet per minute) and the average press speeds observed at the performance demonstrations.

CLEAN-UP AND WASTE DISPOSAL PROCEDURES: Section 6.4 discusses the clean-up procedures used at the performance demonstration sites, as well as some of the broader life-cycle issues associated with energy and natural resource use.

HIGHLIGHTS OF RESULTS

- **UV-cured inks had the lowest ink consumption rates.** In addition, UV inks required almost no press-side additions. Solvent-based inks had the highest consumption rates for ink and materials added at press-side.
- **Water-based inks consumed the least amount of energy** (assuming pollution control equipment is not needed). At a press speed of 500 feet per minute, UV-cured inks were the next lowest consumer, but at the press speeds observed during the performance demonstration, solvent-based inks were the second-lowest energy consumer per unit of image.
- For solvent- and water-based inks, **air recirculation in dryer units can significantly reduce energy requirements** by increasing the temperature of the incoming air.
- **The environmental impacts due to energy production were lowest for water-based inks**. This ink system consumed the least amount of energy, and much of the energy it did use was derived from natural gas. Based on a national average of energy emissions by source, the CTSA found that natural gas released less emissions per unit of energy than electricity. Depending on the geographical location of a flexographic printing facility (and thus the specific electricity source), emissions could be very different.
- Most solvent-based and some water-based ink wastes are classified as hazardous waste. Non-hazardous waste (e.g., waste substrate and some cleaning solutions) can be recycled or reused.

CAVEATS

- Ink consumption was calculated during the performance demonstrations by recording the amount of ink added to the press and subtracting the amount removed during cleanup. Several site-specific factors could have affected the calculated ink consumption figures: type of cleaning equipment, anilox roll size, and the level of surface tension of the substrate.
- The energy consumption section only considers equipment that would differ among the ink systems. Therefore, drying/curing equipment is included, but substrate winding equipment and ink pumps are not.
- Except for corona treaters, information was not available about the difference in energy requirements when equipment is run at different press speeds. UV lamps also will have different energy demands at different energy speeds, but it is assumed in this analysis that their energy consumption is constant. Therefore, the energy consumption of UV lamps may be overestimated at lower press speeds.
- The clean-up and waste disposal procedures section presents the methods observed at the performance demonstration sites. These procedures were developed independently by the individual sites, and do not represent recommended practices by EPA.

6.1 INK AND PRESS-SIDE SOLVENT AND ADDITIVE CONSUMPTION

By reducing resource consumption, businesses can increase process efficiency, decrease operating costs, and decrease demand for natural resources. Ink is one of the main resources consumed by the flexographic printing process. The amount of ink required to print an image not only affects printing costs, but also influences the potential risk to workers and the environment from exposure to ink constituents. This section of the CTSA presents average consumption of inks and press-side additions from the performance demonstrations. The data are in units of pounds of ink consumed per 6,000 images and per 6,000 ft^2 of image, as printers commonly use these terms in estimating and comparing costs.

Methodology

The amounts of ink, press-side materials, and substrate consumed during the performance demonstrations are shown in Appendix 6-A.

The on-site observer weighed the pre-mixed ink components (extender, water, solvent, etc.) that were put in the ink sump at the beginning of makeready and whenever ink components were added to the sump. During clean-up, the observer weighed the ink remaining in the sump, the ink scraped or wiped out of the press, the cleaning solution (water, detergent, or solvent) added to the press, and the ink and cleaning solution removed from the press. The total ink consumed during makeready and the demonstration run for each color was calculated from the following equation.

$$I_{total} = I_{pre} + \sum I_{add\text{-}mk} + \sum I_{add\text{-}pr} - I_r - I_s + C_{in} - C_{out}$$

where

I_{total} = total amount of ink plus press-side solvents and additives consumed (printed or evaporated) during makeready and the demonstration run
I_{pre} = amount of pre-mixed ink put in the ink sump at the beginning of makeready
$\sum I_{add\text{-}mk}$ = the sum of additional ink components put in the ink sump during makeready
$\sum I_{add\text{-}pr}$ = the sum of the ink components added to the system during the press run
I_r = amount of ink remaining in the sump at the end of the run
I_s = amount of ink scraped or wiped out of the press at the end of the run
C_{in} = amount of cleaning solution added to the press during clean-up
C_{out} = amount of cleaning solution and ink mixture removed from the press during clean-up

Ink Consumption

Ink consumption was calculated for each demonstration site using the following information:

- total amount of ink consumed during makeready and the press run (I_{total})
- amount of substrate printed (S)
- total area of the image (16 by 20 inches with a 16-inch repeat)

Substrate consumption was recorded from the press meter at the beginning of makeready, at the end of makeready, and at the end of the press run for each substrate. The consumption numbers are listed in Appendix 6-A.

Sample calculations for white, water-based ink at Site 1 follow, to help readers understand the methodology and to allow reproducibility of results. The complete data are provided in Appendix 6-A.

Total white ink consumed (I_{total}) = 56.4 pounds (lbs)
Total substrate consumed including makeready (S) = 62,892 linear feet (ft)
Total area of image = 2.22 square feet (ft^2)
Repeat length of image = 1.33 ft

Number of images (N) = S / 1.33 feet per image
= 62,892 feet / 1.33 feet per image
= 47,200 images

Ink per 6,000 images = $(I_{total}/N) \times 6{,}000$ images
= (56.4 lbs/47,200 images) × 6,000 images
= 7.17 lbs per 6,000 images

Ink per 6,000 ft^2 of image = $(I_{total}/N) \times 6{,}000\ ft^2$ of image / Area of image
= (56.4 lbs/47,200 images) × 6,000 ft^2 / 2.22 ft^2 per image
= 3.23 lbs per 6,000 ft^2 of image

White ink was not printed on the PE/EVA substrate. Thus, PE/EVA substrate is excluded from ink consumption calculations for white ink.

Table 6.1 presents the percent area of coverage for each ink. White dominates the ink coverage of the image (60.8%), blue and green (line colors) account for 24.1% coverage, and cyan and magenta (process colors) account for 5.2% coverage.

Table 6.1 Image Area by Color

Color	Area (in^2)	Area (ft^2)	Percent coverage (%)[a]
Blue	43.5	0.30	13.6
Green	33.5	0.23	10.5
White	194.7	1.35	60.8
Cyan	8.2	0.06	2.6
Magenta	8.2	0.06	2.6

[a] The total percent coverage does not equal 100% because of overlapping colors and unprinted area.

Facilities running more than one substrate did not clean the press between substrates. Thus, only total weights, not the weight of ink applied to each substrate, are available. For the purposes of this analysis, it is assumed that the weight of ink consumed per unit area is not a function of the film type.

Press-side Solvent and Additive Consumption

During the course of a print run, printers may add solvent or water to correct the viscosity of the ink, or other components, such as extenders or cross-linkers, to improve the performance of the ink. Solvent and additive weights were calculated assuming the weight of each component consumed is directly proportional to the component weight added to the system.

The solvent and additive consumption rates were then calculated in a manner similar to the ink consumption rates.

The method for calculating ink weights assumes equal volatilization rates for each component. It does not account for solvent emissions from the ink sump or ink pan. Because solvents are expected to volatilize at a more rapid rate than other components, this method slightly underestimates solvent consumption rates and slightly overestimates rates for the other components. Sample calculations for solvent and additive weights using solvent-based, blue ink data from Site 5 follow, with numbers taken from Table 6-A.12 in Appendix 6-A:

Weight of blue ink added to system (I_{added}) = 20.90 lbs
Weight of solvent added to the blue ink (S_{added}) = 4.81 lbs
Total ink used (I_T) = 18.16 lbs

Total components added (T) = $I_{added} + S_{added}$
= 20.90 lbs + 4.81 lbs
= 25.71 lbs

Ratio of I_{added} to T (R_I) = 20.90 lbs / 25.71 lbs
= 0.81
Ratio of S_{added} to T (R_S) = 4.81 lbs / 25.71 lbs
= 0.19

Weight of ink consumed = $I_T \times R_I$
= 18.16 lbs × 0.81
= 14.8 lbs

Weight of solvent consumed = $I_T \times R_S$
= 18.16 lbs × 0.19
= 3.4 lbs

Limitations and Uncertainties

The limitations of and uncertainties in the data are related to the limited number of demonstration sites, variability among the equipment and operating procedures at the test sites, and uncertainties in the measured ink component weights. Each of these are discussed below.

Limitations Due to the Number of Demonstration Sites
Ink consumption data were collected during twelve performance demonstrations at ten flexographic printing facilities across the United States and one press manufacturer's pilot line in Germany. As such, the data represent a "snapshot" of how the inks performed at the time of the performance demonstrations (November 1996 — March 1997) under actual operating conditions at a limited number of facilities. Because no two printing plants are identical, the sample may not be representative of all flexographic printing plants (although there is no specific reason to believe they are not representative).

Variability among Equipment and Operating Procedures
Several operating parameters were specified in the performance demonstration methodology (see Appendix 6-B) in an attempt to ensure consistent conditions across demonstration sites.

These included target specifications for anilox rolls (screen count and anilox volume) which directly affect the amount of ink applied to print an image.

The specified target ranges for the anilox rolls were not always met. Because of the production needs of the volunteer facilities, changing anilox rolls or acquiring new anilox rolls to meet the specified targets was impractical. Table 6.2 lists the target anilox specifications and the average configurations by ink type for the anilox rolls actually used at the demonstration sites. The Site Profiles section of the Performance chapter (Chapter 4) lists the particular anilox configurations used at each of the test sites. Facilities using anilox volumes and screen counts greater than the specifications would be expected to consume more ink to print the test image. Similarly, facilities using anilox volumes and screen counts less than the specifications would be expected to consume less ink to print the test image. Also, these specifications do not address the fact that the anilox roll volume would differ depending on the color printed; for example, the volumes for light colors would be larger than those for dark colors.

Table 6.2 Average Anilox Configurations and Target Anilox Specifications

Ink	Screen count (lpi)[a]			Volume (BCM)[b]		
	Line (color)	Line (white)	Process	Line (color)	Line (white)	Process
Target Specifications	440	150	600 to 700	4 to 6	6 to 8	1.5
Solvent-based	350	260	650	5.5	6.8	2.1
Water-based	290	300	580	6.3	5.9	3.0
UV-cured	480	250	610	4.9	7.3	3.3

[a] lines per inch
[b] billion cubic microns per square inch

Uncertainties in Ink Component Weights

As discussed previously, the on-site observer collected information on the amounts of ink, solvents, additives, and cleaning solution added to or removed from the system during makeready, the press run, and clean-up. In some cases, however, site operating procedures, such as the type of cleaning system being used, prevented measurement of some of these parameters. In these cases, the weights were estimated based on other site data.

Ink and Press-side Solvent and Additive Consumption Estimates

Tables 6.3 and 6.4 present the average ink and and press-side solvent and additive consumption rates for the performance demonstration sites by ink type, substrate, and color. Site-specific consumption rates can be found in Tables 6-A.3 and 6-A.4 in Appendix 6-A.

In general, the UV-cured ink formulations used substantially less ink than the solvent-based or water-based formulations. On LDPE, the UV-cured ink systems used 57% less ink than the solvent-based ink systems and 28% less than the water-based ink systems. On PE/EVA, the UV-cured ink systems used 82% less ink than the solvent-based ink systems and 56% less than the water-based ink systems. These results are consistent with the general expectation that less UV-cured ink is needed because nearly all of the ingredients are incorporated into the dried coating, unlike with solvent- and water-based inks.

Components added to the water-based ink formulations included water, extender, solvent, ammonia, cross-linker, slow reducer, and defoamer. Components added to the solvent-based formulations were primarily solvents, but one company also added extender to the ink, whereas another added acetate. Water-based ink solvents and additives tended to comprise a smaller percentage of the overall total weight than did solvent-based ink solvents and additives. In the solvent-based systems, these additions accounted for about 25% of total consumption. No additives were used at the UV-cured ink demonstration sites, except for a low-viscosity monomer added to the green ink at Site 11.

Table 6.3 Average Ink and Press-side Solvent and Additive Consumption Rates for Performance Demonstrations (Pounds per 6,000 Images)

	Ink					Solvents and Additives			Sub-total: Ink	Sub-total: Solvents and Additives	Total
	Blue	Green	White[a]	Cyan	Magenta	Extender	Solvent	Additives			
Solvent-based ink											
LDPE	2.34	2.63	7.36	2.91	2.77	0.00	5.61	0.00	18.01	5.61	23.62
PE/EVA	2.34	2.63	0.00	2.91	2.77	0.00	3.78	0.00	10.65	3.78	14.43
OPP	1.36	1.55	7.86	1.37	1.25	0.16	4.44	0.78	13.39	5.38	18.77
Water-based ink											
LDPE	1.30	1.45	6.53	0.75	0.75	0.16	0.26	0.64	10.78	1.06	11.84
PE/EVA	1.30	1.45	0.00	0.75	0.75	0.00	0.06	0.37	4.25	0.43	4.68
OPP	1.30	1.09	6.79	0.59	0.60	0.19	0.17	0.08	10.37	0.44	10.81
UV-cured ink											
LDPE	0.94	0.73	5.18	0.37	0.48	0.00	0.00	0.01	7.71	0.01	7.72
PE/EVA	0.68	0.44	0.00	0.34	0.43	0.00	0.00	0.00	1.89	0.00	1.89
OPP	n/a[b]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[a] White ink was not printed on PE/EVA.

[b] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

Table 6.4 Average Ink and Press-side Solvent and Additive Consumption Rates for Performance Demonstrations (Pounds per 6,000 Square Feet of Image)

	Ink					Solvents and Additives			Sub-total: Ink	Sub-total: Solvents and Additives	Total
	Blue	Green	White[a]	Cyan	Magenta	Extender	Solvent	Additives			
Solvent-based ink											
LDPE	1.05	1.18	3.31	1.31	1.27	0.00	2.52	0.00	8.12	2.52	10.64
PE/EVA	1.05	1.18	0.00	1.31	1.27	0.00	1.70	0.00	4.81	1.70	6.51
OPP	0.61	0.70	3.54	0.62	0.56	0.08	2.00	0.35	6.03	2.43	8.46
Water-based ink											
LDPE	0.58	0.65	2.94	0.34	0.34	0.07	0.12	0.28	4.85	0.47	5.32
PE/EVA	0.58	0.65	0.00	0.34	0.34	0.00	0.03	0.18	1.91	0.21	2.12
OPP	0.58	0.49	3.05	0.40	0.27	0.09	0.08	0.04	4.79	0.21	5.00
UV-cured ink											
LDPE	0.42	0.33	2.33	0.16	0.22	0.00	0.00	<0.01	3.46	0.00	3.46
PE/EVA	0.31	0.20	0.00	0.15	0.20	0.00	0.00	0.00	0.86	0.00	0.86
OPP	n/a[b]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[a] White ink was not printed on PE/EVA.

[b] n/a = not applicable; there were no successful runs of UV-cured ink on OPP in the performance demonstrations.

6.2 ENERGY CONSUMPTION

Energy conservation is an important goal for flexographic printers who strive to cut costs and seek to improve environmental performance. This section of the CTSA discusses the electricity and natural gas consumption rates of the flexographic printing equipment listed in Table 6.5, including background information and assumptions. Energy consumption rates are used in the cost analysis (Chapter 5) to calculate energy costs. They are also used in Section 6.3 to evaluate the life-cycle environmental impacts of energy consumption.

Table 6.5 Equipment Evaluated in the Energy Analysis

Equipment	Function	Ink system		
		Solvent-based	Water-based	UV-cured
Hot air drying system	Dries the ink between stations and in the overhead tunnel (main) dryer.	✓	✓	
Catalytic oxidizer[a]	Converts VOCs to carbon dioxide and water.	✓		
Corona treater	Increases the surface tension of the substrate to improve ink adhesion.		✓	✓
UV curing system	Cures UV-cured ink applied to substrate.			✓

[a] In some states, oxidizers may be required for water-based inks with high VOC content.

Energy estimates were to be prepared from the individual site data for each of the performance demonstration sites, similar to the site-specific ink consumption estimates presented in Section 6.1. However, limited or no energy data were available for one or more pieces of equipment at several of the sites, particularly for catalytic oxidizers used at solvent-based sites. In addition, press size, age, and condition of presses varied significantly across sites, as did equipment operating conditions, such as dryer temperature. For these reasons, equipment vendor estimates, rather than site-specific data, are used in the cost analysis to calculate energy costs.

Methodology

This section presents the methodology used to estimate energy requirements and provides background information and key assumptions on the types of equipment evaluated: hot air drying systems, catalytic oxidizers, corona treaters, and UV curing systems.

Energy Consumption

Equipment vendors estimated equipment energy requirements in kilowatts (kW) for electrical power and British thermal units (Btu) per hour for natural gas. This information was then converted into energy consumption rates for each ink type in Btus per 6,000 images and per 6,000 ft^2 of printed substrate. Table 6.6 lists the press, substrate, and image characteristics used in the energy estimates. These characteristics are consistent with assumptions used in the cost analysis and with the substrates and image printed during the on-site performance demonstrations. Where applicable, two sets of estimates were made: one using the project methodology press speed of 500 feet per minute (fpm) for all three ink types, and one using the average press speed achieved for each ink type at the performance demonstration facilities. Additional assumptions for each type of equipment and energy rate calculations are listed in the sections below.

Table 6.6 Press, Substrate, and Image Information for Estimating Energy Use

Parameter	Description	Comments
Press	48-inch, 6-color, CI press; new, average quality	Press costs are presented in Chapter 5.
Press speed	Solvent-based ink: 500 fpm and 453 fpm Water-based ink: 500 fpm and 394 fpm UV-cured ink: 500 fpm and 340 fpm	Two scenarios for each ink system are used in the corona treatment energy estimates.
Substrates	LDPE, PE/EVA, OPP	
Web width	20 inches	A second case assuming a 40-inch web was used in oxidizer and corona treater energy estimates.
Image size	16 in x 20 in (2.22 ft^2)	

Sample calculations based on the average press speed at water-based sites follow. Estimates were provided by equipment vendors.

Drying oven natural gas consumption = 500,000 Btu/hour
Blower electricity = 30 kW
Corona treater electricity = 1.6 kW
Total electricity = 31.6 kW
Average press speed (P) = 394 feet per minute
Image size = 2.22 ft^2
Image repeat (R) = 1.33 feet

Images printed per minute = P/R
= 394 feet per minute / 1.33 feet per image
= 296 images/minute
= 17,800 images/hour
Time to print 6,000 images = 6,000 images / 17,800 images/hour
= 0.34 hours
Natural gas per 6,000 images = 500,000 Btu/hour × 0.34 hours
= 170,000 Btu
Electricity per 6,000 images = 31.6 kW × 0.34 hours
= 11 kW-hr

Images per 6,000 ft^2 = 6,000 ft^2 / 2.22 ft^2 per image
= 2,700 images
Time to print 6,000 ft^2 = 2,700 images / 17,800 images/hour

= 0.15 hours
Natural gas per 6,000 ft^2 = 500,000 Btu/hour × 0.15 hours
= 76,000 Btu
Electricity per 6,000 ft^2 = 31.6 kW × 0.15 hours
= 4.7 kW-hr

Hot Air Drying Systems

Most solvent-based and water-based presses are equipped with between-color (interstation) dryers (BCDs) and an overhead (main) dryer. Supply and exhaust blowers are used to provide air flow through the dryers and maintain negative pressure within the dryer. The supply blowers draw air into the drying system to be heated by the burners. Most printers draw the dryer make-up air from the ambient environment outside the plant.[1] Exhaust blowers are used to draw the heated air though the dryers to the exhaust outlet.

The BCDs are positioned after each print station. They dry each color as it is applied to the web to prevent pick-up or tracking when the next color is applied. The overhead dryer consists of a tunnel located above the print stations, through which the web passes to further dry the ink before the web is rewound.

The energy consumed by hot air drying systems includes electrical power for the supply and exhaust blowers and natural gas for the drying oven. Typically, the gas energy required to heat the process air is greater than the energy needed to dry the ink.[2]

Kidder, Inc., a press manufacturer, provided energy estimates for hot air drying systems based on the press, substrate, and image details listed in Table 6.6, the average ink consumption rates listed in Table 6.3, and the hot air drying system assumptions listed in Table 6.7. Dryer energy estimates for both solvent- and water-based inks are based on the same air flow rates but different dryer temperatures. New presses are now designed to work with either water-based or solvent-based inks. Usually, a press operator will reduce the amount of heat instead of the air flow when using solvent-based inks.[3] Air flow rates are given in units of cubic feet per minute (cfm).

Table 6.7 Hot Air Drying System Assumptions

Parameter	Assumption	Comments
BCD air flow rate	2800 cfm	Four dryer boxes at 700 cfm/box, based on average BCD flow rate of 15 cfm/inch of width/dryer box[a]
Main dryer air flow rate	3000 cfm	Typical value for 48-inch press[a]
Dryer temperature (solvent-based Inks)	150°F	Typical temperature for Project substrates[a]
Dryer temperature (water-based inks)	200°F	Typical temperature for Project substrates[a]
Make-up (outdoor) air temperature	0°F, 50°F, 70°F	Three scenarios
Percent recirculation of dryer air	0%, 50%	Two scenarios

cfm = cubic feet per minute.

[a] Reference 4.

The assumed dryer temperature for water-based inks is higher than the maximum temperature to which some film substrates can be subjected without potentially damaging the film. However, in practice, the film temperature would be less than the dryer temperature due to impression cylinder cooling and evaporative cooling.[5]

The hot air drying system energy estimates were prepared for six different operating scenarios, assuming three different outside air temperatures for the make-up air and two dryer air recirculation scenarios (no recirculation and 50% recirculation). All six scenarios were analyzed to illustrate the influence make-up air temperature and air recirculation on dryer costs. The different air temperatures represent the range of air temperatures that might be encountered in different seasons. If make-up air is taken from the outdoor environment (as is typically done), dryer costs will be significantly higher in winter than in summer. The 50°F temperature was used in the cost analysis to represent an annual average. Most new presses are designed to recirculate dryer air, either to save on dryer air heating costs or to reduce the air flow to the pollution control device.[6] However, many older presses do not have dryer air recirculation, and retrofitting may be ineffective with smaller, low air flow presses. A recirculation rate of 50% was used in the cost analysis since this is more representative of a new press, the subject of the cost analysis.

Catalytic Oxidizers

A catalytic oxidizer is a type of add-on emissions control equipment used to convert VOC emissions to carbon dioxide and water by high temperature oxidation. Catalytic incinerators employ a catalyst bed to facilitate the overall combustion reaction by increasing the reaction rate. This enables conversion at lower reaction temperatures than in thermal oxidizers. Oxidizers are used primarily with solvent-based inks, but may be required with water-based inks in some states.

A basic catalytic oxidizer assembly consists of a heat exchanger, a burner, and a catalyst. First, the dryer exhaust stream is preheated by heat exchange with the oxidizer effluent and, where necessary, further heated to the desired catalyst inlet temperature by a natural gas-fired burner. The heated stream then passes through the catalyst where VOCs are converted to carbon dioxide and water. The combustion reaction between oxygen and gaseous pollutants in the waste stream occurs at the catalyst surface. The oxidizer effluent is then recirculated back to the heat exchanger and may also be recirculated to the dryer to save drying fuel.

Two oxidizer suppliers, Anguil Environmental Systems, Inc. and MEGTEC Systems [formerly Wolverine (Massachusetts) Corporation], provided energy estimates based on the press, substrate, and image details listed in Table 6.6 and the additional oxidizer assumptions presented in Table 6.8.[7] As with the other equipment, the oxidizer energy estimates represent energy requirements for a particular set of circumstances (e.g., solvent loading, dryer exhaust temperature, flow rate), and they are not necessarily representative of other operating conditions.

Table 6.8 Catalytic Oxidizer Assumptions

Parameter	Assumption	Comments
Number of presses vented to oxidizer	Two	
Solvent content	13,000 Btu/lb	Average of typical values provided by two oxidizer suppliers
Heat exchanger efficiency	70%	Typical efficiency value based on vendor input. Equipment vendors also provided oxidizer energy estimates for 65%, 75%, and 80% efficiencies.
Air flow to oxidizer	5800 cfm	Combined air flow after recirculation for two 48-inch presses; same as air flow used in dryer energy estimates
Dryer exhaust temperature	150°F	Dryer temperature assumed for drying oven energy calculations
Catalyst inlet temperature	600°F	Depending on solvent type, catalyst inlet temperatures can vary from 475°F to 650°F [8,9,10,11,a]
Solvent loading (two cases)	70 lb/hr 140 lb/hr	Solvent loading for two presses; solvent loading at performance demonstration sites averaged 35 lb/hr for one press. Solvent loading assuming each 48-inch press is running two 20-inch images, side by side (i.e., solvent loading for a 40-inch web width).

The catalytic oxidizer energy estimates were prepared assuming two different solvent loadings (70 and 140 lb/hr). The solvent loadings were based on two web widths (20-inch and 40-inch). A solvent loading of 70 lb/hr was used in the cost analysis.

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[a] Technology developments are allowing for decreased catalyst inlet temperatures. A published estimate notes that a typical catalyst inlet temperature is 550-700°F. Another industry estimate notes that with solvent loading, the typical temperature can rise to 650°F. However, some new oxidizers are capable of operating at 500°F.

Two scenarios for solvent loading are provided because it would be very unusual for a facility with a 48-inch press to run a 20-inch image, which reduces solvent loading to the oxidizer. Oxidizer energy costs decrease with increased solvent loading until the oxidation reaction becomes self-sustaining (e.g., requires no make-up fuel). Using a 20-inch image on a 48-inch press and the associated lower solvent loading would tend to overestimate energy costs. Solvent loading of 140 lb/hr portrays a more realistic situation, in which two 20-inch images are run side by side on a 48-inch press.

A heat exchanger efficiency of 70%, a typical efficiency, was used in the cost analysis. The other values (65%, 75%, and 80%) were submitted by oxidizer vendors to illustrate the effect of heat exchanger efficiency on oxidizer energy costs.

Corona Treaters

Corona treatment is a process that increases the surface energy of a substrate to improve ink adhesion. It can be performed three ways: by the substrate supplier, when the substrate is on the printing press, or both by the substrate supplier and on press. On-press corona treatment systems may be used with all three ink types, but are mainly used with water-based and UV-cured inks, which typically have lower surface energy than solvent inks. None of the performance demonstration sites running solvent-based inks used corona treatment on the press.

A corona treatment assembly consists of a power supply and treater station. The power supply accepts standard utility electrical power and converts it into a single-phase, higher-frequency power that is supplied to the treater station. The treater station applies the higher frequency power to the surface of the material via a pair of electrodes.[12]

The energy consumed by a corona treatment system can depend on a number of factors, including web width, production speed, type of substrate (e.g., material, slip additives), and watt density (watts per unit area per unit time) required to treat the substrate. Table 6.6 presents press, substrate, and image details. Enercon Industries Corporation, a corona treater supplier, provided corona treatment energy estimates, including the power supply size and input power. Input power represents the actual power drawn from the utility grid. Watt density was not specified, so the equipment suppliers determined the appropriate watt density.

UV Curing Systems

UV presses employ UV lamps, which emit UV radiation to polymerize or cross-link the UV-cured ink monomers. In addition to the lamps, a UV curing system has supplemental cooling capacity to counter the infrared heat produced by the UV lamps. The curing system may also include a blower to extract ozone generated during the UV curing process, and an anilox heater to pre-heat the ink. Only one of the three UV performance demonstration sites had a separate ozone blower and anilox heater.

Energy estimates for UV curing systems were developed based on operating data collected during the performance demonstrations; supplemental information from Windmöller & Hölscher, an equipment supplier; and information from another equipment supplier, Fischer & Krecke, Inc. Table 6.9 presents the UV curing system assumptions. Lamp output is assumed to be constant at both press speeds evaluated (i.e., at 500 fpm and 340 fpm). However, in most UV systems lamp power increases with press speed up to some maximum power output level, depending on the press. For example, lamp output provided by one press manufacturer ranged from 48 watts per centimeter of press width (W/cm) at a press speed of 100 fpm to 160 W/cm at 820 fpm.[13] In another example, manufacturer data for lamp output at a performance demonstration site ranged from 80 w/cm at standby to 200 w/cm at 200 fpm. No data were available to accurately account for the differences in lamp output at the two project press speeds. Lamp energy in watts was calculated by multiplying the lamp output in watts per inch by the press width (48 inches) and by the total number of lamps (six).

Table 6.9 UV Curing System Assumptions

Parameter	Assumption	Comments
Lamp output	175 watts per cm of press width	Average value based on site and vendor data
Number of lamps	Six	Four lamps between colors and two main lamps
Lamp cooling	60 kW	Average value based on site data and vendor data

Limitations and Uncertainties

The limitations of and uncertainties in the energy analysis stem from the lack of energy data at many of the demonstration sites, the limitations in the number of operating scenarios evaluated, limitations in the data for different press speeds, and uncertainties inherent in using estimated data rather than measured data. Each of these limitations is discussed below.

Lack of Energy Data at Performance Demonstration Sites

The performance demonstration methodology called for energy data collection at the 11 performance demonstration sites in order to develop a "snapshot" of energy requirements under actual operating conditions at a limited number of facilities. As discussed previously, little or no energy data were available for one or more pieces of equipment at several of the sites, particularly for catalytic oxidizers used at solvent-based sites. In addition, press size, age, and condition varied significantly across sites, as did equipment operating conditions, such as dryer temperature. For these reasons, equipment vendor estimates, rather than site-specific data, are the focus of the energy analysis. As a result, the data are estimated based on hypothetical operating conditions and do not necessarily represent energy demand experienced at the performance demonstration sites.

Limitations in the Number of Operating Scenarios

The operating conditions and assumptions used in the energy analysis were developed based on the test image, substrates, and operating conditions at the performance demonstration sites, as well as using typical operating conditions provided by equipment vendors. As such, the energy estimates represent a "snapshot" of equipment energy requirements under a particular set of conditions. They are not necessarily indicative of the range of energy requirements that might be experienced for different images, substrates and operating conditions, nor are they intended to represent this range.

Limitations in the Data for Different Press Speeds

The energy consumed by printing equipment is often a direct or indirect function of press speed. For example, the power outputs of UV lamps and corona treaters usually vary directly with the press speed. The amount of make-up fuel required for a catalytic oxidizer depends on the solvent loading, which varies with the ink, image, and press speed, among other factors. However, except for corona treaters, no quantitative data were available to determine the differences in equipment energy draw at the different project press speeds (e.g., the average press speeds observed at performance demonstration sites and the methodology press speed of 500 fpm). This can result in either an overestimation of energy requirements at the lower press speeds or an underestimation of energy requirements at the higher press speeds.

Uncertainties in Estimated Data

Equipment energy requirements were estimated by equipment vendors for use in the cost analysis. Attempts were made to get estimates from at least two vendors for each type of equipment, but in some cases only one estimate was available. Vendor energy estimates were compared to each other, to performance demonstration data, and to other data sources as available, to check for reasonableness and completeness. Either averages or the most complete and representative data are presented in the results below and used in the cost analysis.

Energy Consumption Estimates

Table 6.10 presents the equipment vendor energy estimates used to develop energy consumption rates. Table 6.11 presents gas and electrical energy consumption rates in Btus. Results from the latter table were used in the cost analysis (Chapter 5). The energy consumption results for each type of equipment across the three ink systems are discussed in more detail in the following sections. For the estimated energy costs for each ink system and substrate combination, see Table 5.17 in the Cost chapter.

Under the particular operating parameters and assumptions used in this analysis, the water-based system consumed the least energy at both press speeds. UV energy consumption rates were most influenced by the press speed, due to the lower average press speed achieved at UV performance demonstration sites. However, as noted previously, no data were available to account for the lower lamp energy draw that can occur at lower press speeds. Solvent-based systems have lower drying energy requirements than water-based, but have higher overall energy requirements when the oxidizer energy requirements are taken into account. These results would be reversed (e.g., water-based inks would require more energy than solvent-based inks) if the solvent-loading to the oxidizer was sufficient to make the oxidizer self-sustaining and/or recirculation of dryer air was not taken into account for water-based systems.

The results of the energy analysis in Table 6.11 can be compared to a similar analysis of energy consumption undertaken by a press manufacturer that supplies both hot air and UV cured systems.[14] That study evaluated the relative energy consumption of a 55-inch press running the different ink systems. Table 6.12 shows the results of that analysis, which suggest that solvent-based and water-based systems have roughly the same energy requirements if pollution control equipment is required for both ink types, while UV-cured inks have slightly greater energy requirements.

Table 6.10 Equipment Vendor Energy Estimates Used to Develop Consumption Rates

Ink	Equipment	Natural gas (Btu/hr)	Electricity (kW)	Comments
Solvent-based	Drying oven	360,000	n/a[a]	Based on an outdoor air temperature of 50°F and 50% recirculation of dryer air
	Dryer blowers	n/a	30	Average of values recommended in dryer energy audits from some performance demonstration sites and by equipment vendor
	Oxidizer	290,000	n/a	Average of values from two equipment vendors; based on 70 lb/hr solvent loading
	Oxidizer blower	n/a	25	Average of values from two equipment vendors
Water-based	Drying oven	500,000	n/a	Based on an outdoor air temperature of 50°F and 50% recirculation of dryer air
	Dryer blowers	n/a	30	Average of values recommended by two performance demonstration sites and by equipment vendor
	Corona treater	n/a	2.1, 1.6	Based on worst case substrate (PE/EVA) running at 500 and 394 fpm, respectively
UV-cured	UV lamps	n/a	130	See Table 6.9 for basis
	Lamp cooling	n/a	60	See Table 6.9 for basis
	Corona treater	n/a	2.1, 1.6	Based on worst case substrate (PE/EVA) running at 500 and 394 fpm, respectively

[a] n/a: not applicable

Table 6.11 Average Energy Consumption Rates for Each Ink System

Ink	Press speed (fpm)	Energy per 6,000 images (Btu)[a]	Energy per 6,000 ft^2 of image (Btu)[a]
Solvent-based	500	220,000	100,000
	453[b]	240,000	110,000
Water-based	500	160,000	73,000
	394[b]	220,000	96,000
UV-cured	500	174,000	78,000
	340[b]	260,000	120,000

[a] Electrical energy was converted to Btus using the factor of 3,413 Btu per kW-hr.

[b] Average press speed for the performance demonstration sites.

Table 6.12 Energy Consumption per Job by Ink Type[a]

Equipment	Energy consumption by ink type (Btu/hr)		
	Solvent-based	Water-based	UV-cured
Dryer[b]	≈310,000	≈310,000	n/a[c]
Pollution control[b]	≈200,000	(200,000)[d]	n/a
Corona treatment	n/a	17,000	≈17,000
UV lamps	n/a	n/a	≈550,000
Temperature conditioning	n/a	n/a	≈85,000
Driving motors/pumps	≈200,000	≈200,000	≈200,000
Total	≈710,000	530,000-730,000	≈850,000

[a] Source: Reference 15. Source did not specify the type or length of job evaluated.

[b] Heater plus blower

[c] n/a: not applicable

[d] Pollution control may or may not be required with water-based inks.

Hot Air Drying Systems

As discussed previously, six scenarios were evaluated for the natural gas requirements of a hot air drying system, based on three different ambient air temperatures and the presence or absence of dryer air recirculation. Table 6.13 presents the results of these analyses. The energy requirements for hot air drying systems were calculated using a proprietary formula that considers make-up air temperature, dryer temperature, and air flow.[16] As shown in the table, recirculation can greatly reduce energy load. There are many factors involved, but in this scenario dryer energy with recirculation can be calculated assuming a relationship of 40% fuel savings for 60% recirculation.[17] Whenever recirculating air is used with solvent-based inks, however, it is imperative that the lower explosive limit (LEL) be monitored and controlled to safe limits.[18]

Table 6.13 Natural Gas Energy Estimates for Hot Air Drying Systems

Ambient air temperature (°F)	Percent air recirculation (%)	Natural gas energy (Btu/hr)	
		Solvent-based	Water-based
0	0	720,000	890,000
0	50	480,000	600,000
50	0	530,000	740,000
50	50	360,000	500,000
70	0	440,000	670,000
70	50	290,000	450,000

Source: Reference 19.

Dryer gas energy data collected during the performance demonstrations were largely incomplete. Data that were collected varied widely due to differences in press sizes and operating conditions. For example, gas energy data were only available from four of eight sites (one of which ran both solvent- and water-based ink systems) and ranged from gas burner capacity data to energy estimates from dryer energy audits. The average gas consumption rates reported by solvent-based and water-based sites were 2.4 million Btus/hr and 1.5 million Btus/hr, respectively. These values are significantly higher than the values estimated in Tables 6.10 and 6.13. Differences may be attributed in part to the larger press sizes at these sites (average 54 inches), press age, dryer temperatures and flow rates, and the amount of dryer air recirculation.

Catalytic Oxidizers

Oxidizer vendors were asked to estimate oxidizer energy requirements for two scenarios using the assumptions in Table 6.8: The first scenario is two 48-inch presses running the performance demonstration image vented to the same oxidizer (70 lb/hr solvent loading). The second scenario is two presses fully loaded with two performance demonstration images (140 lb/hr solvent loading). The first scenario is consistent with assumptions used in the cost analysis (Chapter 5) and was used to generate the energy consumption rates in Tables 6.10 and 6.11. The second scenario illustrates the effect of solvent loading on energy requirements. In general, as solvent loading increases, natural gas energy decreases until the solvent loading is sufficient to make the reaction self-sustaining.

In addition to the two scenarios described above, the oxidizer vendors prepared energy estimates based on heat exchanger efficiencies of 65%, 70%, 75%, and 80%. Table 6.14 presents the catalytic oxidizer energy estimates for the various solvent loadings and heat exchanger efficiencies and the specific assumptions in Table 6.8. Other operating parameters that can significantly affect the overall energy requirements of an oxidizer include the solvent heat content, the air flow to the oxidizer, and the inlet air temperature.

Table 6.14 Catalytic Oxidizer Energy Estimates[a]

Solvent loading	Equipment	Energy estimates by heat exchanger efficiency				
		65%[b]	70%[b]	70%[c]	75%[c]	80%[c]
70 lb/hr	Burner (Btu/hr)	560,000	260,000	320,000	130,000	70,000
	Damper/blower (kW)[d]	17[e]	17[e]	32[f]	32[f]	32[f]
140 lb/hr	Burner (Btu/hr)	16,000	16,000	70,000	n/a[g]	n/a
	Damper/blower (kW)[d]	17[e]	17[e]	32[f]	n/a	n/a

[a] Energy estimates are based on the assumptions in Table 6.8 plus additional assumptions made by equipment vendors. Values do not necessarily represent the relative energy efficiency of the vendor's equipment.

[b] Source: Reference 20.

[c] Source: Reference 21.

[d] One kW-hr = 3,413 Btu

[e] Based on 22 hp blower

[f] Based on 40 hp motor with volume blower

[g] n/a: not applicable, unit is at minimum Btu/hr usage with another heat exchanger.

Corona Treaters

Corona treatment energy requirements were estimated for two press speeds (500 fpm and the performance demonstration site averages) and two web widths (20 inch and 40 inch). One corona treater supplier provided power supply and input power estimates for the worst case substrate (2.5 mil PE/EVA, high slip) only, while the other provided watt density and power supply data for all of the substrates, but did not provide input power estimates. Because the remainder of the energy analysis is based on input power rather than power supply, estimates provided by the first supplier were used to generate the results in Tables 6.10 and 6.11. Table 6.15 lists corona treater energy estimates for a 500 fpm press speed. Table 6.16 lists corona treater energy estimates for the average press speed at the performance demonstration sites.

Table 6.15 Corona Treater Energy Estimates (Press Speed of 500 Feet per Minute)

Ink	Substrate	Watt density (watts/m^2/min)		Power supply (kW)				Input power (kW)	
		20" web[a]	40" web[a]	20" web[a]	40" web[a]	20" web[b]	40" web[b]	20" web[b]	40" web[b]
Water-based	LDPE	3,100	6,200	3.0	7.5	ND[c]	ND	ND	ND
	PE/EVA	3,100	6,200	3.0	7.5	2.0	3.5	2.1	3.6
	OPP	3,100	6,200	3.0	7.5	ND	ND	ND	ND
UV-cured	LDPE	3,100	6,200	3.0	7.5	ND	ND	ND	ND
	LDPE (no slip)	2,300	4,600	3.0	5.0	ND	ND	ND	ND
	PE/EVA	3,100	6,200	3.0	7.5	2.0	3.5	2.1	3.6
	OPP	3,100	6,200	3.0	7.5	ND	ND	ND	ND

[a] Source: Reference 22.
[b] Source: Reference 23.
[c] ND = no data

Table 6.16 Corona Treater Energy Estimates (Average Press Speeds at the Performance Demonstration Sites)

Ink	Substrate	Watt density (watts/m^2/min)		Power supply (kW)				Input power (kW)	
		20" web[a]	40" web[a]	20" web[a]	40" web[a]	20" web[b]	40" web[b]	20" web[b]	40" web[b]
Water-based	LDPE	2,400	4,700	3.0	5.0	ND[c]	ND	ND	ND
	PE/EVA	2,400	4,700	3.0	5.0	1.5	3.0	1.6	3.1
	OPP	2,400	4,700	3.0	5.0	ND	ND	ND	ND
UV-cured	LDPE	2,100	4,200	3.0	5.0	ND	ND	ND	ND
	LDPE (no slip)	1,600	3,100	1.5	3.0	ND	ND	ND	ND
	PE/EVA	2,100	4,200	3.0	5.0	1.5	2.5	1.6	2.6
	OPP	2,100	4,200	3.0	5.0	ND	ND	ND	ND

[a] Source: Reference 24.
[b] Source: Reference 25.
[c] ND = no data

Table 6.17 presents power output data (e.g., power applied to the web) read by WMU representatives from the corona treater power supply box during the performance demonstration runs. In some cases, WMU representatives also measured power input in volts and amps during the print run. However, these data are not reported because corona treater suppliers have indicated they cannot be used to calculate power input in kilowatts without knowing site-specific power efficiency factors.[26]

Table 6.17 Corona Treater Power Output at Performance Demonstration Sites

Ink	Substrate	Site	Power output (kW)	
			Makeready	Print run
Water-based	OPP	1	6.4	ND[a]
	LDPE, PE/EVA	2	1.9	ND
	LDPE, PE/EVA	3	4.0	4.0
	OPP	4	3.0	3.0
	OPP	9A	ND	ND
UV-cured	OPP, LDPE, PE/EVA	6	11.0	ND
	OPP, LDPE, PE/EVA	8	2.2	ND
	LDPE (no slip)	11	n/a[b]	n/a

[a] ND: no data
[b] n/a: not applicable; Site 11 did not have a corona treater.

UV Curing Systems
Lamp energy estimates for either press speed were obtained at 160 watts/cm of press width, 174 watts/cm, and 185 watts/cm. Larger differences were seen in the supplemental lamp cooling estimates, which ranged from 25 kW to 90 kW. The smaller value is for a water-cooled system; reportedly, most UV lamp systems are air-cooled.[27]

6.3 ENVIRONMENTAL IMPACTS OF ENERGY REQUIREMENTS

The energy requirements of the solvent-based, water-based and UV ink systems presented in Section 6.3 result in energy costs to printers (see Chapter 5, Cost). Environmental releases from energy production also result in indirect costs to society. Examples of the types of air emissions released during energy production include carbon dioxide (CO_2), sulfur oxides (SO_x), carbon monoxide (CO), sulfuric acid (H_2SO_4), and particulate matter. The potential environmental and human health impacts of these releases include health effects to humans and wildlife, global warming, acid rain, and photochemical smog. For more information on the potential impacts of printing on society, see Chapter 8, Choosing Among Ink Technologies.

This section quantifies the types and amounts of emissions released into the environment from energy production and discusses the potential environmental impacts of the releases. For electrical energy, emissions are typically released at electrical power plants outside the printing facility. Releases from natural gas combustion may occur at the print shop where the combustion process occurs.

Emissions from Energy Production

Energy-related emissions — both at and away from the facility — can be a significant part of the total life-cycle environmental impact of printing. Emissions are released from natural gas-burning dryers and oxidizers as well as from the electricity generation process at offsite power plants. The level of emissions can vary considerably among printing technologies, depending on the fuel type and process efficiency.

The emissions from energy production during the performance demonstrations were evaluated using a computer program developed by the EPA National Risk Management Research Laboratory.[28] This program, which is called *P2P-version 1.50214,* can estimate the type and quantity of releases resulting from the production of energy, as long as the differences in energy consumption and the source of the energy used (e.g., hydro-electric, coal, natural gas, etc.) are known. The program compares the pollution generated by different processes (e.g., extraction and processing of coal or natural gas for fuel).

Electrical power derived from the average national power grid was selected as the source of electrical energy, and natural gas was used as the source of thermal energy for this evaluation. Energy consumption rates per 6,000 ft^2 from Table 6.11 were used as the basis for the analysis. It should be noted that the location of the environmental impacts will vary by energy type; natural gas releases will occur onsite, while electricity-related releases will occur at offsite power plants.

Results of this analysis are presented in Table 6.18. Appendix 6-C contains printouts from the P2P program. Water-based systems generally had the lowest levels of emissions from energy production at either press speed, followed by solvent-based systems. The releases associated with the production of energy for the UV ink system exceeded those from water-based or solvent-based systems for every pollutant category except hydrocarbons. Hydrocarbon emissions were greater for the water-based and solvent-based systems, because of the natural gas consumed by the hot-air dryers used with these systems. Greater emissions from energy production were seen at lower press speeds for all of the systems, due to the longer run times needed to print a given quantity of substrate. However, as noted in Section 6.2, data were not available for all equipment to estimate the differences in energy draw at different press speeds. Emissions from energy production would be reduced if equipment powers down at decreased press speeds.

Table 6.18 Releases Due to Energy Production[a]

Ink System	Press Speed (fpm)	Amount Released (g/6,000 ft^2)								
		Carbon Dioxide (CO_2)	Carbon Monoxide (CO)	Dissolved Solids	Hydrocarbons	Nitrogen Oxides (NO_x)	Particulates	Solid Wastes	Sulfur Oxides (SO_x)	Sulfuric Acid (H_2SO_4)
Solvent-based	500	9,400	8.7	1.3	55	26	8.0	570	44	3.4
	453	10,000	9.6	1.4	60	29	8.8	630	48	3.8
Water-based	500	6,400	5.5	0.81	41	16	4.8	340	26	2.0
	394	8,000	6.8	1.0	52	20	5.9	410	33	2.5
UV-cured	500	16,000	23	3.0	20	70	27	2,000	140	12
	340	24,000	33	4.5	29	100	40	2,900	210	17

[a] Releases for solvent- and water-based ink systems are expected to occur both at the printing facility and at the off-site electricity generation plant; releases from the UV-cured ink system are expected to occur exclusively at the electricity generation plant.

The higher overall emissions for UV systems were due primarily to the differences in fuel mixes used by the three systems (both electrical and natural gas energy for water-based and solvent-based systems, as compared to electrical energy alone for UV). The U.S. electric grid is mainly comprised of coal, nuclear, hydroelectric, gas and petroleum-fired power plants. In 1997 the majority of U.S. electrical energy (57%) was produced from coal-fired generators,[29] which tend to release greater quantities of emissions than gas-fired energy systems. For example, at a 500 fpm press speed, the UV system consumed an estimated 23 kW-hr /6,000ft^2 of electricity, which is equivalent to 78,000 Btu/6,000ft^2. At the same press speed, the solvent-based system consumed an estimated 6.6 kW-hr/6,000ft^2 of electricity plus 78,000 Btu/6,000ft^2 of natural gas, for a total of 100,000 Btu/6,000ft^2 . However, although the UV system consumed less overall energy than the solvent-based system, it still had higher emissions from energy production for the pollutants evaluated, except hydrocarbons.

Environmental Impacts of Energy Production

Table 6.19 lists the pollution categories, pollutant classes, and media of release assigned by the P2P software. Table 6.20 lists total pollution generated by pollutant category and class, and Table 6.21 provides totals for each pollution category.

Based on the release rates shown in Tables 6.21 and 6.22, the water-based systems showed the lowest potential environmental impacts from energy production, including human health, use impairment, or disposal capacity impacts, followed by solvent-based systems. The UV systems had the greatest potential environmental impacts from energy production in each of the pollution categories and classes.

Limitations and Uncertainties

These release rates can only be used as *indicators* of relative potential impacts, not as an assessment of risk. Assessing risk from energy production also would require knowledge of the location and concentration of release, and proximity to surrounding populations. It would also require more information on the specific chemicals emitted, for example the exact identity of the hydrocarbons emitted during natural gas combustion as compared to the hydrocarbons emitted during coal combustion.

The potential environmental impacts of energy requirements for the three ink systems are based on the energy estimates described in Section 6.2 and are subject to the same limitations and uncertainties.

Table 6.19 Pollution Categories, Classes and Media of Release

Pollution Category	Pollutant Class	Chemicals	Affected Resource
Human Health Impacts	Toxic Inorganics[a]	Nitrogen oxides, sulfur oxides	Air
	Toxic Organics[a]	Carbon monoxide	Air
Use Impairment Impacts	Acid Rain Precursors	Nitrogen oxides, sulfur oxides	Air
	Corrosives	Nitrogen oxides, sulfur oxides	Air
		Sulfuric acid	Water
	Dissolved Solids[b]	Dissolved solids, sulfuric acid	Water
	Global Warmers	Carbon dioxide, nitrogen oxides	Air
	Odorants	Hydrocarbons	Air
	Particulates[c]	Particulates	Air
	Smog formers	Carbon monoxide, hydrocarbons, nitrogen oxides	Air
Disposal Capacity Impacts	Solid Wastes	Solid Wastes	Soil, groundwater

[a] Dissolved solids are a measure of water purity and can negatively affect aquatic life as well as the future use of the water.

[b] Toxic organic and inorganic pollutants can cause adverse health effects in humans and wildlife.

[c] Particulate releases can promote respiratory illness in humans.

The program uses data reflecting the national average pollution releases per kilowatt-hour derived from particular sources. It does not account for differences in emission rates at different power plants, nor does it necessarily account for the latest in pollution control technologies applied to power plant emissions.

The P2P program primarily accounts for emissions of pollutant categories and not emissions of the individual chemicals or materials known to occur from energy production, such as mercury. Nor does it provide information on the spatial or temporal characteristics of releases. Thus, the P2P software provides emissions estimates in grams per functional unit (grams per 6,000ft^2 of printed surface, in this case) and assigns them to pollution (impact) categories and classes to develop release rates by impact category. As discussed previously, these release rates can be used as an *indicator* of relative potential environmental impacts, but are not an assessment of risk.

Table 6.20 Emissions Generated by Pollutant Category and Class

Pollution Category	Pollutant Class	Emissions Generated by Pollutant Category and Class[a] (g/per 6,000ft^2)					
		Solvent (500 fpm)	Solvent (453 fpm)	Water (500 fpm)	Water (394 fpm)	UV (500 fpm)	UV (340 fpm)
Human Health Impacts	Toxic Inorganics	70	77	43	53	210	310
	Toxic Organics	8.7	9.6	5.5	6.8	23	33
Use Impairment Impacts	Acid Rain Precursors	70	77	43	53	210	310
	Corrosives	73	81	45	56	220	330
	Dissolved Solids	4.7	5.2	2.8	3.5	15	22
	Global Warmers	9,400	10,000	6,400	8,000	16,000	24,000
	Odorants	55	60	41	52	20	29
	Particulates	8.0	8.8	4.8	5.9	27	40
	Smog formers	90	99	63	79	110	170
Disposal Capacity Impacts	Solid Wastes	570	630	340	410	2,000	2,900

[a] All numbers have been rounded to two significant figures.

Table 6.21 Summary of Pollution Generated by Category

Pollution Category	Pollution Generated [a] (g/per 6,000ft^2)					
	Solvent (500 fpm)	Solvent (453 fpm)	Water (500 fpm)	Water (394 fpm)	UV (500 fpm)	UV (340 fpm)
Human Health Impacts	79	87	48	60	230	350
Use Impairment Impacts	9,500	10,000	6,500	8,100	16,000	24,000
Disposal Capacity Impacts	570	630	340	410	2,000	2,900
Overall Environment	10,000	11,000	6,800	8,500	18,000	27,000

[a] All numbers have been rounded to two significant figures.

6.4 CLEAN-UP AND WASTE DISPOSAL PROCEDURES

This section of Chapter 6 discusses the types of cleaning solutions and clean-up methods used for the three different flexographic ink technologies studied in the CTSA performance demonstrations, and describes the disposal procedures for the various types of wastes generated in each case.

All flexographic printing operations result in waste ink and substrate, soiled shop towels, and cleaning solutions that need to be disposed. However, the volume of waste ink and the specific chemical makeup of wastes differ, depending on the type of ink system that a printer uses. Therefore, the clean-up methods, waste disposal procedures, and overall environmental impacts of a printing process also differ for each ink system.

Most printers employ the same basic procedures to clean solvent-based or water-based ink from a press. Excess ink may be wiped or scraped down and drained from the press. The system is then flushed with a cleaning solution to remove additional ink and prepare the press for a fresh run. Shop towels, usually wetted with a cleaner, are used to wipe down the anilox rolls, doctor blades, or other press parts. UV ink cleaning procedures are similar, except that different cleaners or dry shop towels may be used to wipe down the press.

Most solvent-based ink wastes are classified as hazardous waste and are disposed of accordingly. Water-based ink wastes, however, may or may not be classified as hazardous waste. Although solvent-based waste disposal costs may be reduced because it can be burned and used for heat production, this is not always possible with water-based wastes. Regulations prohibit hazardous waste from being mixed with fuel and burned if it has an energy value of less than 5,000 Btu/lb.[30] Therefore, some printers using low-solvent water-based inks use an "ink splitter" to separate the solids from fluids in their waste ink and cleaning solutions. This substantially reduces the amount of hazardous waste that needs to be disposed. The waste water usually can be reused in-house or discharged to the public water system, but if the original waste qualified as hazardous, the solids also will need to be treated as hazardous waste. (See the Control Options section of Chapter 7 for more information on ink splitters.)

Multi-day runs of UV-cured printing may generate less ink waste than solvent-based or water-based printing for printers who shut down overnight, such as some smaller printers. In this case, the ink can remain indefinitely on the press or in the reservoirs without curing on press parts or the sump.[31] The press is shut down, the ink reservoirs should be covered to prevent dust from getting in, and the press is turned on to resume printing the next day. Also, because correct color adjustment is achieved more quickly at the beginning of a UV run using process colors on dedicated stations, under these conditions UV may generate somewhat less waste of ink and substrate. However, because UV inks are too thick to be modified easily, correct color adjustment may not be achieved more quickly when using matched/Pantone colors that require toning.[32]

Press Clean-Up and Waste Reduction in the CTSA Performance Demonstrations

Table 6.22 summarizes the types of cleaning solutions used at the performance demonstration sites. For solvent-based systems, three sites utilized a blend of alcohol and acetate solutions, and one site reported using alcohol alone. The cleaning solutions used for UV-systems were the same as those for solvent-based systems, except for one site that used an alcohol/water/soap blend. Water, at times mixed with a little alcohol and/or ammonia, was used for clean-up of the water-based ink systems.

Table 6.22 Cleaning Solutions Used at Performance Demonstration Sites

Ink System	Cleaning Solution
Solvent-based	Alcohol/acetate blend (3 sites) Alcohol (1 site)
Water-based	Water only (2 sites) Water/alcohol blend (1 site) Water/ammonia blend (1 site) Water/ammonia/alcohol blend (1 site)
UV-cured	Alcohol (1 site) Alcohol/acetate blend (1 site) Alcohol/water/soap blend (1 site)

The clean-up and waste disposal procedures employed at the performance demonstration sites are summarized in Table 6.23. Appendix 6-B describes these procedures in more detail. All but one site employed reusable shop towels to clean the press. All sites recycled some or all of their waste substrate.

Table 6.23 Clean-up and Waste Disposal Procedures at Performance Demonstration Sites

Ink System	Shop Towels	Ink and Cleaning Solution Disposition	Waste Substrate Disposition
Solvent-based	Sent to industrial laundry (3 sites) Landfilled (1 site)	Solvent mix to cement kiln (1 site) On-site distillation; still bottoms to cement kiln (1 site) Reused 3 times then disposed as hazardous waste (1 site) No data (1 site)	Partially or all recycled (4 sites)
Water-based	Sent to industrial laundry (5 sites)	Mixture incinerated (2 sites) Separated water and solids; incinerated solids (2 sites) Diluted mixture and discharged to POTW (1 site)	Partially or all recycled (5 sites)
UV-cured	Sent to industrial laundry (2 sites) No data (1 site)	Reused once before sending to cement kiln (1 site) On-site distillation; still bottoms disposed (1 site) No data (1 site)	Partially or all recycled (3 sites)

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Chapter 7: Additional Improvement Opportunities

CHAPTER CONTENTS

CHAPTER OVERVIEW

This chapter discusses some techniques beyond alternative ink systems and printing processes that flexographic printers can use to prevent pollution, reduce chemical consumption, and minimize waste. This chapter includes sections on pollution prevention, recycling and resource recovery, and control options.

Pollution prevention, also known as source reduction, involves reducing or eliminating environmental discharges at their source (that is, before they are generated). Pollution prevention requires taking active steps to implement changes in workplace practices, technology, and materials, such as the type of ink used. By reducing the amount of waste produced in the first place, disposal and compliance issues are minimized. Each step in the printing process offers opportunities for pollution prevention. Flexographic printers may be able to receive several benefits from following pollution prevention practices, including cost savings, improved productivity, better product quality, reduced health risks to workers, reduced pressures of regulatory compliance, and of course reduced environmental impacts. Pollution prevention is discussed in Section 7.1.

Recycling, which is also sometimes called resource recovery, is the focus of Section 7.2. Although recycling is not pollution prevention, since it does not reduce the amount of pollution being generated, it too has benefits for flexographers, including reductions in the need for new materials and for solid waste disposal. Thus, recycling can help printers reduce the costs of doing business. Silver, solvents, and many solid wastes can all be recycled.

In addition, several pollution control options are possible for both liquid and gaseous forms of flexographic ink chemicals. Section 7.3 discusses several common control options. These technologies can be very successful in reducing waste and emissions in the flexographic industry. Control options that are discussed in Section 7.3 include oxidizers, adsorption systems, permanent total enclosures (capture devices that work with control options but do not destroy harmful emissions by themselves), and ink splitters. Control options, however, often require a major capital investment, and must receive regular maintenance to function efficiently. Also, even control options that destroy virtually all harmful emissions have no effect on the types and amounts of chemicals being purchased and used by flexographic printers. That is, they do not prevent pollution from being generated.

7.1 POLLUTION PREVENTION OPPORTUNITIES

Pollution prevention, also known as source reduction, reduces or eliminates environmental discharges at their source — that is, by avoiding their creation. Pollution prevention can be achieved by changing workplace practices, substituting safer alternatives for harmful chemicals, and modifying equipment to reduce waste. In addition to reduced environmental impacts, pollution prevention may yield the following benefits:

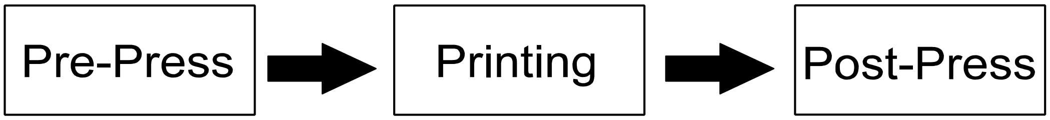
- cost savings
- improved productivity and product quality
- minimized risks to worker health
- reduced pressures of regulatory compliance

A strategy to prevent pollution should be customized to fit each printer's objectives and production process. The first step is to construct a process flow diagram that identifies each stage of the production process. The next step is to consider the inputs and outputs of each process stage. Once the inputs and outputs are identified, waste streams can be prioritized, and the source of those waste streams can be targeted. Pollution prevention options that target these inputs can then be implemented to reduce or eliminate the corresponding waste stream.

Pollution prevention requires commitment from both management and employees. While management action is required for process changes, employees — who are closest to the process — often are best placed to identify pollution prevention alternatives. Pollution prevention involves taking a proactive stance and frequently reviewing the production processes to find new and better ways of doing business. Figure 7.1 lists the specific process steps in the three major stages of the flexographic printing process where pollution prevention opportunities exist.

Table 7.1 expands upon Figure 7.1 by identifying and describing specific pollution prevention opportunities. Each of the major stages of the printing process provides many opportunities to increase efficiency and potentially save money while improving and maintaining performance standards. Facility-wide opportunities to practice pollution prevention are included at the end of the table. Also, two case studies and a video that further describe pollution prevention activities in the flexography industry are available from the U.S. EPA. Complete ordering information is provided at the end of this chapter.

Figure 7.1 Traditional Process Steps in Flexographic Printing



1. Artwork and Product Design
2. Negatives and Color Proofs
3. Platemaking
4. Mounting and Proofing
5. Makeready
6. Printing
7. Cleaning
8. Laminating and Coating
9. Converting

Decision-makers throughout the flexo industry also have many other opportunities to encourage environmental improvements and cleaner, more "sustainable" operations. Pollution prevention involves reducing or eliminating environmental discharges *before they are generated*. Pollution prevention requires taking active steps to implement changes in workplace practices, technology, and materials, such as the type of ink used. By reducing the amount of waste produced in the first place, disposal and compliance issues are minimized. Each step in the printing process offers opportunities for pollution prevention. Flexographic printers may be able to obtain a number of benefits from following pollution prevention practices, including cost savings, improved productivity, better product quality, reduced health risks to workers, reduced pressures of regulatory compliance, and of course reduced environmental impacts. Control options are less desirable than pollution prevention because they manage pollutants that have already been created. Control technology also can break down, and require expensive capital and maintenance costs.

Some opportunities for pollution prevention in flexo printing follow.

Pre-Press

- Use Computers for Proofs and Plates: By using computers to generate all proofs and plates, printers can skip photographic development and eliminate the use of darkroom chemicals.
- Switch from Rubber to Photopolymer Plates: Use of traditional nitric acid baths to etch designs into metal plates may generate wastewater that is low in pH and high in metal content, requiring regulation under the Clean Water Act. Photopolymer plates eliminate this waste stream as well as the metal engravings and wastes generated from the production of conventional molded rubber plates.

Printing

- Cover Volatile Materials: By keeping all cans, drums, and open ink fountains covered, printers can reduce odors and worker health risks by minimizing fugitive VOC emissions.
- Install Enclosed Doctor Blade Chambers: Enclosed doctor blade chambers reduce ink evaporation, which results in better control of ink usage, more consistent color, and improved performance of the inks on press. Making this change to an older press may greatly reduce ink evaporation, thus minimizing worker exposure to hazardous chemicals.
- Use Higher Linecount Anilox Rolls: This enables printers to apply smaller ink droplets closer together, to achieve much finer ink distribution, easier drying, and potentially faster press speeds.
- Rework Press Return Ink: Reworking press return ink can increase efficiency, reduce ink purchases, and reduce hazardous waste if contamination issues can be addressed. Ink can be reworked by blending press return ink with virgin ink or other press return inks.
- Use Computerized Ink Blending: Software and specialized equipment help printers blend ink, reduce surplus ink, and reuse press return ink.
- Print with Four-Color Process: The limited number of inks in four-color process printing can minimize the amount of mixed colored inks used and eliminate residues of unusual colors at the end of each job. With chambered doctor blade systems, the increased use of process printing to produce a broad spectrum of colors has become more easily attainable.

- Co-Extrude Colored Film: Films can be co-extruded to have panels of color in a clear field, which eliminates the need for heavy coverage with colored ink.
- Run Light Colors First: By running lighter jobs before darker jobs, printers can reduce the number of clean-ups.
- Standardize Repeat Print Jobs: Make-ready times and wate materials can be greatly reduced if the press operators knows the anilox roll linecount and cell volume, the sequence of colors, applied, ink parameters such as pH and viscosity, and other set-up information.
- Standardize Anilox Roll Inventory: This saves time during makeready and reduces waste.
- Use Multi-Stage Cleaning: Solvent use can be reduced by using a multi-stage cleaning procedure for the printing decks. This procedure reduces solvent use by reusing solvents that are otherwise discarded. Pre-used solvent is used in the first stage to remove the majority of the ink. In the second stage, a cleaner but still pre-used solvent is employed to remove more ink. In the third stage, clean solvent removes any remaining ink.
- Install Automatic On-Press Cleaning: When paired with solvent recovery, on-press cleaning systems use much less cleaning solution than hand cleaning, while also having a very short cycle time.
- Clean Anilox Rolls Promptly: Prompt attention will prevent the inks from setting, thereby reducing the need for harsh chemicals. Clean rolls also produce more predictable ink densities, potentially reducing on-press waste and improving quality.
- Use Alternative Methods to Clean Anilox Rolls: Printers can choose among many alternatives for cleaning anilox rolls to reduce or eliminate the need for traditional cleaning solvents. These alternatives use sonic cleaning, dry ice, lasers, polyethylene beads, and sodium bicarbonate.
- Recirculate warm press air: Both solvent-and water-based printers can significantly reduce their energy requirements by recirculating warm air from dryers.

Throughout the Printing Process

- Use Safer Chemicals: Switching to inks, cleaning agents, and adhesives that contain a lower percentage of VOCs and fewer HAPs may reduce risks to worker health and the environment.
- Segregate Hazardous Waste: Segregating hazardous wastes allows disposal of pure instead of mixed wastes. Because pure wastes are much easier to treat than mixed ones, they are not only less expensive to dispose of, but also require less energy.
- Return Containers: Using returnable containers prevents unnecessary waste generation and results in additional cost savings.
- Track Inventory: Tracking chemical purchases and disposal can help to maintain a minimum inventory on the shelf, thus reducing the amount of materials wasted. For example, hazardous waste can be minimized by labeling inks with the date and having a “first-in, first-out” rule, i.e., rotating the inks so that the oldest inks are used first. This avoids disposing of expired ink as hazardous waste. Tracking systems using bar codes take inventory control to an even higher level.

- Make a Management Commitment: Management should establish, communicate, and demonstrate their commitment to the concept of pollution prevention, to encourage company-wide source reduction in everyday practice. Management can assemble pollution prevention teams of employees, incorporate pollution prevention into job responsibilities, and provide incentives for employees to prevent pollution.
- Train Employees: Pollution prevention training for company personnel may facilitate process changes by educating workers on the need for such change. Training also helps to encourage general source reduction and stimulate pollution prevention ideas by personnel.
- Monitor Employee Practices: Periodic monitoring helps ensure that source reduction practices are followed.
- Seek Out and Encourage Employee Initiatives: Supporting, encouraging, and actively acknowledging pollution prevention initiatives by company personnel can stimulate innovative ideas for source reduction. This may be especially beneficial because employees who are closest to the process are often in the best position to recommend change.
- Develop an Environmental Management System (EMS): An EMS is a set of management tools and principles designed to guide a company to integrate environmental concerns into its daily business practices.

7.2 RECYCLING AND RESOURCE RECOVERY

Recycling (also known as resource recovery) helps reduce the need for virgin (never previously used) materials and lowers demand for solid waste disposal. Municipal and local governments often sponsor recycling programs and waste exchanges. By incorporating recycling, flexographic printers may be able to avoid or reduce the costs of handling, permitting, shipping, and disposing of wastes, as well as the regulatory and legal liabilities and costs.

Silver Recovery

Silver in wastewater is toxic, and its disposal is regulated locally by publicly owned treatment works (POTWs). Silver is used for film development in pre-press operations. Printers can recover silver from the wastewater coming out of their imaging operations. There are three main methods for recovering silver: metallic replacement, electrolytic silver recovery, and ion exchange.

Metallic Replacement
Wastewater is passed through one or more steel wool filters in which silver is chemically replaced by iron. The silver is collected in the form of sludge, which is then treated off-site to extract the usable metal. This method is used in many pre-press and print shops, and is relatively inexpensive.

Electrolytic Silver Recovery
An electric current passes between two electrodes in silver-laden wastewater, plating the silver on the cathode in a virtually pure form. The silver is easily removed from the cathode for reuse. This system is more expensive to purchase and maintain than the metallic replacement system. This is often used in conjunction with a steel wool filter.

Ion Exchange

Ion exchange can remove an extremely high percentage of silver, but is only suitable for dilute solutions. In addition, this method requires a greater capital investment and handling time than the other two methods.

Solvent Recovery

Flexographic printers who use solvent-based inks and cleaners can recover much of the solvent for reuse in the facility. A solvent recovery system captures VOC emissions, and uses a separation/distillation unit to separate and collect the solvent. Recycled solvent sometimes needs further treatment before it can be reused. Recycled solvent is often used in cleaning operations and saves the printer the cost of buying virgin solvent.

Solid Waste Recycling

Flexographic printing operations generate solid waste that must be disposed of in landfills or incinerated. Printers have found that recycling solid waste can reduce shipping and disposal costs, and that items can be reused in the shop or by the supplier. Flexographic printers can reduce solid waste in any of the following ways:

- Require suppliers to take back all containers and packaging.
- Work with local government to establish recycling practices.
- Choose materials (e.g., substrates) that can be recycled.
- Minimize coatings that hinder recycling.

Some specific examples of solid waste recycling include the following ideas:

- Bale paper waste, corrugated cartons, and pallet tote boxes for recycling.
- Return cores that are used to wind rolls of films, papers, and paperboard to the supplier for reuse.
- Collect and return shrinkwrap films for recycling. Segregate plastics by type to enable efficient reuse of the materials.
- Clean and reuse cans, bottles, plastic jugs, drums and other containers.
- Recycle photographic chemicals and platemaking chemicals. Negatives and photographic papers can be treated to recover silver.
- Pelletize unusable rubber, photopolymer plates, and mixed substrate wastes (e.g., laminations and pressure-sensitive materials) to use as alternative fuel at cement kilns and power generation plants.
- In some states, printers can recycle components of fluorescent lamps, including hazardous wastes like mercury.

7.3 CONTROL OPTIONS

Control technologies minimize the toxicity and volume of flexographic pollutants by destroying them or capturing them for reuse, recycling, or disposal. Specific control option choices need to be based on many considerations, such as regulations, the facility's printing equipment, the ink systems and chemicals that the facility uses, cost and performance needs, and risks to the safety and health of workers and the environment.

Control systems can be costly, must be maintained, and have the potential to fail. Using chemicals that contain or generate pollutants carries risks for workers and the environment, and may present a public relations problem. Disposal of regulated wastes may require a printer to obtain status as a hazardous waste generator. The potential disadvantages of control systems make it important for printers to consider pollution prevention, which can reduce the need for control systems in flexographic facilities.

Sources of Flexographic Ink Pollutants Amenable to Treatment or Control Options

Pollutants that are related to flexographic printing inks and that can be mitigated using treatment or control options fall into several categories:

- Air emissions
- Hazardous liquid wastes, especially solvents
- Non-hazardous liquid wastes, including many waste inks, additives, and colored wash-water

Control Options and Capture Devices for Air Releases

All solvent-based and some water-based flexographic inks contain significant amounts of volatile organic compounds (VOCs). Some flexographic inks also contain one or more hazardous air pollutants (HAPs), as defined by the Clean Air Act.[a]

Several types of control options[b] for handling air emissions related to working with flexographic inks are currently available and will be discussed in this section. In addition, a capture device such as a permanent total enclosure (PTE) may be installed in conjunction with control options and are part of the overall control efficiency. Three types of devices associated with emission control are discussed in this section.

- permanent total enclosures
- oxidizers (thermal, catalytic, and regenerative)
- adsorption systems

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[a] Smaller amounts of ozone also may be generated by the use of corona treaters and UV lamps, but ozone can be easily destroyed at the source by relatively inexpensive devices supplied (often with the primary equipment) by the manufacturer/distributor. Ozone that is destroyed immediately upon creation does not present an environmental concern.

[b] Biofiltration, also known as bioremediation, is a currently experimental method of destroying VOCs. This technology uses microbes that eat and digest VOCs, breaking them down into more environmentally benign chemicals. Biofiltration may hold promise for flexographic printing in the future, if the technology can be improved to enable reliable destruction of virtually all VOCs.

Capture Devices

A permanent total enclosure (PTE) is a structure that captures all fugitive emissions from a source (e.g., a single press or an entire press room) and sends them to a destruction/recovery device. A PTE alone only captures emissions; it neither destroys them nor reduces their use, but is part of the overall control efficiency or capture efficiency. Because of this, a PTE is used in combination with an oxidizer, adsorption system, or biofiltration device, which separates or destroys VOCs.

Regulations controlling air emissions are expected to continue to be strict across the country for the foreseeable future. A PTE is currently the only capture tool that effectively captures 100% of fugitive emissions.[1] Because a PTE is a permanent structure, only one demonstration inspection is required for a new PTE. Thereafter, as long as the facility continues to use the PTE in the same way without significant structural modifications, additional air inspections are not necessary.

A specific method and criteria have been set forth by EPA for constructing a PTE that will pass inspection. Depending upon the scope and size of the work that is needed, construction of a PTE can be fairly modest, or it can involve a substantial capital investment ranging up to tens of thousands of dollars.[2] The installation of a PTE also may involve compliance with local fire codes that designate the enclosed area as a hazardous area (H occupancy) and require steps or devices such as emergency ventilation, fire containment (fire walls and doors), an emergency egress route, and spill containment.[3] However, since most of the cost relates to capital and construction rather than operation and maintenance, in the long run some printers may find a PTE to be quite economical.

A well-designed PTE captures all fugitive emissions and eliminates fugitive air emissions to the local community. In addition, some printers may be able to benefit economically from PTEs, as more areas introduce the use of transfer credits for air emissions. Because a PTE guarantees 100% capture efficiency, printers in areas that require a lower percentage of capture efficiency may be allowed to sell or trade their credits.[4] For all these reasons, PTEs are expected to continue to be an important method of controlling fugitive air emissions for flexographic printers.

Oxidizers

Oxidizers burn air that contains VOCs and sometimes other pollutants generated in flexography. An oxidizer breaks down VOCs into water, carbon dioxide, and other gases. Oxidation works by mixing the emissions from the press exhaust with oxygen and heat. There are several types of oxidizers, including catalytic, thermal, thermal recuperative, and regenerative oxidizers. All types of oxidizers have the potential to achieve virtually complete destruction of VOCs. Straight thermal oxidizers require high operating temperatures (typically at least 1600˚F), whereas thermal recuperative oxidizers recover much of the waste heat from exhaust gases and thus are more economical. Catalytic oxidizers can operate at lower temperatures than thermal types (up to about 1250˚F) and use less fuel. Regenerative oxidizers may be either thermal or catalytic, as defined above.[5]

Catalytic oxidizers are more common in the flexographic printing industry than are thermal oxidizers; however, recent technical advances in thermal systems may make these appropriate for some printers.[6] Because of their lower operating temperatures, catalytic oxidizers create a very low percentage of NOx (nitrogen oxide) emissions[c] compared to

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[c] Nitrogen oxides are ozone precursors.

thermal oxidizers. However, catalytic oxidizers may not be effective in treating gases from certain silicone ink additives, because silicone masks or poisons the catalyst.[7]

Oxidizers usually involve a significant capital and installation investment, as well as substantial operating expenses. The total capital cost of an oxidizer can range from $150,000 to $400,000 or more, depending upon the size and needs of the facility.[8,9,10,11] Energy consumption considerations for catalytic oxidizers are discussed in Chapter 6.

Adsorption Systems

These devices contain a bed of activated carbon, zeolite (an aluminum-silicate crystal), or polymers. This substance attracts VOCs, which adsorb (concentrate) on the surface of the medium. Adsorption separates but does not destroy VOCs. The air that no longer contains VOCs then can be released, and the VOCs can be reused or recycled. A typical adsorption system alone has the potential to remove 95% or more of VOCs,[6] and is normally used in conjunction with a PTE to ensure virtually complete removal of VOCs.

Carbon adsorption systems work most efficiently in capturing a single solvent or a very dilute stream of VOCs, and they are not necessarily compatible with all inks. Because flexography typically uses a large number of solvents, carbon adsorption was not appropriate for most printers at the time of publication of this CTSA.[6]

The costs of adsorbent systems ranges widely depending on a number of factors, including the type and size of the facility, the type of absorbent system, state regulatory requirements, and permitting issues. Systems can cost from several thousand to several hundred thousand dollars. Also, since an adsorption system is normally used in conjunction with a PTE, that cost must be considered as well. For these reasons, a meaningful cost range for this technology is beyond the scope of this document.[d]

Control Options for Liquid Releases

Flexographic facilities need to pay attention to three characteristics of liquid ink wastes: percentage of solvents, turbidity (discoloration), suspended solids, and hazardous substances.

The maximum solvent content allowed in wastewater is site-specific. For facilities using only water-based inks, if the percentage of petroleum-based solvents is below the level allowed by the facility's municipal wastewater facility (Publicly Owned Treatment Works, or POTW) or permit (if applicable), the liquid waste might not be regulated as hazardous waste. Facilities using only UV inks typically will not have solvent-containing liquid wastes.

For all types of inks, EPA considers discoloration of water to constitute "turbidity," which is a pollutant category. Pigments and other discoloring substances may have to be removed before the water can be discharged to a POTW. Also, ink wastes may have other substances that are regulated as hazardous (e.g., metals) and must be removed before discharge. Please see Chapter 2, Federal Regulations, for more information on chemicals in this CTSA that may be regulated as hazardous wastes.

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[d] The U.S. EPA's Office of Air Quality Planning and Standards "EXPOS Control Cost Manual" (5th Ed., February 1996, document EPA 453/B-96-001), provides detailed procedures, data, and equations for sizing and estimating capital and operating costs of thermal regenerative carbon adsorption systems.

Ink splitters are used to separate out the solids in wastewater. The water then can be released to a POTW and the pigment-containing sludge sent to a landfill. The capital cost of an ink splitter can range from several thousand dollars to more than $30,000, which can be offset by lower disposal costs and POTWS fees. The relatively low cost of ink splitters and their benefits in helping printers to comply with water emissions standards can make this technology useful to many flexographers.

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Chapter 8: Choosing Among Ink Technologies

CHAPTER CONTENTS

CHAPTER OVERVIEW

Earlier chapters of this CTSA presented the findings of the research regarding risk, performance, cost, and resource requirements. This chapter takes a different look at some of that information. Section 8.1 summarizes the individual ink systems and product lines, using the solvent-based ink system as the baseline and providing comparisons to water-based and UV-cured inks. Performance tests, environmental and health impacts, and resource conservation are discussed.

Section 8.2 provides a qualitative social benefit-cost assessment of the different ink system, analyzing the private (printer) and social implications of the CTSA findings. Social costs and benefits are those that do not affect the flexographic facility directly, but that do affect the larger population and the environment. This viewpoint is one that is rarely considered within an industry setting.

Section 8.3 compares the three ink systems broadly. This section describes the chemical categories analyzed in the CTSA, and identifies the hazards and risks of each chemical. Flexographic professionals can use this information to identify chemicals that they either may wish to avoid or may use as safer alternatives.

8.1 SUMMARY BY INK SYSTEM AND PRODUCT LINE

Introduction

The results of the DfE Flexography Project, as shown in this CTSA, present information about several important factors that contribute to the selection of a flexographic ink. The performance, human and environmental risk, and operational costs associated with an ink are issues that a printer must consider when choosing among ink technologies. Though this research is not an exhaustive analysis of all flexographic inks, it provides an indication of how nine product lines of solvent-based, water-based, and UV-cured inks compare on wide-web film substrates. Individual printers will have conditions (and results) that vary from those encountered in this analysis, but the results in this report will be a starting point for determining how changes might affect the circumstances of a particular facility. Ink formulators also may gain from this analysis by learning how the hazards posed by chemicals in isolation translate into health and environmental risks when the chemicals are placed in the context an ink mixture used in a printing facility.

The DfE Flexography Project studied solvent-based, water-based, and UV-cured inks on three wide-web films: low-density polyethylene (LDPE), co-extruded polyethylene/ethyl vinyl acetate (PE/EVA), and oriented polypropylene (OPP). For each type of ink, between two and four specific product lines were tested. Table 8.1 indicates which substrates were used with each product line.

Table 8.1 Ink and Substrate Combinations

Product Line	Substrate
Solvent-based #1	OPP
Solvent-based #2	LDPE, PE/EVA, OPP
Water-based #1	OPP
Water-based #2	OPP
Water-based #3	LDPE, PE/EVA
Water-based #4	OPP
UV-cured #1	LDPE
UV-cured #2	LDPE, PE/EVA
UV-cured #3	PE/EVA

The performance chapter (Chapter 4) discussed the results of 18 tests on the nine product lines that were studied in the CTSA. Five of these tests were selected to highlight in this summary (Table 8.2).[1] These performance tests were selected because they were measured for all three systems; they display a range of important ink properties; and they were minimally dependent on external factors such as press equipment and operator expertise. Please see Chapter 4 for the results of the other performance tests.

Table 8.2 Selected Key Performance Indicators

Indicator	Description	Scale	Interpretation
Blocking	Measures the bond between ink and substrate when heat and pressure are applied. Ink transfer from a printed substrate to a surface in contact with the print indicates that blocking has occurred.	0-5	0 = no blocking and a good ink-substrate bond. 5 = complete blocking or removal
Gloss	Measures the reflected light directed at the surface from an angle. The test was only performed on LDPE and PE/EVA substrates, because gloss is irrelevant on laminated substrates (such as the OPP product in this project).	0-100	Higher numbers indicate higher reflectivity
Ice Water Crinkle	Measures the integrity and flexibility of the ink on the substrate when exposed to refrigerator and freezer conditions. The sample was submerged in a container of ice water for 30 minutes, then removed and twisted rapidly 10 times.	0-100	0 = intact ink finish 100 = complete removal of finish
Mottle	Measures the spottiness or non-uniformity of an ink film layer.	Open-ended	Lower values indicate a more consistent finish. Higher values indicate a more variable finish.
Trap	Measures the ability of an ink to adhere to an underlying ink. This trait is important where inks are printed on top of one another in order to generate precise color hues.	0-100%	100% = ideal

The **operating cost** information developed in this CTSA includes costs for materials, labor, capital, and energy, calculated per 6,000 square feet of image based on the methodology press speed of 500 feet per minute.

The **energy consumption** of each ink system is calculated per 6,000 square feet of image. Equipment included in this calculation includes hot air dryers, blowers, oxidizers, UV curing lamps, and corona treaters.

The results of the selected performance tests and the operating cost and energy consumption analyses are summarized in Table 8.3. Data for these three categories are presented for each product line (e.g., solvent-based ink #1), and also are averaged across the whole ink system. The solvent-based ink system is considered the baseline for this analysis; each water-based and UV-cured product line is compared with the baseline results in Table 8.3 through the use of ✰ (better than the baseline) or ✘ (worse than the baseline).

Table 8.4 summarizes the human health risks of each product line. Three categories of information are included in this table.

- **Range of chemicals with clear concern for risk**: This column shows the total number of compounds with a clear health risk[a] to pressroom workers for each formulation in a product line. For example, if two chemicals with a clear concern for risk were found in one formulation of solvent-based #1, four were found in another formulation, and the other three formulations had numbers between these, the range would be 2-4. This range incorporates compounds that are expected to pose a clear concern for occupational risk to flexographers based on either toxicological studies or EPA's Structure Activity Team (SAT) assessments.
- **Categories with chemicals of clear concern for risk**: Lists the chemical categories that contained at least one chemical with a clear concern for inhalation risk to pressroom workers or dermal risk to press- and prep-room workers. Superscripts next to each category name indicate whether the compounds presented a clear concern for risk through inhalation (inhal) or dermal (derm) exposure. Categories are denoted with "(SAT)" if the compound with a clear concern for risk was analyzed by the SAT. An SAT evaluation is considered to be a less accurate measurement method than toxicological information. (See Chapter 3: Risk.)
- **Toxicological endpoints:** In toxicological tests, researchers record observed effects of the given chemical. These qualitative observations, called toxicological endpoints, indicate effects that have been associated with compounds in formulations in each of the respective product lines. The information is separated based on the exposure route, because effects may be different depending on whether a compound is absorbed dermally or by inhalation. Toxicological endpoints can be useful for highlighting the scope of potential human health effects of the ink systems. The user of flexographic inks should be aware that the risk of health effects may be present with *any* ink. *Toxicological endpoints provide an indication of such potential effects, but only offer a broad perspective.* "Liver effects," for example, may range in significance from liver enlargement to cirrhosis or changes in liver cells that may lead to the growth of tumors. The first effect may have little practical importance, but the latter may jeopardize survival. *The table does not indicate the severity of effects, nor does it imply that all of the effects would be observed at the exposure levels in typical flexographic prep or press rooms.*

Table 8.5 presents indicators of safety and environmental concerns associated with each product line.

- **Safety information:** Three categories of safety hazards are included: reactivity, flammability, and ignitability. Reactivity and flammability are based on scales of 0-4; 0 indicates that a compound is stable and will not burn, respectively, and 4 indicates that it is readily explosive or flammable. Ignitability is characterized as yes or no; a compound is ignitable if it has a flashpoint below 140°F.
- **Smog-related emissions:** The flexographic printing process emits pollutants that cause smog in two ways. First, VOCs are released directly from the ink formulations as ink is applied to the substrate. Second, VOCs, nitrogen oxides, and carbon monoxide are produced during the production of the electricity and heat used in printing.
  - **Ink content:** Two important indicators of possible air impacts are the concentration of VOCs and HAPs. The concentrations of both were taken from the ink MSDSs and averaged across each formulation within each product line.

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[a] Clear concern for risk indicates that for the chemical in question under the assumed exposure conditions, adverse effects are predicted to occur. Section 3.7 of the CTSA has more information about risk rankings.

Table 8.3 Summary of CTSA Competitive Tests

	Performance					Cost	Energy
Product Line	**Blocking (0=none)**	**Gloss (100= maximum)**	**Ice Water Crinkle (0%=intact)**	**Mottle (lower=more desirable)**	**Trap (100%= optimum)**	**Total Cost per 6,000 ft^2 of Image[a]**	**Btu per 6,000 ft^2 of image**
Baseline: Solvent-based Ink System							
Solvent-based #1	1.8	NA[b]	NA	192	101%	$31.89	100,000
Solvent-based #2	2.7	53.0	0%	217	98%	$34.06[c]	100,000
Average across Solvent-based Inks	*2.3*	*53.0*	*0%*	*205*	*100%*	*$32.98*	*100,000*
Range across Solvent-based Inks	*1.8-2.7*	*53.0*	*0%*	*192-217*	*98-101%*	*$31.89-$34.06*	*100,000*
Alternative 1: Water-based Ink System							
Water-based #1	4.0	NA	NA	592	90%	$30.04	73,000
baseline comparison	✘[d]	NA	NA	✘	✘	☆	☆
Water-based #2	3.0	NA	NA	186	87%	$26.78	73,000
baseline comparison	✘	NA	NA	☆	✘	☆	☆
Water-based #3	1.3	46.5	Partial removal on 8 of 22 samples	478	93%	$25.36[c]	73,000
baseline comparison	☆	✘	✘	✘	✘	☆	☆
Water-based #4	2.5	NA	NA	115	89%	$24.23	73,000
baseline comparison	✘	NA	NA	☆	✘	☆	☆
Average across Water-based Inks	2.7	46.5	36%	342	90%	$26.60	73,000
baseline comparison	✘	✘	✘	✘	✘	☆	☆
Range across Water-based Inks	1.5-4.0	46.5	36%	115-592	87-93%	$24.23-$30.04	73,000

Table 8.3 Summary of CTSA Competitive Tests (continued)

	Performance					Cost	Energy
Product Line	**Blocking (0=none)**	**Gloss (100= maximum)**	**Ice Water Crinkle (0%=intact)**	**Mottle (lower=more desirable)**	**Trap (100%= optimum)**	**Total Cost per 6,000 ft^2 of Image[a]**	**Btu per 6,000 ft^2 of image**
New Developing Technology: UV-Cured Ink System							
UV-cured #1	1.0	32.3	0%	271	82%	$51.00	78,000
baseline comparison	☆	✘	*(even)*	✘	✘	✘	☆
UV-cured #2	2.1	47.0	Partial removal on 8 of 8 samples	205	90%	$35.78[c]	78,000
baseline comparison	☆	✘	✘	*(even)*	✘	✘	☆
UV-cured #3	1.0	35.9	0%	273	95%	$23.69[c]	78,000
baseline comparison	☆	✘	*(even)*	✘	✘	☆	☆
Average across UV-cured Inks	1.4	38.4	33%	250	89%	$36.82	78,000
baseline comparison	☆	✘	✘	✘	✘	✘	☆
Range across UV-cured Inks	1.0-2.1	32.3-47.0	0-100%	205-273	82-95%	$23.69-$51.00	78,000

[a] Costs are based on the methodology press speed of 500 feet per minute.

[b] NA indicates the test was not performed on the product line.

[c] This product line was printed on PE/EVA for some or all of its performance demonstrations; because this substrate did not require the use of white ink, costs may be lower than expected.

[d] ☆ Indicates better than baseline; ✘ Indicates worse than baseline.

Table 8.4 CTSA Occupational Health Information For Each System and Product Line

	Risk		Toxicological Endpoints	
Product Line	**Chemicals with Clear Concern for Occupational Risk**		**Dermal**	**Inhalation**
	Range (No.)^{a}	**Chemical Categories^{b}**		
Baseline: Solvent-based Ink System				
Solvent-based #1	2-4	alcohols^{inhal,derm}, alkyl acetates^{inhal,derm}, inorganics^{derm}, organic acids or salts^{derm}, organometallic pigments (SAT)^{derm}, organotitanium compounds (SAT)^{derm}	bile duct, blood, bone, bone marrow, developmental, endocrine, eye, g.i., heart, hormone, immune, kidney, liver, lymphatic, pancreatic, neurotoxic, rectal, reproductive, respiratory, and skin effects; increased mortality; altered body and organ weights; decreased survival; changes in serum chemistry and blood pressure	blood, bone marrow, developmental, eye, g.i., heart, kidney, liver, neurotoxic, reproductive, respiratory, spleen, and thymus effects; altered organ weights; changes in enzymes, clinical, serum, and urine chemistry; changes in blood pressure; decreased growth
Solvent-based #2	2-4	alcohols^{inhal,derm}, hydrocarbons – low molecular weight^{inhal}, organometallic pigments (SAT)^{derm}, propylene glycol ethers^{inhal,derm}	bile duct, blood, bone, developmental, endocrine, g.i., heart, hormone, immune, liver, lymphatic, neurotoxic, pancreatic, rectal, reproductive, respiratory, skin, and spleen effects; altered body and organ weights; decreased survival; increased mortality; changes in clinical chemistry	auditory, blood, bone marrow, developmental, liver, neurotoxic, reproductive, respiratory; spleen, thymus effects; altered serum chemistry; changes in enzymes, clinical, and urine chemistry; decreased growth; altered organ weights
Average across Solvent-based Inks	3.2			
Range across Solvent-based Inks	2-4			

Table 8.4 CTSA Occupational Health Information For Each System and Product Line (continued)

Product Line	Risk		Toxicological Endpoints	
	Chemicals with Clear Concern for Occupational Risk		Dermal	Inhalation
	Range (No.)[a]	Chemical Categories[b]		
Alternative 1: Water-based Ink System				
Water-based #1	2-4	alcohols$^{\text{inhal,derm}}$, amides or nitrogenous compounds$^{\text{inhal,derm}}$, ethylene glycol ethers$^{\text{inhal,derm}}$, organic pigments$^{\text{derm}}$	bile duct, blood, bone, bone marrow, developmental, eye, kidney, liver, lymphatic, neurotoxic, respiratory, skin, and stomach effects; altered organ weights; decreased body weight; decreased survival; benign skin tumors	eye, liver, neurotoxic, reproductive, respiratory, skin, and spleen effects; benign skin tumors; changes in enzymes, clinical, and urine chemistry
baseline comparison	*(even)*			
Water-based #2	2-4	alcohols$^{\text{inhal}}$, amides or nitrogenous compounds$^{\text{inhal,derm}}$, ethylene glycol ethers (SAT)$^{\text{derm}}$	bile duct, bladder, blood, blood chemistry, bone, bone marrow, kidney, liver, lymphatic, neurotoxic, reproductive, respiratory, and spleen effects; altered organ weights; decreased survival; decreased food consumption; changes in enzyme levels	bladder, blood, blood chemistry, corneal, developmental, kidney, liver, neurotoxic, reproductive, respiratory, spleen, effects; changes in enzyme levels; altered body weights
baseline comparison	*(even)*			
Water-based #3	1-4	alcohols$^{\text{inhal,derm}}$, amides or nitrogenous compounds$^{\text{inhal,derm}}$, ethylene glycol ethers$^{\text{inhal,derm}}$, organometallic pigments$^{\text{derm}}$	bile duct, blood, blood chemistry, bone, bone marrow, developmental, eye, kidney, liver, lymphatic, neurotoxic, reproductive, respiratory, skin, spleen, and thymus effects; altered organ weights; decreased survival; decreased body weight; changes in clinical chemistry	bladder, blood, corneal, enzyme, eye, kidney, liver, neurotoxic, reproductive, respiratory and spleen effects; altered organ weights; changes in enzymes, clinical and urine chemistry
baseline comparison	☆			

Table 8.4 CTSA Occupational Health Information For Each System and Product Line (continued)

	Risk		Toxicological Endpoints	
Product Line	Chemicals with Clear Concern for Occupational Risk		Dermal	Inhalation
	Range (No.)[a]	Chemical Categories[b]		
Water-based #4	3-4	alcohols^{inhal,derm}, amides or nitrogenous compounds^{inhal,derm}, organometallic pigments^{derm}	bile duct, blood, bone, bone marrow, clinical chemistry, developmental, eye, kidney, liver, lymphatic, neurotoxic, respiratory, skin, and thymus effects; altered body and organ weights; decreased survival; increased mortality	corneal, developmental, eye, kidney, liver, neurotoxic, reproductive, respiratory, and spleen effects; changes in enzymes, clinical, and urine chemistry; decreased growth; altered body and organ weights
baseline comparison	✘			
Average across Water-based Inks	3.1			
baseline comparison	☆			
Range across Water-based Inks	1-4			

Table 8.4 CTSA Occupational Health Information For Each System and Product Line (continued)

	Risk		**Toxicological Endpoints**	
Product Line	**Chemicals with Clear Concern for Occupational Risk**		**Dermal**	**Inhalation**
	Range (No.)[a]	**Chemical Categories**[b]		
New Developing Technology: UV-Cured Ink System				
UV-cured #1	1-2	acrylated polymerrs (SAT)^{derm}, amides or nitrogenous compounds(SAT)^{inhal,derm}, inorganic pigments (SAT)^{derm}, organometallic pigments^{derm}	bile duct, developmental, lymphatic, respiratory, and thymus effects; altered body and organ weights; changes in clinical chemistry	developmental effects
baseline comparison	☆			
UV-cured #2	4-5	acrylated polymers (SAT)^{inhal,derm}, acrylated polyols^{inhal,derm}, organometallic pigments^{derm}, organophosphorous compounds^{derm}	adrenal, bile duct, blood, developmental, enzyme, eye, kidney, liver, lymphatic, neurotoxic, reproductive, respiratory, skin, and thymus effects; altered body and organ weights; changes in serum and clinical chemistry; decreased body weight	developmental, liver, respiratory effects; altered organ weights
baseline comparison	✘			
UV-cured #3	1-2	acrylated polymers (SAT)^{derm}, acrylated polyols (SAT)^{inhal,derm}, amides and nitrogenous compounds (SAT)^{inhal,derm}	bile duct, blood, lymphatic, reproductive, respiratory, and skin effects; altered body weights; decreased body weight	None identified
baseline comparison	☆			
Average across UV-cured Inks	2.4			
baseline comparison	☆			
Range across UV-cured Inks	1-5			

[a] Indicates the range in the number of compounds with clear worker health risk per formulation within each product line.
[b] Chemical categories listed in this column appear in at least one of the five formulations in the respective product lines.
inhal = clear concern for worker risk via inhalation exposure; derm = clear concern for worker risk via dermal exposure

Table 8.5 CTSA Environmental and Safety Findings For Each System and Product Line

	Safety Hazard			Smog-Related Emissions			Ink Content[g,h]	
Product Line	**Reactivity[a] (0-4)**	**Flammability[a] (0-4)**	**Ignitability[b] (yes/no)**	**Ink-Related VOC Emissions[e] (g/6,000 ft^2)**	**Energy-Related Emissions[f] (g/6,000 ft^2)**	**Total Smog-related Emissions (g/6,000 ft^2)**	**Average VOC content (%)**	**Average HAP Content (%)**
Baseline: Solvent-based Ink System								
Solvent-based #1	0	3	yes	667 (1991)	90	757 (2081)	62	0
Solvent-based #2	0	3	yes	980 (2925)	90	1070 (3015)	54	0
Average across Solvent-based Inks	0	3	yes	824 (2458)	90	914 (2548)	58	0
Range across Solvent-based Inks	0	3	yes	667-980 (1991-2925)	90	757-1070 (2081-3015)	54-62	0
Alternative 1: Water-based Ink System								
Water-based #1	0	1-3	no	250	63	313	9	3.4
baseline comparison	*(even)*	☆	☆	☆	☆	☆	☆	✘
Water-based #2	0	0-1	no	110	63	173	1	0.72
baseline comparison	*(even)*	☆	☆	☆	☆	☆	☆	✘
Water-based #3	0	1	no	135	63	198	1	0.14
baseline comparison	*(even)*	☆	☆	☆	☆	☆	☆	✘
Water-based #4	0	0-3	no	138	63	201	14	0
baseline comparison	*(even)*	☆	☆	☆	☆	☆	☆	*(even)*
Average across Water-based Inks	0	1.7	no	158	63	221	6.3	1.1
baseline comparison	*(even)*	☆	☆	☆	☆	☆	☆	✘
Range across Water-based Inks	0	0-3	no	110-250	63	173-313	1-14	0-3.4

Table 8.5 CTSA Environmental and Safety Findings For Each System and Product Line (continued)

	Safety Hazard			Smog-Related Emissions			Ink Content[g,h]	
Product Line	**Reactivity[a] (0-4)**	**Flammability[a] (0-4)**	**Ignitability[b] (yes/no)**	**Ink-Related VOC Emissions[e] (g/6,000 ft^2)**	**Energy-Related Emissions[f] (g/6,000 ft^2)**	**Total Smog-related Emissions (g/6,000 ft^2)**	**Average VOC content (%)**	**Average HAP Content (%)**
New Developing Technology: UV-Cured Ink Systems								
UV-cured #1	NA[c]	NA[d]	no	77	110	187	1[i]	0
baseline comparison	NA	NA	☆	☆	✘	☆	☆	*(even)*
UV-cured #2	1	1	no	413	110	523	1	0
baseline comparison	✘	☆	☆	☆	✘	☆	☆	*(even)*
UV-cured #3	NA	NA	no	81	110	191	1	0
baseline comparison	NA	NA	☆	☆	✘	☆	☆	*(even)*
Average across UV-cured Inks	1	1	no	190	110	300	1	0
baseline comparison	✘	☆	☆	☆	✘	☆	☆	*(even)*
Range across UV-cured Inks	1	1	no	77-413	110	187-523	1	0

Footnotes for Safety Hazard columns

[a] Scale of 0-4, in order of increasing hazard. See Chapter 2: Introduction for details on the rating scales.

[b] A formulation is classified as ignitable if it has a flashpoint below 140°F.

[c] Incomplete data — reactivity information was only available for UV-cured #2.

[d] Incomplete data — flammability information was only available for UV-cured #2.

Footnotes for Smog-related Emissions

[e] Includes calculated releases from inks and press-side additions. For solvent-based ink systems, assumes the use of a control system with a 70% capture efficiency and a 95% efficient control device (oxidizer). Solvent-based emissions calculated without an oxidizer are listed in parentheses.

[f] Includes carbon monoxide, hydrocarbons, and nitrogen oxides released by electric utilities and natural gas-fired oxidizers and ovens. Only includes emissions from power consumption due to curing/drying, emission control, and corona treaters. Represents total load of smog forming chemicals, not smog formation potential. The latter will vary depending on the mix of pollutants, shown in Table 6-18 in the Resource Conservation chapter, and atmospheric/meteorological conditions.

Footnotes for Ink Content columns

[g] Content percentages are calculated by weight.

[h] VOCs and HAPs may overlap between columns.

Solvent-based Inks

Solvent-based inks were considered the baseline for this analysis because they traditionally are used by the most printers in the wide-web film industry segment. There were two solvent-based product lines. Solvent-based ink #1 was used with OPP at one facility, and solvent-based ink #2 was used with all three substrates (LDPE, PE/EVA, and OPP) at three facilities.

Performance

Solvent-based inks performed relatively well on each performance test. The **blocking resistance** test produced results that were not ideal, but were acceptable in most cases. Solvent-based ink #1, printed in OPP, displayed a result of 1.8 (between slight cling and cling). Solvent-based ink #2 displayed an average result of 2.7 (between cling and slight blocking). For Solvent-based ink #2, the results may have been affected by facility-specific conditions. The eight samples taken at Facility 5 (four each on LDPE and PE/EVA) yielded an average score of 2.1. In contrast, the results at Facility 7 (also four samples each on LDPE and PE/EVA) had an average score of 3.6 (between slight blocking and considerable blocking).

Gloss was measured for solvent-based ink #2, which was printed on LDPE and PE/EVA. For this product line, the average gloss was 53. Within these results, the values appear to have been affected by both substrate and facility conditions. The ink appeared to produce a glossier finish on PE/EVA; the average value on this substrate was 59 in comparison to the average 51 on LDPE. Also, higher gloss was found at Facility 7 than Facility 5; the average values were 57 and 51, respectively.

The **ice water crinkle** test was performed with solvent-based ink #2. All samples of this ink resisted removal during this test, resulting in a 0% removal rate. These results indicated that this solvent-based ink would be appropriate for use in cold, wet conditions.

Mottle was measured for both solvent-based inks. Solvent-based inks #1 and #2 had values of 192 and 217, respectively, on the mottle scale. Though mottle does not have an industry standard, these values were lower than those for the other two ink systems. It should be noted, however, that although the average mottle rating for the two product lines were similar, there was significant variation between the two measured formulations within each product line. Blue inks were much more mottled than green inks. This difference was consistent across all substrates and facilities.

Trap measurements for both solvent-based product lines were consistently near 100%. The two solvent-based inks attained near-complete trapping; i.e., the top ink adhered to the underlying ink as well as it did to exposed substrate.

Overall, the solvent-based inks performed quite well in these tests. They exhibited good physical characteristics through the blocking, ice water crinkle, and trap tests, and displayed comparatively good visual results in the gloss and mottle tests. For more detail on these tests or others, please see Chapter 4: Performance.

Environmental and Health Impacts

Table 8.4 shows the number of chemicals with a clear concern for worker risk for each formulation within the solvent-based product lines (presented as a range). In addition, the table lists the categories with chemicals that present a clear risk concern for pressroom workers, and identifies the exposure route of concern for each category.

In the **occupational risk** assessment, solvent-based ink #1 contained between two and four chemicals with clear concern for occupational risk in each formulation. All chemicals of concern presented a concern for dermal risk, and two categories (alcohols and alkyl acetates) also presented a clear concern for occupational risk via inhalation. Solvent-based ink #2 also had between two and four chemicals with a clear concern for risk in each formulation. Three chemical categories contained chemicals that presented a clear concern for risk: alcohols presented clear concern for risk via both dermal and inhalation exposure, low molecular weight hydrocarbons presented a clear concern for risk via inhalation exposure, and organometallic pigments presented a clear concern for risk via dermal exposure.

Across both product lines, the concern for inhalation risk stems from chemicals that are solvents and multiple-function compounds. The compounds presenting a clear concern for dermal risk are solvents, colorants, additives, and compounds listed as multiple-function.

The toxicological endpoints column of Table 8.4 presents possible health impacts of these chemicals with a clear concern for risk. For solvent-based inks, health effects are possible via both dermal and inhalation exposure.

The **safety hazards** of the solvent-based inks, as presented in Table 8.5, included significant rankings for both flammability and ignitability. The flammability score of 3 indicated that the ink could be easily ignited under almost all normal temperature conditions and that water may be ineffective in controlling or extinguishing such a fire. Both product lines also were ignitable, indicating that they had a flashpoint (the lowest temperature at which vapor is sufficiently concentrated that it can ignite in air) below 140°F.

Table 8.5 shows estimated **air emissions** of smog-related air releases resulting from inks and energy use. Although the estimates for the solvent-based product lines assumed that an oxidizer would be used to control emissions from the inks, the assumed capture efficiency was only 70%. This resulted in a relatively high amount of uncaptured emissions, so that overall, the two product lines were estimated to release 757 and 1,070 grams of smog-related emissions per 6,000 ft^2 of image, respectively. Emissions from solvent-based presses with an oxidizer may vary; they can be lower if the capture efficiency is better (presses equipped with enclosed doctor blades can have a capture efficiency of approximately 85%), but emissions may be higher if the oxidizer is not operated optimally and consistently.

Table 8.5 indicates that, as expected, both solvent-based inks have a relatively high **VOC content**, at an average of 58% by weight. Neither product line contained any chemicals designated as HAPs.

Operating Costs

The operating costs associated with using these solvent-based inks are shown in Table 8.3. The costs of ink, labor, capital, and energy per 6,000 square feet of substrate (at a press speed of 500 feet per minute) were expected to be $31.89 for solvent-based ink #1 and $34.06 for solvent-based ink #2.

For both of these product lines, the ink costs were the highest expense (between $14 and $24 per 6,000 ft^2, depending on the consumption rate at the individual performance demonstration sites). Capital costs were the second-largest component of the operating costs, at \$11.87 per 6,000 ft^2, and labor and energy the least significant part of overall cost, at \$5.29 and \$0.53 per 6,000 ft^2, respectively.

Two factors drove the operating costs of solvent-based ink relative to the other two ink systems. First, this system required the use of an oxidizer. This component added approximately \$128,000 to the capital cost of the press, which in turn increased the per-hour capital cost by \$3.80, assuming a 15% annual depreciation rate over 20 years. Second, the high evaporation rate of solvent from solvent-based inks required the press-side addition of additional solvent. This led to a high rate of press-side solvent consumption.

Some factors were not considered in this analysis that may affect the cost of solvent-based inks, as well as water-based and UV-cured inks. These include the ability of an ink to print at higher press speeds, ink monitoring requirements, and cleaning difficulties. Factors such as these may vary among ink systems and alter their relative costs.

Resource Conservation

Energy use was the highest for solvent-based ink, at 100,000 Btu per 6,000 ft^2 of image. The dryers and associated blowers were the most significant consumers of energy, consuming approximately 460,000 Btu/hour, or 55,000 Btu/6,000 ft^2. The oxidizer accounted for much of the remaining energy demand. It should be noted, however, that it has become more common to recirculate exhaust from the oxidizer into the dryers. This practice lowers energy requirements for the dryers so that the net effect on energy use by adding an oxidizer is minimal.

Ink consumption, as discussed in the operating cost summary above, also was relatively high. Based on performance demonstrations excluding those on PE/EVA (for which white ink was not used), an average of 7.07 lbs/6,000 ft^2 of solvent-based ink was consumed, and an average of 2.48 lbs/6,000 ft^2 of additives were used. This high consumption rate is due to the relatively low solids content of solvent-based inks, which in turn necessitates anilox rolls with larger volumes.

Summary of Solvent-based Inks

The solvent-based inks performed well on the performance tests, but they had liabilities with respect to worker health risks, safety hazards, operating costs, and the consumption of ink and energy.

- This system produced ideal results on the ice water crinkle and trap tests, and produced comparatively good results on the blocking, gloss, and mottle tests (for which no industry standards are available).
- The formulations in both product lines contained chemicals with a clear concern for worker risk for both inhalation and dermal exposure routes, presented both flammability and ignitability characteristics, and had high VOC emissions despite the use of oxidizers.
- Operating costs were relatively high, due to the required use of oxidizers and higher ink consumption rates.
- Ink and press-side additive consumption rate was high, due to the high evaporation rates of solvents.
- Energy consumption was high, because of the added energy demands of oxidizers.

Water-based Inks

Four water-based inks were tested in this analysis. Water-based inks #1 and #2 were tested on OPP at one facility each. Water-based #3 was tested on LDPE and PE/EVA at two sites. Water based ink #4 was tested on OPP at one site.

Performance

The results varied considerably among water-based product lines. **Blocking** was one of the tests in which the results were inconsistent across the product lines. Water-based ink #1 displayed the worst results, with an average score of 4.0 (considerable blocking). Water-based inks #2 and #4 performed slightly better, with scores of 3.0 and 2.5 (slight blocking and between cling and slight-blocking), respectively. Water-based ink #3 performed quite well, with an average score of 1.3 (between slight cling and cling). Unlike for the solvent-based inks, the results did not appear to be facility-specific. Water-based ink was used at both Facility 2 and Facility 3; at each, the average value was 1.3. The system as a whole compared unfavorably to the results for the solvent-based inks for blocking resistance.

Gloss was measured for water-based ink #3, the one product line tested on LDPE and PE/EVA. The average measurement was 46.5, which was somewhat lower (i.e., less desirable) than the average for solvent-based inks. Like for the solvent-based inks, the results seemed to be influenced by the substrate; on LDPE, the average gloss was 42.3, and on PE/EVA, the average gloss was 54.1. Overall, this water-based product line did not provide quite as glossy a finish as the solvent-based inks that were tested.

Ice water crinkle was also only tested for water-based ink #3. Of the 16 samples tested, part of the coating was partially removed on five of them. In each case, only a small fraction (about 5%) of the coating was removed; most of this removal was associated with the blue and green formulations. The results appeared to be facility-specific; no removal was observed at Facility 2. At Facility 3, however, five of the eight samples had some removal (including all four samples on LDPE). These results were worse than the solvent baseline, with which no removal was observed.

The **mottle** results also showed a wide range among the product lines. Water-based inks #1 and #3 had scores of 592 and 478, respectively, which were much higher (worse) than those for solvent-based inks. In contrast, the scores for water-based inks #2 and #4 were 186 and 115, respectively — comparable or much lower than those for the solvent-based inks. Overall, the mottle scores for water-based inks were higher (worse) than the solvent baseline. Like for the solvent-based inks, the blue water-based inks overall were much more mottled than the green inks.

The water-based inks had fairly consistent scores for **trapping** – between 87 and 93%. The results may have been facility-specific; at Facility 2 (using water-based ink #3 on LDPE and PE/EVA), the average was 84% and at Facility 3 (also using ink #3 on LDPE and PE/EVA), the average score was 101.5%.

Overall, the performance of the water-based inks was marked by inconsistency. In several cases, such as blocking resistance with water-based ink #3 and mottle with inks #2 and #4, the inks produced results better than those seen for either of the solvent-based inks. However, several tests of the water-based inks produced results worse than the baseline. In addition, there was variation between facilities using the same product line and substrates for the ice water crinkle and trap tests. The results may indicate that it is possible for water-based inks to obtain or exceed the level of performance of solvent-based inks for some parameters, but that it may be necessary to match the ink closely to the substrate being printed and to control other operating conditions carefully.

Environmental and Health Impacts

In the **occupational risk** assessment, the water-based product lines, as indicated in Table 8.4, had between one and four chemicals with a clear concern for worker health risk in each formulation. Water-based inks #1 and #2 both had the same range of chemicals with a clear concern for risk as the solvent-based inks — between two and four. The range for water-based ink #3 was between one and four, and that for ink #4 was between three and four chemicals with a clear risk concern per formulation.

In each product line, alcohols and amides or nitrogenous compounds produced a clear concern for worker risk via dermal exposure and in most cases via inhalation as well. Other chemical categories chemicals that presented a clear concern for risk included ethylene glycol ethers, organic pigments, and organometallic pigments. The concern for risk in these water-based inks, therefore, arose from solvents, pigments, and multiple-function compounds.

Table 8.4 presents toxicological endpoints associated with compounds in the water-based inks. As with the solvent-based inks, effects may occur both via dermal and inhalation exposure.

The **safety hazard** characteristics of the water-based inks in this analysis were variable, as indicated in Table 8.5. None were reactive or ignitable. Likewise, for flammability, water-based inks #2 and #3 both had ratings of 0 or 1. In contrast, however, water-based inks #1 and #4 had flammability ratings of 3 for some formulations. This difference illustrates that despite the common classification as “water-based,” the content of flammable solvents can vary considerably.

The **VOC content** data also demonstrate the differences among product lines. In Table 8.5, inks #1 and #4 were comprised of 9 and 14% VOCs by weight, respectively. Printers who use water-based ink to comply with the Clean Air Act generally use inks with less than 4% VOC content and minimize their use of VOC press-side solvents and additives. It should be noted, however, that although product lines #2 and #3 contain only small levels of VOCs (1% in each), they also contain small concentrations of HAPs.

Table 8.5 presents the estimated smog-related **air emissions** associated with the use of water-based inks. Despite the lack of an oxidizer, emissions were calculated to be considerably lower than those for the baseline. Inks and press-side materials were expected to release between 110 and 250 grams per 6,000 ft^2, with another 63 grams released due to energy consumption.

Overall, the concern for risk associated with water-based inks is quite variable. Water-based inks #2 and #3 had an equal or lower number of chemicals with a clear concern for worker health risk compared to the baseline, had flammability ratings of 1, and had among the lowest releases of smog-related compounds of the three systems. In contrast, water-based inks #1 and #4 had an equal or higher number of chemicals with a clear concern for risk compared to the baseline, had flammability ratings that for several formulations were equal to that of the baseline, and produced high levels of smog-related compounds. It is clear, then, that the concern for risk associated with these water-based inks was very much formulation-specific.

Operating Costs

For all product lines, water-based ink was less expensive than the baseline. The costs for materials, labor, capital and energy ranged between \$24 and \$30 per 6,000 ft^2 of image, but on average the water-based inks were \$6.40 less expensive to use than the solvent-based inks. Two effects were responsible for this difference: the lack of an oxidizer and the lower consumption of ink and press-side fluids.

The oxidizer generates a strain both on capital and energy costs. As discussed in the solvent-based ink summary, an oxidizer used on two presses may cost approximately \$250,000 to purchase and install. In addition, depending on the amount of solvent loading, energy costs for the oxidizer can be approximately \$2.11 per hour, or \$0.25 per 6,000 ft^2 of image.

In addition, the ink and additive costs were lower for water-based inks. The per-pound price of water-based inks was actually higher: \$1.60 and \$3.00 per pound for white and colored water-based inks, respectively, compared to \$1.40 and \$2.80 per pound for the solvent-based inks. However, the consumption rate was considerably lower for water-based inks, which led to the overall lower costs.

Resource Consumption

As indicated in Table 8.3, energy consumption was the lowest for water-based inks. Among the gas-heated air dryer and electric blower and corona treater, the water-based inks were expected to demand 610,000 Btu/hour, or 73,000 Btu/6,000 ft^2 of substrate. The dryers were expected to consume considerably more energy than those for solvent-based ink (500,000 Btu/hour for the water-based inks compared to 360,000 Btu/hour for solvent-based ink), because water is more difficult to dry than organic solvents; however, the lack of an oxidizer more than offset the difference.

Ink consumption also was lower for water-based ink compared to the baseline. On average (excluding ink usage on PE/EVA, the white substrate), 4.73 lbs of ink and 0.31 lbs of press-side solvents and additives were consumed per 6,000 ft^2 for the water-based system. This represents a 33% decrease in ink consumption and an 88% decrease in press-side solvent and additive consumption compared to the baseline.

Summary of Water-based Inks

The water-based inks studied in this CTSA were very diverse in their performance and risk results and chemical composition, but had better operating cost and resource consumption characteristics.

- Individual product lines performed equal to or better than the baseline in blocking and mottle. However, many of the results for these and other tests were worse than the baseline, highlighting the importance of carefully choosing the specific product when using a water-based ink.
- With respect to the chemical composition and concern for worker health risks of the formulations, as indicated in Table 8.5, these inks contained from 1% to 14% VOCs and from 0% to 3.4% HAPs by weight. The relatively high VOC content in two of the product lines had significant impacts on the safety hazard ratings, and the presence of HAPs may have increased the number of chemicals with clear concern

for worker risk. Though water-based inks are often considered to be safer than solvent-based inks, the results indicate that water-based inks are not always "clean." It should be noted that the health concerns associated with cross-linkers were not addressed by this study. These chemicals, which can be added to water-based inks to improve adhesion, are thought to cause worker health concerns but were not used in the performance demonstrations.

- The operating costs and energy consumption of water-based inks were substantially better than the baseline. Much of the difference was due to the lack of an oxidizer; for water-based inks with VOC contents above state-mandated control levels, this cost and energy advantage may be reduced substantially.

UV-cured Inks

UV-cured inks were considered a "new developing technology" for wide-web film applications when the performance demonstrations were planned and conducted in 1996. Significant changes and improvements have been made to the system and equipment since then.

Three UV-cured inks were used in this analysis. UV-cured ink #1 was tested on LDPE, UV ink #2 was tested on LDPE and PE/EVA, and UV-cured ink #3 was tested on PE/EVA; each ink was tested at one location.

Performance

As with water-based inks, some performance results were better than those of the baseline, but many were not. **Blocking** was one test in which UV-cured inks performed very well. UV-cured inks #1 and #3 both scored an average of 1.0, indicating only slight cling. UV-cured ink #2 had an average score of 2.1, which indicates more substantial cling but very little actual blocking. In contrast, the average score for the solvent baseline was 2.3. This indicates that these UV-cured inks performed well in conditions of heat and pressure.

The ratings for **gloss** were substantially lower (worse) than those for the baseline. The average score for the three coatings was 38.4, compared to the baseline value of 53.0. This is an unexpected result, since high gloss is generally thought of as a feature of UV-cured inks. The reason for this discrepancy is unknown, but it may indicate that if a high-gloss UV-cured ink is needed for a given application, the specific formulations should be chosen carefully.

The **ice water crinkle** test results were perfect on UV-cured inks #1 and #3 – no ink removal was observed. However, ink #2 was partially removed on each of the eight samples tested. This removal was observed on both LDPE and PE/EVA substrates, indicating that the effect may not be simply substrate-dependent. It may be possible that the removal is due to the formulation itself or to variables at the performance demonstration site.

Mottling associated with UV-cured inks was slightly worse than the solvent baseline, but better than that of the water-based inks. UV-cured ink #2 was equal to the baseline, with a mottle index of 205, but inks #1 and #3 were higher at 271 and 273, respectively. As for solvent- and water-based inks, the blue inks in each product line displayed more mottling.

The formulations showed a range of **trapping** values, but ultimately the average was close to that of the water-based inks. The trapping value of UV-cured ink #3 was 95%, which approached the value of the baseline. However, ink #1 had a score of only 82%. The average among the three product lines was 89%.

As for water-based inks, UV ink performance results varied considerably. Even within a product line, the performance could vary from test to test. For example, UV-cured ink #3 performed very well on the physical tests (a blocking score of 1.0, no removal with the ice water crinkle test, and a trap value of 95%). However, it received relatively poor gloss and mottle scores. The converse was true for ink #2; it had the best gloss and mottle scores of the UV inks, but had the worst blocking and ice water crinkle results.

Environmental and Health Impacts

Overall, the concern for risk associated with UV-cured inks is marked by uncertainty. In the **occupational risk** assessment, few of the chemicals have been subjected to toxicological testing. Though the EPA Structure Activity Team (SAT) analyzed the chemicals based on their molecular structure and similarity to chemicals that have been tested, the information is considered to be less certain than that based on direct toxicological research. Testing is necessary to better understand the risks associated with this ink system. The results are based on the risks of the uncured inks, such that risk results may be overestimated if the harmful components chemically react and are integrated into the finished coating.

For UV-cured inks #1 and #3, one or two chemicals per formulation presented a clear concern for occupational risk. This range was lower than that of the baseline. However, UV-cured ink #2 had four or five chemicals with a clear concern for risk per formulation, which was higher than the baseline range. Across the three product lines, the chemicals with a clear concern for worker risk were monomers, oligomers, colorants, and multiple function compounds. In their uncured form, some of these chemicals were reported to present a clear concern for risk through both dermal and inhalation exposure routes.

The toxicological endpoints associated with compounds in UV-cured inks are presented in Table 8.4. In contrast to the solvent-based and water-based inks, fewer types of possible human health effects associated with inhalation of the UV-cured inks were reported. It is not known, however, whether there were fewer observed effects because UV-cured inks are safer or simply because less research has been undertaken on the compounds used in this ink system.

The **safety hazard** information provided in Table 8.5 is not fully available for UV-cured chemicals, because the MSDSs for two of the product lines were generated according to guidelines other than those of the U.S. The one product line for which information was available showed a reactivity level of 1, a flammability level of 1, and it was not ignitable. These levels represent a lesser flammability and ignitability concern compared to the baseline, but the (minimal) reactivity score indicates that the ink should be stored in a dry location that is not subject to high temperatures or pressures.

As shown in the Smog-Related Emissions columns of Table 8.5, the exclusive dependence of UV-cured inks on electricity causes the energy-related emissions to be the highest of any ink system. When combined with the potential emissions from the inks themselves, the UV-cured ink system has the second-highest emissions rate, behind the solvent-based system.

Overall, the UV-cured inks appeared to have fewer chemicals of concern compared to the solvent baseline, and these concerns may decrease further for cured ink. However, more research is needed into the potential health effects of the chemicals for which no direct data were available. Furthermore, though UV-cured inks #1 and #3 had fewer chemicals with a clear concern for worker risk and lower emissions than the baseline, the opposite was true for

UV-cured ink #2. The concern for risk associated with UV-cured ink formulations, therefore, may vary significantly.

Operating Costs

The cost of operating a UV-cured system was calculated to be higher than for the other two systems. The average cost was \$3.80 higher than the baseline per 6,000 ft^2. One ink, UV-cured ink #3, had lower operating costs than the baseline, but much of this is due to the fact that it was only printed on PE/EVA, and therefore white ink was not necessary.

Several factors contributed to these higher operating costs. First, the prices of UV-cured inks are approximately \$6 more for white ink and \$7 more for colored inks, per pound. Ink consumption per square inch of substrate is lower for UV inks, but if anilox rolls are not optimized for these inks, the lower consumption would not be fully realized. Another factor is that UV-cured systems also run exclusively on electricity. In contrast, solvent- and water-based inks typically fuel dryers and oxidizers with natural gas, which is less expensive. Finally, the capital cost of a UV-cured press is higher than that of a water-based ink press. Though a UV-cured press does not require hot-air dryers, the UV curing lamps are more expensive than these dryers. (The cost of a UV-cured press is expected to be similar to that of a solvent-based press, however, which also has an oxidizer system.)

Resource Conservation

UV-cured inks had both lower energy and ink consumption rates compared to the baseline. The UV-cured process consumed approximately 650,000 Btu/hour, or78,000 Btu/6,000 ft^2 at a press speed of 500 feet per minute. Both the energy costs and air releases are higher for UV than for the other two systems, though; this is because all of the energy is obtained from electricity, which is both more expensive and is produced inefficiently in comparison to on-site natural gas combustion.

The consumption rate of UV-cured inks was the lowest among the three systems. On non-PE/EVA substrates, an average of 3.47 lbs (and almost no additives) were consumed per 6,000 ft^2. When comparing this figure to the amount of ink and additives consumed by the baseline, UV-cured inks consumed six pounds less material per 6,000 ft^2.

Summary of UV-cured Inks

Like water-based inks, UV-cured inks displayed variability among the product lines.

- The performance tests had mixed results – improving upon the baseline for blocking but mostly trailing the baseline for the other tests.
- For worker risk, the UV-cured inks on average contained fewer chemicals with a clear concern for risk per formulation than the baseline. However, one ink (#2) had relatively high VOC air emission rates and more chemicals with a clear concern for risk, indicating a potential variability among the UV-cured product lines. The comparatively high number of chemicals with a clear concern for worker health risk that only were analyzed by the SAT signals two issues. Specifically for this analysis, it indicates that there is considerable uncertainty associated with the UV risk analysis. More generally, it may indicate that compounds used in UV-cured inks are of concern but that their risks are poorly understood. These results indicate that research on these chemicals should be a priority.

- Operating costs of the UV-cured inks were higher compared to the solvent baseline, primarily because of the price of ink.
- The UV-cured inks produced better results than the baseline for resource conservation; they required less energy and considerably less ink.

8.2 QUALITATIVE SOCIAL BENEFIT-COST ASSESSMENT

Introduction to Social Benefit-Cost Assessment

Social benefit-cost analysis[b] is a tool used by policy makers to systematically evaluate the impacts to all of *society* resulting from individual decisions. A social benefit-cost analysis seeks to compare the benefits and costs of a given action, considering both the internal and external costs and benefits.[c] Such an approach is unlike business decision making, which generally only considers the internal (or private) costs and benefits of an action without taking into account any accompanying externalities.

The decision evaluated in this assessment is the choice of a flexographic ink system for wide-web film applications. Flexographic printers have a number of criteria they may use to assess which ink system technology or product line they will use. For example, a printer might consider what impact their choice of an ink system might have on operating costs, liability costs, insurance premiums, or the cost of compliance with environmental regulations. These criteria are all part of the internal decision making process; they do not include considerations that may be of importance to society as a whole.

This benefit-cost assessment considers both the impact of choosing between various ink systems and product lines on the printer (internal costs and benefits) and on other members of society (external costs and benefits), such as reductions in environmental damage and reductions in the risk of illness for the general public. Table 8.6 defines a number of terms used in this benefit-cost assessment, including externality, and public (external) costs and benefits.

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[b] The term "analysis" is used here to refer to a more quantitative analysis of social benefits and costs, where a monetary value is placed on the benefits and costs to society of individual decisions. Examples of quantitative benefit-cost analyses are the regulatory impact analyses done by EPA when developing federal environmental regulations. The term "assessment" is used here to refer to a more qualitative examination of social benefits and costs. The evaluation performed in the CTSA process is more correctly termed an assessment because many of the social benefits and costs of flexographic ink technologies are identified, but not monetized.

[c] Private costs typically include any direct costs incurred by the decision maker and are generally reflected in the manufacturer's balance sheet. In contrast, public costs are incurred by parties other than the primary participants to the transaction. Economists distinguish between private and public costs because each will affect the decision maker differently. Although public costs are real costs to some members of society, they are not incurred by the decision maker, and firms do not normally take them into account when making decisions. A common example of these "externalities" is an electric utility whose emissions are reducing crop yields for the farmer operating downwind. The external costs experienced by the farmer in the form of reduced crop yields are not considered by the utility when making decisions regarding electricity production. The farmer's losses do not appear on the utility's balance sheet.

Table 8.6 Glossary of Benefit-Cost Analysis Terms

Term	Definition
Cost of Illness	A financial term referring to the liability and health care insurance costs a company must pay to protect itself against injury or disability to its workers or other affected individuals. These costs are known as illness benefits to the affected individual.
Exposed Population	The estimated number of people from the general public or a specific population group who are exposed to a chemical through wide dispersion of a chemical in the environment (e.g., DDT). A specific population group could be exposed to a chemical due to its physical proximity to a manufacturing facility (e.g., residents who live near a facility using a chemical), use of the chemical or a product containing a chemical, or through other means.
Exposed Worker Population	The estimated number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be based on market share data as well as estimations of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration.
Externality	A cost or benefit that involves a third party who is not part of a market transaction; "a direct effect on another's profit or welfare arising as an incidental by-product of some other person's or firm's legitimate activity."[2] The term "externality" is a general term which can refer to either external benefits or external costs.
Human Health Benefits	Reduced health risks to workers in an industry or business as well as to the general public as a result of switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile organic compound, lessening worker inhalation exposures as well as decreasing the formation of photochemical smog in the ambient air.
Human Health Costs	The cost of adverse human health effects associated with production, consumption, and disposal of a firm's product. An example is respiratory effects from stack emissions, which can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work.
Indirect Medical Costs	Indirect medical costs associated with a disease or medical condition resulting from exposure to a chemical or product. Examples would be the decreased productivity of patients suffering a disability or death and the value of pain and suffering borne by the afflicted individual and/or family and friends.
Private (Internal) Benefits	The direct gain received by industry or consumers from their actions in the marketplace. One example includes the revenue a firm obtains in the sale of a good or service. Another example is the satisfaction a consumer receives from consuming a good or service.
Private (Internal) Costs	The direct costs incurred by industry or consumers in the marketplace. Examples include a firm's cost of raw materials and labor, a firm's costs of complying with environmental regulations, or the cost to a consumer of purchasing a product.
Public (External) Benefits	A positive effect on a third party who is not a part of a market transaction. For example, if an educational program results in behavioral changes which reduce the exposure of a population group to a disease, then an external benefit is experienced by those members of the group who did not participate in the educational program. For the example of nonsmokers exposed to second-hand smoke, an external benefit can be said to result when smokers are removed from situations in which they expose nonsmokers to tobacco smoke.
Public (External) Costs	A negative effect on a third party who is not part of a market transaction. For example, if a steel mill emits waste into a river which poisons the fish in a nearby fishery, the fishery experiences an external cost as a consequence of the steel production. Another example of an external cost is the effect of second-hand smoke on nonsmokers.
Social Costs	The total cost of an activity that is imposed on society. Social costs are the sum of the private costs and the public costs. Therefore, in the example of the steel mill, social costs of steel production are the sum of all private costs (e.g., raw material and labor costs) and the sum of all public costs (e.g., the costs associated with the poisoned fish).
Social Benefits	The total benefit of an activity that society receives, i.e., the sum of the private benefits and the public benefits. For example, if a new product yields pollution prevention opportunities (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the public benefit (benefit society receives from reduced waste).
Willingness-to-pay	Estimates used in benefits valuation are intended to encompass the full value of avoiding a health or environmental effect. For human health effects, the components of willingness-to-pay include the value of avoiding pain and suffering, impacts on the quality of life, costs of medical treatment, loss of income, and, in the case of mortality, the value of life.

Internal benefits of selecting an alternative ink system may include increased profits resulting from improved worker productivity and company image, a reduction in energy use, or reduced property and health insurance costs due to the use of less hazardous chemicals. External benefits may include improved public health from a reduction in pollutants emitted to the environment or reduced use of natural resources. Costs of the alternative ink systems may include private costs such as changes in operating expenses and public costs such as change in the price of the product charged to the consumer. Some benefits and cost are both internal and external. For example, use of an alternative ink system may result in natural resource savings. This may benefit the printer in the form of reduced water usage and a reduction in payments for water, and society as a whole in the form of reduced consumption of shared resources.

Benefit-Cost Methodology and Data Availability

The methodology for conducting a social benefit-costs assessment can be broken down into four general steps: 1) obtain information on the relative human and environmental risk, performance, cost, process safety hazards, and energy and natural resource requirements of the baseline and the alternatives; 2) construct matrices of the data collected; 3) when possible, monetize the values presented within the matrices; and 4) compare the data generated for the alternative and the baseline in order to produce an estimate of net social benefits. Section 8.1 presented the results of the first two tasks by summarizing performance, cost, energy use, risk, and safety hazard information for the baseline and alternative ink system technologies. The remainder of Section 8.2 interprets the presented data in the context of social benefit-cost assessment: the first part presents an analysis of the potential private and public costs, the second part discusses the potential private and public benefits.

Ideally, this benefit-cost chapter would quantify all of the social benefits and costs of using the different ink systems and identify the technology whose use results in the largest net social benefit. However, because of resource and data limitations and because some of the observations in the demonstrations were very site-specific, the analysis presents a qualitative description of the economic implications of the risks and other external effects associated with each technology. Benefits derived from a reduction in risk are described and discussed, but not quantified. Nonetheless, the information presented can provide useful insights when deciding between different ink systems or product lines.

The following discussions provide examples that qualitatively illustrate some of the important benefit and cost considerations. However, no overall recommendation is given. Rather, personnel in each individual facility will need to examine the information presented and identify, based on their own concerns and priorities, the best choice of ink system and product line for their facility.

Potential Private and Public Costs

It not possible to obtain comprehensive estimates of all private costs of the alternative ink systems. However, some cost components were quantifiable. For example, the cost analysis estimated the average operating costs associated with each ink system, including the material costs (ink and additive costs), labor costs for a press operator and assistant, overhead costs (rent and heat, fire and sprinkler insurance, indirect labor, repair to equipment, and administrative and sales overhead), average capital costs (base equipment, required add-ons, and installation), and energy costs (electricity and natural gas). Other cost components may contribute significantly to overall operating costs, but were not quantified because they could not be reliably estimated. These cost components include press cleaning costs, wastewater costs, sludge recycling and disposal costs, and other solid waste disposal costs.

External costs are those costs that are not included in the printer's pricing and printing decisions. These costs are commonly referred to as "externalities" and are costs that are borne by society and not by the individuals who are part of a market transaction. These costs occur in a variety of ways in the printing process. For example, if a printer uses large quantities of a non-renewable resource during the printing process, society will eventually bear the cost of depletion of this natural resource. Another example of an external cost are health effects on the population living in the communities surrounding the facility which may result from the emission of chemicals from a printing facility. The printer does not pay for any illnesses that occur outside the facility even if they are caused by the facility's air emissions. Society must bear these costs in the form of medical payments or higher insurance premiums.

Differences in the operating costs estimated in the cost analysis are summarized below.

Private Costs
Operating costs are arguably the most obvious and measurable factor influencing a business's choice of ink technologies. Lower operating costs are a direct and immediate benefit to the printer because they will directly influence the facility's bottom line. In addition, lower operating costs may allow the printer to reduce the cost per image to the consumer, thus placing the printer into a more competitive position in the market.

Table 8.7 presents the overall operating costs for all ink systems studied in the performance demonstrations, as well as a comparison between the average costs for the alternatives and the baseline. All cost data are presented for 6,000 square feet of image created at a press speed of 500 feet per minute. The data in Table 8.7 show that water-based inks (Alternative 1) had a lower average operating cost than the baseline (solvent-based inks) during the demonstrations. Water-based inks averaged a operating cost of $26.60 per 6,000 square feet of image, while solvent-based inks averaged $33.43. In addition, the range for water-based inks ($24.23 to $30.04) fell well below the range for the baseline ($31.89 to $34.06). UV-cured inks (a new developing technology for wide-web film applications) showed an average cost of $36.82, higher than both the baseline and Alternative 1. However, the lower bound of the range for this technology ($23.69) fell below the average costs for both the baseline and Alternative 1. The large range in costs for this technology ($23.69 to $51.00) is not surprising given that UV-cured inks are a new developing technology. With further technological developments, this technology is likely to become more cost competitive with the more established ink technologies.

Table 8.7 also presents a breakdown of costs used to calculate the operating cost number. Labor costs were constant across all ink systems at $5.29. Capital and energy costs changed across the systems but did not change at the product line level, with the lowest costs occurring in the water-based system at $11.41 and $0.35 respectively. Material costs were the only costs that differed by product line within an ink system. Material costs are the sum of the costs for color inks, white inks, and additives used during the performance demonstrations. With the exception of one UV product line, water-based inks had the lowest material costs.

It should be noted that these calculations are based on the costs of printing on three different substrates used during the performance demonstrations. One of the substrates, PE/EVA, does not require white ink and therefore has a lower material cost than substrates that do require white ink. Since all three systems were tested on all three substrates during the performance demonstrations, and a similar image can be created on all three substrates, the cost estimates presented in Table 8.7 are based on all results. However, actual material costs for specific systems or product lines may be higher than in the performance demonstrations if a substrate other than PE/EVA were used. Each individual printer should determine the specific costs of a system and product line, based on the substrate and facility-specific conditions, before making decisions on a system or product line.

Table 8.7 Operating Cost Breakdown per 6,000 ft^2 of Image at 500 Feet per Minute

Product Line	**Material Cost**	**Labor Cost**	**Capital Cost**	**Energy Cost**	**Total Cost**
Baseline: Solvent-based Ink Systems					
Solvent-based #1	$14.20	$5.29	$11.87	$0.53	$31.89
Solvent-based #2	$16.37	$5.29	$11.87	$0.53	$34.06
Average across Solvent-based Inks	*$15.29*	*$5.29*	*$11.87*	*$0.53*	*$32.98*
Alternative 1: Water-based Ink Systems					
Water-based #1	$12.99	$5.29	$11.41	$0.35	$30.04
Water-based #2	$9.73	$5.29	$11.41	$0.35	$26.78
Water-based #3	$8.31	$5.29	$11.41	$0.35	$25.36
Water-based #4	$7.18	$5.29	$11.41	$0.35	$24.23
Average across Water-based Inks	*$9.55*	*$5.29*	*$11.41*	*$0.35*	*$26.60*
New Developing Technology: UV-cured Ink Systems					
UV-cured #1	$32.81	$5.29	$11.87	$1.03	$51.00
UV-cured #2	$17.59	$5.29	$11.87	$1.03	$35.78
UV-cured #3	$5.50	$5.29	$11.87	$1.03	$23.69
Average across UV-cured Inks	*$18.63*	*$5.29*	*$11.87*	*$1.03*	*$36.82*

While lower operating costs are likely to be an important factor in a printer's choice of an ink system, it is important to note that additional costs associated with the conversion from one ink system to another may negate some or all of the cost savings discussed above. For example, substantial capital investments may be required to switch from one system to another. Examples of the costs of purchasing a new press and retrofitting a press from one system to another are presented in Table 8.8. A switch to an alternative ink system also may involve costs to retrain employees on the new printing equipment. Another influence on private costs is the press speed of the new system. In the cost chapter of the CTSA where costs were calculated at both the methodology speed and the speeds observed during the performance demonstrations, the per-image costs for labor, capital, and energy decreased at the same rate that press speed increased. Press speed is a critical cost driver, and its impacts should be assessed when an ink system switch is considered. Issues such as the level of required monitoring, along with differences in setup and cleanup, may also impact a decision among ink systems. The decision to switch from one ink technology to another is necessarily site-specific and should be made based on all costs relevant to the facility and the ink system under consideration.

Public Costs

In addition to profitability considerations, there are potential cost savings to the consumer associated with the operating cost differentials among the ink system technologies. A switch to a cheaper technology by large parts of the flexographic ink market might enable the printers to reduce the price charged to consumers.[d] However, this would only be the case if overall costs, including potential capital costs and training costs associated with switching to a different ink system, were lower than the baseline costs. Alternatively, a switch to a more expensive technology may lead to an increase in the cost to the consumer.

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[d] In a competitive market, each individual firm is assumed to be a price-taker. Therefore, a benefit in terms of reduced prices to the consumer would only be possible if the number of printers switching to a cheaper technology is large enough to exert an influence on prices.

Table 8.8 Capital Costs of Changing Ink Press Technologies

	Capital Costs for New Presses			Capital Cost for Retrofitting a Press[d]		
Ink System	**Base Press Cost**	**Additional Cost**	**Total Capital Cost**	**Cost of Retrofit from Solvent System Press**	**Cost of Retrofit from Water System Press**	**Cost of Retrofit from UV System Press**
Baseline: Solvent-based Ink Systems	$2.5 million	$128,500[a]	$2.6 million		NA	NA
Alternative 1: Water-based Ink Systems	$2.5 million	$25,000[b]	$2.5 million	$60,000 - $100,000		$32,000
New Developing Technology: UV-cured Ink Systems	$2.4 million	$200,000[c]	$2.6 million	$400,000 to $500,000 when possible	$180,000 to $240,000 ($30,000 per deck)	

[a] Cost for pollution control

[b] Cost for a corona treater

[c] Cost for a corona treater, UV lamps, power supplies, and cooling unit

[d] Retrofit costs include only the additional costs of equipment. The labor, training, and downtime costs associated with a retrofit were not included because these costs are highly variable and situation specific.

Potential Private and Public Benefits

To provide the necessary information for the overall private benefit-cost comparison, a qualitative discussion of private benefits, including occupational health risks and safety hazard considerations, is presented. While these benefits could not be monetized or even quantified, they have the potential to directly affect a facility's costs and profits, and should therefore be carefully considered in the decision-making process.

Public, or external, benefits are those that do not benefit the printer directly. For example, an alternative that produces less air pollution results in both private and public benefits: the printer pays for fewer raw materials and society in general benefits from better air. The potential external benefits associated with the use of an alternative ink system include reduced health risk for the general public, reduced ecological risk, and reduced use of energy and natural resources.

Private Benefits

Performance Related Benefits

In addition to costs, performance is generally of greatest importance to any business operating in a competitive market. Performance is closely linked to the quality and appearance of the delivered product. In general, performance improvements lead to increased product revenues, and performance shortcomings lead to decreased customer satisfaction and revenues.

The CTSA assessed performance with 18 standard tests (see Chapter 4: Performance). Five of these tests were selected as summary performance tests based on their importance and quantifiability (see Section 8.1, Table 8.3). Average performance demonstration results of Alternative #1 (water-based inks) in the five summary tests were close to, but lower than, those of the baseline (solvent-based inks). The average performance results of the developing technology (UV-cured inks) were also close to, but lower than, the baseline in four of five tests. However, it is important to note that performance results of individual product lines and formulations varied considerably, so that there is substantial overlap in the performance range of the three systems. This indicates that flexographers may be able to achieve many of the performance parameters needed for their products from any of the three systems. The variation in performance by demonstration site also underscores the need to optimize ink performance (via formulation and equipment selection as well as the use of press side solvents and additives) with all systems.

Ideally, flexographers would always choose the best-performing ink system with the lowest cost. However, this CTSA indicates that there may be some cost-performance tradeoffs. Lower-cost systems and formulations may yield lower performance. Alternatively, the CTSA indicates that printers may want to consider using systems and formulations with equal or better performance and higher costs if those higher costs are accompanied by environmental benefits. Three examples of private environmental benefits in the CTSA are discussed below — reduced occupational health risk, reduced safety hazards and regulatory costs, and reduced energy use.

Occupational Health Risk

Occupational health risk refers to any health impairments that may result from the workers' exposure to hazardous chemicals. Improved occupational health may have several tangible benefits to the facility: it may lead to fewer sick days, improved worker satisfaction, improved worker productivity, and reduced insurance or compensation costs. In the context of this CTSA, occupational health risk refers to press room workers subject to dermal and inhalation exposure and prep room workers subject to dermal exposure of hazardous chemicals contained in the various ink formulations.

Table 8.4 in Section 8.1 presents a range of chemicals of concern for each product line used in the performance demonstrations. The average number of chemicals assessed by the SAT with a clear concern for occupational risk associated with both Alternative 1 (1 to 4 chemicals) and the new developing technology (1 to 5 chemicals) was slightly lower than that of the baseline (2 to 4 chemicals). This CTSA uses the number of chemicals with occupational concern as an indication of the potential risk to press room workers. However, other factors, such as the concentration of chemicals of concern, also play an important role in assessing occupational health risks.

Lower risk to workers may have a number of monetary benefits for the printer: Reduced health risk may lead to reduced illnesses by the facility's workers, which positively influences the facility's productivity. In addition, better worker health is also likely to increase worker satisfaction (or decrease worker dissatisfaction), which can also influence worker productivity. A less hazardous working environment may also lead to lower health insurance premiums, part of which the facility may pay, and reduced workers compensation expenditures.

Safety Hazard and Regulatory Costs

Additional private benefits of reducing the number of chemicals of concern may be realized from reduced safety hazards at the facility and reduced regulatory compliance requirements. Safety hazards associated with flexographic inks include reactivity, flammability, and ignitability. Improved chemical characteristics with respect to these hazards may lead to a reduction in the insurance premiums paid by the printer, as well as a potential reduction in waste disposal and storage costs. In addition, by switching away from hazardous chemicals, a facility may be able to avoid certain regulatory and reporting requirements associated with hazardous materials. Similarly, a reduction in reporting and regulatory requirements would also produce public benefits for government, and therefore taxpayers. These benefits may stem from permit writers having to issue permits to fewer facilities or for a reduced number of chemicals, or less enforcement actions being required.

Table 8.5 in Section 8.1 summarizes safety hazard results for the three ink systems. Of the three ink systems, only solvent-based inks pose *ignitability* concerns, resulting in a greater safety hazard. Data were incomplete for reactivity and flammability characteristics of UV inks. The water-based ink technology compared favorably to the solvent-based technology in terms of *flammability* (a range of 0 to 3 compared to 3 for solvent based inks), while no difference in *reactivity* was observed between the two systems (both showed zero reactivity).

Energy Use

Energy use is another direct cost of production to the printing facility. Employing more energy efficient technologies may benefit a printer by reducing production costs as well as improving the facility's public image. With increasing environmental consciousness by the public, facilities using environmentally friendly production technologies may be able to create considerable goodwill in their communities and take advantage of advertising opportunities in addition to providing benefits to the environment and society as a whole.

The energy used by each ink system is expressed in terms of the number of British thermal units (Btu) used to produce 6,000 square feet of image. Table 8.3 in Section 8.1 shows that water-based inks and UV inks use less energy than solvent-based inks, with averages of 73,000 and 78,000 Btu, respectively, compared to 100,000 Btu used by the solvent-based ink technology. This reduced energy use may result in private and social benefits, as discussed above.

All things equal, choosing an ink technology that uses less energy during the printing process will have public benefits as well as private benefits. A reduction in energy use conserves natural resources, a benefit to society as a whole and future generations. However, it is interesting to note that the environmental impacts of energy use (and therefore public benefits) differ by energy source. For example, natural gas is relatively clean-burning compared to some sources of electricity, such as high-sulfur coal. Thus the public benefit of switching to a more energy-efficient process may be decreased if that switch entails a fuel source change from gas to coal-derived electricity.

Public Benefits

Public Health Risk

A reduction in the number of chemicals of concern not only presents private benefits to the printer but may also produce several public benefits. Society may benefit from reductions in air releases from the printing facility, which can lead to such health effects as asthma, red eyes, nausea, or headaches.[e] When present, these health effects can lead to sick days among the general public and workers living near the facility, and cause absenteeism at those workers' place of employment. A reduction in air emissions may also lead to a reduction in private and public health care costs.

Table 8.5 in Section 8.1 summarizes smog-related emissions associated with the different product lines. The table shows that at the assumed capture efficiency of 70%, solvent-based emissions of smog-related compounds from ink and energy sources are considerably higher than those from the other two systems. Solvent-based emissions ranged from 757 to 1070 g/6,000 ft^2. In contrast, water-based inks ranged from 173 to 313 g/6,000 ft^2, and UV-cured inks ranged from 187 to 523 g/6,000 ft^2. Table 8.5 also compares the product lines tested for the three ink systems in terms of VOC and HAP content. No HAP content was measured for solvent-based and UV-cured inks, whereas the HAP content for water-based inks ranged from 0 to 3.4% by weight. UV-cured inks have the lowest calculated VOC content, with 1% reported for each of the three tested product lines. The VOC content for water-based inks ranges from 1 to 14% by weight, while solvent-based inks record a range of 54 to 67%.

In addition to air emissions, there is a potential for chronic general population exposure via other pathways (e.g., drinking water, fish ingestion, etc.), or acute short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other one-time release. Again, these potential risks are reduced when the number of chemicals of concern used at a facility is lowered.

Partially because of the chemical diversity of ink formulations within each system, potential public health benefits from a switch in ink technologies could not be quantified for this CTSA. However, some general examples can illustrate the potential economic impacts that less exposure to hazardous chemicals may have. Table 8.9 presents estimates of the economic costs of some of the illnesses or symptoms associated with exposure to flexographic printing

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[e] Asthma, red eyes, and headaches have been associated with ozone, a product of VOCs released from inks and from energy production. Lung and neurotoxic effects, which may include asthma and headaches, respectively, have been associated with compounds with a potential concern for general population risk.

chemicals. To the extent that flexographic printing chemicals are not the only factor contributing to the illnesses described, individual costs may overestimate the potential benefits to society from substituting alternative ink technologies for the baseline ink system. In addition, if an alternative ink system contains some of the same chemicals, the full economic benefit may not be realized.

Eye irritation, headaches, nausea, and aggravation of previously existing respiratory problems are effects associated with ozone (derived from VOCs in inks or released during energy production) or with individual compounds with a possible concern for general population risk. The economic literature provides estimates of the costs associated with eye irritation, headaches, nausea, and asthma attacks. An analysis by Unsworth and Neumann summarizes the existing literature on the cost of illness based on estimates of how much an individual would be willing to pay to avoid certain acute effects for one symptom day.[3] These estimates are based upon a survey approach designed to elicit estimates of individual willingness-to-pay to avoid a single-day incidence of the illness. They do not reflect the lifetime costs of treating the disease.

Table 8.9 presents a summary of the low, mid-range, and high estimates of individual willingness-to-pay to avoid eye irritation, headaches, nausea, and asthma attacks. These estimates provide an indication of the benefit per affected individual that would accrue to society if switching to a substitute ink technology reduced the incidence of these health endpoints.

Table 8.9 Estimated Willingness-to-Pay to Avoid Morbidity Effects for One Symptom Day (1995 dollars)

Health Endpoint	Low	Mid-Range	High
Eye Irritation[4]	$21	$21	$46
Headache[5]	$2	$13	$67
Nausea[6]	$29	$29	$84
Asthma Attack[7]	$16	$43	$71

Ecological Risk

A potential ecological benefit of using ink formulations with fewer hazardous chemicals is reduced aquatic toxicity and less hazardous waste that needs to be disposed of in the community. Aquatic toxicity can negatively affect fish populations near the points of discharge and lead to a reduction in the variety of fish species (particularly species intolerant of environmental stressors) or a reduction in the size of fish populations. Such impacts on fish populations can impair recreational and commercial fishing opportunities. An ink system that results in the discharge of fewer chemicals of concern to aquatic populations could therefore lead to direct economic benefits in the communities surrounding the facility.

Summary of Social Benefit-Cost Assessment

The following sections present a summary of each of the three ink system technologies across the benefit and cost categories discussed in this chapter.

Solvent-based Inks

- The solvent-based ink system, on average, had lower total operating costs than UV-cured inks, but higher than water-based ink systems. This higher cost can be attributed mostly to higher material and capital costs of solvent-based technologies. In particular, average material costs for solvent-based systems (per 6,000 square feet of image) were approximately $5.00 higher than those for water-based systems.
- In the performance area, the solvent-based system on average outperformed both water-based and UV-cured systems. This system was the best with respect to gloss and trap and among the best on the other three summary performance tests.
- On average, solvent-based inks contained two to four chemicals with a clear concern for occupational risk, slightly higher than the ranges for water-based and UV-cured inks. This may indicate a higher occupational risk.
- Public health risk was evaluated through releases of smog-related compounds, VOC and HAP content, and the systemic and developmental risks to the general population. Despite the fact that this system used oxidizers, emissions were calculated to be considerably higher than the emissions of the other systems. VOC content was, as expected, much higher than either of the two other systems. This system did not contain any HAPs. For general population risks, two chemical categories in Solvent #2 contained chemicals that presented a potential concern for risk.
- In terms of process safety, solvent-based inks had more concerns than the other systems, although the results for UV-cured inks were incomplete. Only solvent-based inks presented an ignitability concern and also presented a higher flammability concern than water-based inks.
- Solvent-based inks were shown to use more energy to produce the same square footage of image.

Water-based Inks

- Operating costs were lowest for the water-based ink product lines. In fact, in all cost categories, water-based ink systems had the lowest average cost. Cost savings were particularly pronounced for material costs.
- Though water-based ink formulations #2 and #4 had the best mottle scores of all product lines, overall the water-based inks did not perform as well as the solvent-based inks in the five summary performance categories. The system also was outperformed by the UV-cured inks in three categories. While this may indicate a lower quality product, it is important to note that in many cases the differences were small and may be insignificant.
- In the occupational health area, water-based inks presented a lower average number of chemicals with a clear concern for risk per product line, indicating a better chance of reducing occupational health risks compared to the baseline.
- The amount of smog-related emissions that resulted from ink releases and energy production with the water-based system was considerably lower than that from solvent-based system, and was comparable to that from the UV-cured system. Water-based inks had a much lower VOC content than solvent-based inks, but were the only inks that contained HAPs.
- Like with solvent-based inks, printers often add VOC solvents and additives at press side to water-based inks. In substantial amounts, these materials compromise the low-VOC content of the ink and can pose clear pressroom worker risks. At one site using water-based inks (Site 3), over half of the emissions resulted from materials added at press-side.

- The safety of water-based inks was better than that of solvent-based inks. There was no indication of ignitability or reactivity. However, water-based inks had a higher flammability risk than UV-cured inks.
- As for energy expenditures, water-based inks had the lowest average energy use.

UV-cured Inks

- The UV-cured inks had the highest average operating costs. However, since it is a new developing technology for wide-web film, these costs are likely to fall as the technology develops. The biggest cost differential was the material costs, falling approximately \$8.00 per 6,000 ft^2 of image above the average costs for water-based inks. It is also worth noting that energy costs of the UV systems were considerably higher — nearly two times the cost for solvent-based inks and nearly three times the cost for water-based inks.
- The performance of the UV-cured inks was generally worse than the solvent-based baseline, though this system had better blocking resistance, and individual product lines had ice water crinkle and mottle results that were equal to the solvent-based results. The performance results were slightly better than those of the water-based inks.
- The UV-cured inks presented the lowest chance of occupational health risk, and with respect to public health, had the lowest HAP content (none) and VOC content. A couple of SAT-analyzed compounds present a potential concern for general population risk, however, indicating that research on some compounds is needed.
- Safety hazard data were incomplete for UV inks. However, UV inks were the only inks that present the potential for reactivity.
- Finally, the energy used by UV-cured systems was approximately 22% less than that of the baseline, and was only slightly higher than that of the water-based inks. The air releases associated with the energy production were higher than the baseline, however, because all energy required by the UV system was derived from electricity — a more pollution-intensive energy source in comparison to natural gas.

The intent of this benefit-cost assessment is to illustrate the possible benefits and costs of switching ink systems and to give individual printers insight into the potential social benefits and costs of their current ink system. When drawing conclusions from the above discussion in this chapter, it is important to note that many of the results are based on the performance demonstrations conducted for this report. Printers may therefore find that an individual facility will not experience similar results in some or all of the benefit-cost categories. If a printer chooses to make a change in ink systems, it is important to consider the specific needs and requirements of the facility and the printer's customers.

8.3 DECISION INFORMATION SUMMARY

Introduction

This CTSA presents comparative information on the relative risk, performance, costs, and resource conservation of the three flexographic ink systems. However, it does not provide recommendations or judgments about whether or not to implement an alternative. This section may assist decision makers in choosing the most appropriate ink technology for individual circumstances. There are three parts in this section:

The **ink system comparison** summarizes the findings of Sections 8.1 and 8.2 with respect to solvent-based, water-based, and UV-cured inks. By integrating the findings of the first section and the practical benefits and costs described in the second, this comparison describes the anticipated impacts of each system based on the findings of the research in this CTSA.

After an ink system is selected, it is necessary to select specific formulations. The **chemical categories** section presents the hazard, risk, and regulatory characteristics of the groups of chemicals in this CTSA. This section may be useful for printers and ink formulators alike who wish to identify chemicals that should be avoided or that are potentially safer substitutes for harmful ingredients.

The final section, **suggestions for improvements**, summarizes the steps that can be taken by printers and ink companies to minimize the health and environmental risks of inks and considerations for selecting the best ink formulations for a facility.

Ink System Comparison

As indicated in Sections 8.1 and 8.2, the results did not identify any one ink system as a best choice for all situations. This section discusses the relative benefits and drawbacks that were found with each system.

Baseline: Solvent-based inks

The solvent-based inks were the baseline for this analysis, and they displayed solid performance characteristics and reasonable costs — two factors of primary concern to many decision makers. However, the analysis indicated that they fared poorly on other factors, such as health risks, safety hazards, regulatory costs, and energy use.

The strength of the solvent-based inks in this CTSA was performance. On average, this system produced the best performance results on four of the five tests discussed in this chapter. The results indicated that these particular inks may be the most appropriate for particularly challenging printing tasks, such when process colors must be matched precisely or when the product is intended for use in cold, wet conditions.

Health risks, safety hazards, regulatory costs, and energy use generally were negative aspects of the solvent-based inks. As indicated in Table 8.4, solvent-based inks had the highest average number of chemicals with a clear concern for worker risk per formulation (3.2). Most of the chemicals with a clear concern for risk were solvents, with some of those added at press side. The solvent-based inks had the highest VOC content— an average of 58% by weight. This directly affected the emissions rate of smog-related compounds — the average rate (914 g/6,000 ft^2) was more than three times the average rate for water-based and UV-cured systems (221 and 300 g/6,000 ft^2, respectively) at the assumed capture efficiency rate. The solvent-based inks were the only formulations that were classified as ignitable, and they also had a relatively high flammability rating of 3 (on a scale of 0-4).

Under the operating parameters assumed for this analysis, the high health risk and safety hazard indicators suggest that these solvent-based inks may result in costs to the firm in the form of more worker sick days, decreased worker satisfaction, decreased worker productivity, and increased insurance premiums. These costs would result in lower profits. Possible social impacts of solvent-based inks include increased sick days among the general public and an increase in health care costs. The flammability and ignitability of the formulations may require more effort to comply with environmental and fire regulations, thereby increasing waste disposal and storage costs. (Note, however, that many types of ink wastes can be blended with fuel for energy recovery or distilled for reuse. Either of these practices may reduce waste disposal costs.) Finally, because oxidizers are required when using solvent-based inks, energy use was the highest for this system. The emissions associated with this energy consumption, however, were comparable to those of the other two systems, because much of the energy was derived from relatively clean-burning natural gas.

As shown in Table 8.6, the average operating cost of the solvent-based inks (\$32.98 per 6,000 ft^2) was higher than that of the water-based inks (\$26.60 per 6,000 ft^2), but lower than that of the UV-cured inks (\$36.82 per 6,000 ft^2). Costs were increased by the use of an oxidizer and the high ink consumption rate but were moderated by the relatively low per-pound price of ink.

Alternative #1: Water-based inks
The water-based inks that were evaluated had both private advantages and disadvantages; however, the social impacts of water-based inks appear to be of less concern in comparison to the solvent baseline.

This ink system had inconsistent performance test results. Though some individual test results were better than the baseline, the average outcome of the water-based inks for each test was poorer than that of the solvent-based inks. Such a decrease in quality may either prevent printers from switching technologies or may require them to take steps to improve the quality. Two water-based product lines had better mottle results than the baseline, and in general the gloss and blocking were comparable to the solvent-based inks. Under conditions where the product is subjected to minimal physical demands, the visual characteristics of water-based inks may be similar to those of solvent-based inks. However, if the ink were to be exposed to cold or wet conditions — like those measured by the ice water crinkle test — these product lines may compare unfavorably to solvent-based inks or may require modifications.

By some measures, a switch to water-based inks may yield both private and social benefits with respect to health risks and safety hazards. In terms of safety hazards, none of the inks were ignitable or reactive. The flammability of the water-based inks ranged from 0-3, in contrast to solvent-based inks which were all rated 3. The VOC content was an average of 6% by weight, compared to the concentration of nearly 60% in solvent-based inks. For inks with low flammability and VOC content, improvements may be seen in lower insurance premiums, worker's compensation expenditures, and regulatory costs compared to those for the baseline. From a social perspective, a reduction of VOC emissions may have impacts beyond the printing facility, possibly including a reduction in cases of asthma, red eyes, and headaches. The economic benefit of avoiding additional cases of these ailments potentially could include reduced medical expenditures, increased productivity, and reduced pain and suffering.

Other health risk and safety measures indicated that the water-based inks may have been comparable to or worse than the baseline. There was an average of 3.1 compounds with a clear or potential concern for worker health risk in the water-based inks, which was close to the 3.2 found in the solvent-based inks. Some of this risk — one compound of clear concern per formulation on average — resulted from the press-side addition of solvent and additives. Three of the four water-based ink product lines contained HAPs, while none were found in the other two systems. The variability of health risks and safety hazards of these water-based inks relative to the baseline highlights the importance of carefully scrutinizing information about particular formulations.

Benefits associated with a switch to the water-based inks in this analysis also include a decrease in energy use and costs. The system used approximately 73,000 Btu per ft^2 of image — the lowest among the ink systems and 27% less than the solvent-based inks. Private benefits of reduced energy use include reductions in the cost of energy. Social benefits include lower emissions at the sources of energy generation (i.e., electric power plants and the exhaust stack of natural gas furnaces), reduced demand for fossil fuels, and decreased strain on the capacity of the power grid.

The cost of using the water-based inks also was lower. This system was, on average, $6.40 less expensive than the baseline per 6,000 ft^2 of image. The lower cost resulting from a switch to these water-based inks has obvious benefits for a printer's profitability, and also may result in benefits to the public in the form of lower prices for printed products. When considering a switch from the baseline to a water-based ink system, additional costs for the retraining of workers would be incurred. These costs should be taken into account in the overall decision.

New Emerging Technology: UV-cured Inks

Research in this CTSA indicated that a switch to the tested UV-cured inks may present higher private costs in comparison to the baseline, because of lower performance and higher operating costs. It is worth noting that developing technologies often have higher operating costs. However, performance shortcomings indicate there is room to improve UV-cured formulations and to optimize UV equipment for wide-web film applications.

The performance results for the UV-cured inks were mixed. They performed better than the baseline on one test (blocking resistance), but produced mostly poorer results on the other tests. These results indicate that UV-cured inks may be an appropriate choice for certain film applications that require pressure and heat resistance, but that a UV system may require modifications, such as different-sized anilox rolls, to improve other performance characteristics. The performance of these inks may represent a cost to printers who are switching in that either a lower quality product is produced or that significant effort is required to improve the quality. Lower quality products affect consumers in that printed products, such as packaging, may have less realistic colors and lower durability.

These inks showed potential for greater social benefits arising from reduced health risks and safety hazards. An average of 2.4 compounds with a clear or potential concern for occupational risk were found in the UV formulations, which was lower than the average for the baseline. There were no HAPs in the formulations, and based on post-curing estimates, the system had a VOC content below 1%. Safety hazard information was incomplete, but the formulations for which information was available had a reactivity level of 1, a flammability of 1 (both on 0-4 scales of increasing severity), and no ignitability. UV-cured product lines #1 and #3 were calculated to have smog-related emissions of 187 and 191 g/6,000 ft^2 of product, respectively (based on the uncured formulations). These were the lowest emission rates of all product lines in the three systems. In contrast to these relatively low figures, however, UV-cured ink #2 had VOC emissions expected to be 523 g/6,000 ft^2. The benefits of switching to a UV-cured ink, therefore, may be formulation-specific. It should be noted that many compounds used in UV-cured inks have not been subjected to toxicological studies. As a result, conclusions about the risks associated with these inks can not be as certain as conclusions based primarily on toxicological information.

The UV-cured inks consumed less energy (78,000 Btu per 6,000 ft^2) than the solvent baseline (100,000 Btu per 6,000 ft^2), but more than the water-based inks (73,000 Btu per 6,000 ft^2). As indicated in Table 8.5, the releases of smog-related compounds associated with UV-cured energy consumption were the greatest among those of the three ink systems, because electricity — the sole form of energy used by the UV system — is more pollution-intensive than natural gas. This pollution is not evident at the facility, however, because the emissions are released at the site of the power plant.

The UV-cured inks had the lowest ink consumption rate of the three systems. An average of 2.78 pounds of UV-cured ink and additives were consumed per 6,000 ft^2 of image; in contrast, the water-based system consumed 4.57 pounds of ink and additives per 6,000 ft^2, and solvent-based inks consumed 8.11 pounds per 6,000 ft^2.

With regard to costs, the UV ink system was the most expensive of the three, costing approximately $3.80 per 6,000 ft^2 of image more than the solvent baseline and $10 more than the water based system. Two factors drove this high cost. The per-pound ink price was the highest of the three ink systems. One reason for this is that higher-grade pigments are required in order to minimize product performance issues.[8] Another factor is that the system exclusively uses electricity, which is more expensive than natural gas. A switch to these UV-cured inks could result in a private cost to printers, and may negatively affect consumers, because the cost might be translated into higher prices for materials printed with UV-cured inks.

Summary

No ink system is inherently free of human health risks and safety hazards. There are many tradeoffs in every system. Many solvent-based inks have undergone technical reformulating in recent years to reduce the use of some of the more hazardous substances. Also, printers using solvent systems are required to use oxidizers, which can substantially reduce VOC air emissions from these inks. (Oxidizers do not, however, protect pressroom workers from the effects of solvents.) UV inks, because they are much newer, contain many more untested chemicals, and the risks of exposure to many of them are largely unknown. Water-based inks gained popularity initially in part because they were thought to be safer than solvent inks.

However, as shown by this CTSA, the relative occupational risk reductions are formulation-specific. Some water-based inks do potentially pose a lower risk than some solvent-based inks. There were fewer chemicals with a clear concern for worker health risk in some formulations, and water-based ink #2 did not contain compounds with a clear concern for developmental risks. This was not true for water-based ink #4, however; the range in the number of chemicals with a clear concern for occupational risk was slightly higher than the baseline, and this product line had a VOC content of 14% by weight. For a water-based ink, it is important to keep the VOC content as low as possible since no emission controls are used with these inks in most locations.

Another issue that emerged from the results are that press side solvents and additives can increase the risk to workers using ink. In both solvent-based and water-based inks, some solvents and additives added at press side presented a clear concern for occupational risk. In water-based inks in particular, a third of the chemicals of clear concern were added at press side. This point highlights both the risks associated with working with press side solvents and additives and the worker health improvements that can be made by minimizing their use.

Highlights of Chemical Category Information

As noted in earlier sections of this chapter, there can be significant variation in the risks of different ink product lines, even within one ink system. The risk associated with a formulation often can be driven by just a few individual compounds. This section includes information about the hazard, risk, and regulatory information for each compound used in this CTSA, grouped by chemical category. This information may be helpful for printers who wish to identify compounds that may present issues for human health and the environment. Ink formulators may use this information to help identify chemical compounds that contribute to the overall risk of a formulation, as well as compounds that are worth considering as possible safer alternatives.

This section presents an overview and interpretation of the hazard, risk, and regulatory information. The following section — Hazard, Risk, and Regulation of CTSA Chemicals — consists of a more detailed description of each chemical category.

Hazard and risk

Hazard represents a compound's *inherent* ability to cause harm to health, that is, regardless of its concentration in an ink. Risk describes the relationship between a compound's hazard level and its potential for exposure. Because potential for exposure is a factor of the compound's concentration in the ink as well as its chemical properties, the concentration of a chemical in a formulation affects its risk. As shown in Table 8.13 in the next section, a chemical can have a low hazard score and a high risk score if the chemical is used in fairly high concentrations in an ink formulation. Thus, it is not necessarily true that pressroom workers can be safely exposed to inks even if they do not contain any highly hazardous chemicals.

The reverse may also be true. A chemical with a high hazard score can receive a low risk score because it has a very small concentration in the ink that was tested for the CTSA. That does not indicate, however, that the chemical is safe in all ink formulations. If the same chemical had been present in a high concentration in another formulation, it might have received a high risk score as well. Thus, it is important to pay close attention to *both* hazard and risk when this information is available.

It is also important to consider aquatic risk. Though it was assumed in this CTSA that ink would not be released to the aquatic environment, accidental releases are possible. As noted in Chapter 3 (Risk), 18 of the compounds were of high hazard concern for aquatic effects, and another 35 were of medium hazard concern. The aquatic hazard of ingredients should considered in order to minimize the impacts associated with potential discharges of ink.

Toxicological and SAT data

Ideally, a chemical's ability to cause harm in animals and humans is measured by toxicological studies. However, less than half of the compounds used in this CTSA have been subject to toxicological testing. (This situation is generally true beyond the inks that were used in this CTSA. Many hundreds of new chemicals enter the market each year, and testing has not kept up with these advances.) For CTSA chemicals with no toxicological data, EPA's Structure Activity Team (SAT) estimated toxicity based on the compound's molecular structure and its similarity to compounds that have been studied. SAT findings, although developed by experts and far better than no information, are inherently less reliable than toxicological studies, because they are not based upon actual tests of the chemical in question.

It is important, therefore, to know more about chemicals for which no toxicological data are available. As discussed in the hazard and risk section, a chemical with a low SAT risk concern may in fact be present in a particular formulation in a high enough concentration to be a worker health issue.

Exposure via dermal and inhalation routes

Flexographic workers can come into contact with all chemical compounds in ink formulations through dermal (skin) exposure, particularly if they do not consistently wear contact-barrier gloves while working with or in the immediate vicinity of inks. In contrast, workers are only subject to inhalation exposure from compounds that are volatile (have a vapor pressure at ambient temperatures). For compounds in this CTSA that did not have a significant vapor pressure (0.001 mm Hg or greater), their inhalation risk is noted as "no exposure."

Fifteen chemicals that were tested in the CTSA presented a *clear concern for dermal risk,* and eleven others had a potential concern for dermal risk, documented with toxicological data. These chemicals spanned all ink systems, and a number of them are not explicitly regulated under any federal acts included in the table. SAT findings indicate that many other chemicals may also be of concern for dermal exposure. This finding indicates that flexographic workers can come into skin contact with multiple chemicals that carry significant health and safety risks. The compounds that presented a clear concern for risk as determined by toxicological data or the SAT are presented in Table 8.10.

Dermal exposure can be avoided mostly thorough implementation of a policy that requires workers to wear contact-barrier gloves while working with ink (and other chemicals), whether or not they expect to contact the ink directly. Butyl (preferred) and nitrile gloves are considered appropriate for inks. Latex gloves offer little or no protection because they degrade rapidly after being exposed to many ink chemicals.

Table 8.10 Compounds with a Clear Concern for Dermal Risk

Chemical Category	Chemical	Data Source
Acrylated polyols	Dipropylene glycol diacrylate	SAT
	1,6-Hexanediol diacrylate	SAT
	Hydroxypropyl acrylate	Tox
	Trimethylolpropane triacrylate	Tox
Acrylated polymers	Glycerol propoxylate triacrylate	Tox
Alcohols	Ethanol	Tox
	Isopropanol	Tox
Alkyl acetates	Butyl acetate	Tox
Amides or nitrogenous compounds	Ammonia	Tox
	Ammonium hydroxide	Tox
	Ethanolamine	Tox
	Hydroxylamine derivative	SAT
Ethylene glycol ethers	Alcohols, C11-15-secondary, ethoxylated	SAT
	Butyl carbitol	Tox
	Ethyl carbitol	Tox
Inorganics	Barium	Tox
Organophosphorous compounds	Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	Tox
Organotitanium compounds	Isopropoxyethoxytitanium bis (acetylacetonate)	SAT
	Titanium diisopropoxide bis(2,4-pentanedionate)	SAT
	Titanium isopropoxide	SAT
Pigments — organic	C.I. Pigment Red 23	Tox
Pigments — organometallic	D&C Red No. 7	Tox
Propylene glycol ethers	Propylene glycol methyl ether	Tox

For inhalation risk, thirteen chemicals showed a *clear concern for inhalation risk* to pressroom workers based on toxicological data. SAT findings indicate that three more chemicals present a clear concern for inhalation risk. These chemicals are listed in Table 8.11.

It is much more difficult to protect pressroom workers from inhalation exposure to ink chemicals than from dermal exposure. This is of particular concern for chemicals that have a clear or potential concern for inhalation risk from toxicological studies, as well as those with a moderate to high concern for inhalation risk via SAT findings. Inhalation exposure can be minimized, however, by using enclosed doctor blades and providing sufficient ventilation.

Table 8.11 Compounds with a Clear Concern for Inhalation Risk

Chemical Category	Chemical	Data Source
Acrylated polyols	Dipropylene glycol diacrylate	SAT
	1,6-Hexanediol diacrylate	SAT
	Hydroxypropyl acrylate	Tox
Alcohols	Ethanol	Tox
	Isobutanol	Tox
	Isopropanol	Tox
Alkyl acetates	Butyl acetate	Tox
	Ethyl acetate	Tox
Amides or nitrogenous compounds	Ammonia	Tox
	Ammonium hydroxide	Tox
	Ethanolamine	Tox
	Hydroxylamine derivative	SAT
Ethylene glycol ethers	Butyl carbitol	Tox
	Ethyl carbitol	Tox
Hydrocarbons — low molecular weight	n-Heptane	Tox
Propylene glycol ethers	Propylene glycol methyl ether	Tox

Regulatory status

Some of the compounds in this CTSA are regulated under major federal environment, health and safety acts. The following federal regulations were considered:

- Clean Air Act (CAA)
- Resource Conservation and Recovery Act (RCRA)
- Toxic Substances Control Act (TSCA)
- Clean Water Act (CWA)
- Safe Drinking Water Act (SDWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Emergency Planning and Community Right to Know Act (EPCRA)
- Occupational Safety and Health Act (OSH Act)

Table 8.13 shows the regulation (last column) for each explicitly regulated compound. In addition, chemicals that appear to be "unregulated" in fact may be regulated due to their properties; for example, many compounds are regulated as VOCs because they match the definition (all organic compounds except those that are determined by EPA to be negligibly photochemically reactive).

Of the more than 100 chemicals studied in this CTSA, only 25% are explicitly regulated by any of the major federal environmental and health acts. Of the roughly 75 other compounds, 11 presented a clear concern for occupational risk and another 36 presented a potential concern for occupational risk. Table 8.12 presents the compounds that posed a clear or potential concern for occupational risk based on either toxicological data or SAT evaluations that are not explicitly listed in regulations. The large number of compounds not explicitly regulated that posed a clear or potential concern for risk indicates that at least for the flexographic inks studied in this analysis, significant risk may be present in a formulation despite a lack of regulatory requirements.

Table 8.12 Compounds with a Clear or Potential Concern for Occupational Risk Not Explicitly Regulated[a]

Chemical	Data Source	Dermal Risk Concern Level	Inhalation Risk Concern Level
C.I. Pigment Red 23	Tox	Clear	n.e.
D&C Red No. 7	Tox	Clear	n.e.
Glycerol propoxylate triacrylate	Tox	Clear	n.e.
Phosphine oxide, bis(2,6-dimethoxybenzoyl) (2,4,4-trimethylpentyl)-	Tox	Clear	n.e.
Trimethylolpropane triacrylate	Tox	Clear	n.e.
Alcohols, C11-15-secondary, ethoxylated	SAT	Clear	n.e.
Dipropylene glycol diacrylate	SAT	Clear	Clear
Hydroxylamine derivative	SAT	Clear	Clear
Isopropoxyethoxytitanium bis (acetylacetonate)	SAT	Clear	n.e.
Titanium diisopropoxide bis(2,4-pentanedionate)	SAT	Clear	n.e.
Titanium isopropoxide	SAT	Clear	n.e.
C.I. Pigment Green 7	Tox	Potential	n.e.
Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide	Tox	Potential	n.e.
Distillates (petroleum), solvent-refined light paraffinic	Tox	Potential	Potential
2-Hydroxy-2-methylpropiophenone	Tox	Potential	Potential
2-Methyl-4'-(methylthio)-2-morpholinopropiophenone	Tox	Potential	n.e.
Propylene glycol propyl ether	Tox	Potential	Potential
Acrylated epoxy polymer	SAT	Potential	n.e.
Acrylated oligoamine polymer	SAT	Potential	n.e.
Acrylated polyester polymer (#s 1 and 2)	SAT	Potential	n.e.
Acrylic acid polymer, insoluble	SAT	Potential	n.e.
Butyl acrylate-methacrylic acid-methyl methacrylate polymer	SAT	Potential	n.e.
C.I. Basic Violet 1, molybdatephosphate	SAT	Potential	n.e.
C.I. Basic Violet 1, molybdatetungstatephosphate	SAT	Potential	n.e.
C.I. Pigment Red 48, barium salt (1:1)	SAT	Potential	n.e.
C.I. Pigment Red 48, calcium salt (1:1)	SAT	Potential	n.e.
C.I. Pigment Red 52, calcium salt (1:1)	SAT	Potential	n.e.
C.I. Pigment Violet 27	SAT	Potential	n.e.
C.I. Pigment White 7	SAT	Potential	n.e.

Table 8.12 Compounds with a Clear or Potential Concern for Occupational Risk Not Explicitly Regulated (continued)

Chemical	Data Source	Dermal Risk Concern Level	Inhalation Risk Concern Level
C.I. Pigment Yellow 14	SAT	Potential	n.e.
Distillates (petroleum), hydrotreated light	SAT	Potential	Potential
Ethoxylated tetramethyldecyndiol	SAT	Potential	n.e.
Methylenedisalicylic acid	SAT	Potential	n.e.
Nitrocellulose	SAT	Potential	n.e.
Paraffin wax	SAT	Potential	n.e.
Polyethylene glycol	SAT	Potential	n.e.
Propyl acetate	SAT	Potential	Potential
Rosin, polymerized	SAT	Potential	n.e.
Siloxanes and silicones, di-Me, 3-hydroxypropyl Me, ethers with polyethylene glycol acetate	SAT	Potential	n.e.
Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl)-, hydrolysis products with silica	SAT	Potential	n.e.
Solvent naphtha (petroleum), light aliphatic	SAT	Potential	Potential
Styrene acrylic acid polymer (#s 1 and 2)	SAT	Potential	n.e.
Styrene acrylic acid resin	SAT	Potential	n.e.
Thioxanthone derivative	SAT	Potential	n.e.
Trimethylolpropane ethoxylate triacrylate	SAT	Potential	n.e.
Trimethylolpropane propoxylate triacrylate	SAT	Potential	n.e.

n.e.: No exposure via indicated exposure route

[a] This list contains chemicals that are not explicitly listed under federal laws and regulations. Chemicals in this list may be subject to general requirements, such as those that address VOCs.

Hazard, Risk and Regulation of Individual CTSA Chemicals

This section contains hazard, risk, and regulatory information for each compound used in this CTSA. The intent of this section is to summarize the hazard and risk findings of the CTSA for the decision maker. It is intended to be a starting point in the evaluation of a chemical for use in new formulations. The data are presented in Table 8.13.

The hazard and risk information is presented separately for inhalation and dermal exposure. For both exposure routes, hazard effects can be either systemic (affecting an organ system of the body, such as the lungs) or developmental (associated with the growth and maturation of an organism). The notation used in Table 8.13 allows presentation of both systemic and developmental effects for each chemical category. The first letter that appears in each human health hazard column of the table represents the concern for systemic effects; the second represents the concern for developmental effects. For example, the second compound in the table, 1,6-hexanediol diacrylate, has “M/L” under Dermal Hazard. This indicates a moderate hazard of systemic effects, and a low hazard of developmental effects.

Table 8.13 also includes the results of the risk analysis performed in this CTSA. Risk incorporates a compound's hazard level and its potential for exposure to produce an overall risk concern ranking. Dermal risk concern levels were determined based on model assumptions of routine two-hand contact by workers in both the preparation room and the press room, and are considered high-end estimates. Inhalation risks were expected only for press room workers. Because potential for exposure depends on the compound's concentration in the ink as well as its chemical properties, the risk concern rating of a chemical can vary among ink formulations if its concentration is different. Table 8.13 lists the *highest* observed risk concern rating.

The final column of Table 8.13, Regulatory Concern, lists the regulations under which each compound is explicitly regulated. It should be noted that this is not an exhaustive list of regulatory requirements associated with each compound.

The following paragraphs summarize the hazards and risks of the chemicals in each chemical category. Though hazards and risks can vary among chemicals within a category, there are trends in exposure pathways and the magnitudes of concern that can be useful to printers and formulators who use chemicals in these categories.

Acrylated polyols

Compounds in this category were used in UV-cured inks as monomers. Of the four compounds, two (hydroxypropyl acrylate and trimethylolpropane triacrylate) have been subjected to toxicological testing. Both had a medium hazard concern for systemic effects via dermal exposure, and both were found in the inks in sufficient quantities to present a clear concern for risk via dermal exposure. Hydroxypropyl acrylate also posed a medium systemic hazard concern and clear concern for risk via inhalation. Trimethylolpropane triacrylate did not have an appreciable vapor pressure and therefore did not pose a hazard or risk concern via inhalation. Both of these compounds had a medium aquatic hazard level, but neither had a cancer hazard rating.

The two compounds analyzed by the Structure Activity Team (SAT), dipropylene glycol diacrylate and 1,6-hexanediol diacrylate, presented medium hazard and clear risk concern by both dermal and inhalation exposure routes. The two compounds presented moderate and high hazard levels, respectively, for aquatic effects, and both were expected to have a low-moderate hazard level for carcinogenic effects.

Two compounds in this category, 1,6-hexanediol diacrylate and hydroxypropyl acrylate, are regulated under TSCA. In general, these compounds presented a clear occupational risk concern but have not been well studied.

Acrylated polymers

These six compounds were used in UV-cured inks as monomers and polymers. One compound, glycerol propoxylate triacrylate, was determined based on toxicological data to have a medium systemic dermal hazard level, and because of its concentration in the formulations, presented a clear concern for dermal occupational risk. It also had a high aquatic hazard level.

For each of the other five compounds, the SAT found that they had a low-moderate dermal hazard level and a potential concern for dermal occupational risk. No exposure via inhalation was expected. Of these compounds, trimethylolpropane ethoxylate triacrylate had a high aquatic hazard level, trimethylolpropane propoxylate triacrylate had a medium aquatic hazard level, and the other three — acrylated epoxy polymer, acrylated ologoamine polymer, and acrylated polyester polymer — had a low aquatic hazard level. All five of the SAT-evaluated compounds had a low-moderate cancer hazard level.

Aside from those that qualify as VOCs, none of the compounds are regulated under the federal regulations discussed in this report.

Acrylic acid polymers

Compounds in this category were used as additives in water-based inks. Four compounds, acrylic acid-butyl acrylate-methyl methacrylate styrene polymer, butyl acrylate-methacrylic acid-methyl methacrylate polymer, and acidic acrylic acid polymers #1 and #2 were assigned low dermal hazard levels by the SAT and potential risk concern ratings. The other four compounds were assigned ratings of low-moderate hazard and potential concern for occupational risk via dermal exposure by the SAT. Five of the compounds — acidic acrylic acid polymers #1 and #2, styrene acrylic acid polymers #1 and #2, and styrene acrylic resin — were assigned medium aquatic hazard ratings and the other three compounds were assigned low ratings. None of the compounds were known to present a cancer hazard, nor are they explicitly regulated under the federal regulations discussed in this report.

Alcohols

Alcohols were used in all three ink systems as solvents. All except tetramethyldecyndiol have received toxicological testing and had human health hazard and occupational risk concern via both dermal and inhalation exposure. Most compounds presented only low or medium hazard concern, but because of their typically high concentrations, their occupational risk ratings were higher. Three had a clear concern for inhalation risk (ethanol, isobutanol, and isopropanol), and two had a clear concern for dermal risk (ethanol and isopropanol). Tetramethyldecyndiol, as determined by the SAT, had a medium aquatic hazard level; the other compounds had a low aquatic hazard level.

Ethanol has been assigned by the International Agency for Research on Cancer (IARC) as a Group 1 compound, indicating that it is carcinogenic to humans. Propanol has been assigned as an EPA Group C compound, indicating that it is a possible human carcinogen. Isopropanol has been assigned as an IARC Group 3 compound, indicating that its characteristics with respect to cancer are not classifiable. The evidence of the carcinogenicity of isopropanol in humans is inadequate, and in experimental animals it is inadequate or limited.

Four compounds in this category have OSHA Personal Exposure Limits (PELs); for ethanol, it is 1,000 ppm; for isobutanol, it is 100 ppm; for isopropanol, it is 400 ppm; and for propanol it is 200 ppm. Three compounds are regulated by TSCA, and RCRA, CERCLA, and EPCRA regulations apply to one compound.

Alkyl acetates

The three compounds in this category were used as solvents in solvent-based inks. Butyl acetate and ethyl acetate have been subjected to toxicological testing. Like alcohols, they had fairly low human health hazard levels, but their relatively high concentrations in these inks caused both compounds to have a clear occupational risk concern via inhalation exposure. Butyl acetate also presented a clear concern for occupational risk via dermal exposure. Propyl acetate, which was studied by the SAT, was given low-moderate hazard and potential risk concern levels via both exposure pathways. All three compounds presented a medium aquatic hazard, and none were known to pose a cancer hazard.

Butyl and ethyl acetate are regulated under CERCLA, TSCA, and have OSHA PELs of 150 ppm and 400 ppm, respectively. In addition, butyl acetate is regulated under CWA and ethyl acetate is regulated under RCRA. Propyl acetate has an OSHA PEL of 200 ppm.

Amides or nitrogenous compounds

This is a broad category, incorporating compounds serving a variety of functions in all ink systems. Four compounds — ammonia, ammonium hydroxide, ethanolamine, and hydroxylamine derivative — presented a clear concern for occupational risk via both dermal and inhalation exposure routes. Ethanolamine also presented a high human health hazard for developmental effects by both exposure routes. In contrast, the other three compounds presented low hazard and occupational risk concern levels. Two compounds — hydrogenated tallow amides and ammonia — presented a high aquatic hazard, and three others — ammonium hydroxide, ethanolamine, and hydroxylamine derivative — presented a medium aquatic hazard concern. None of the compounds were known to present a cancer hazard.

Ammonia and ammonium hydroxide are subject to CWA, CERCLA, and EPCRA requirements, and ammonia is also subject to CAA, SARA, TSCA and has an OSHA PEL of 50 ppm. Ethanolamine has an OSHA PEL of 3 ppm, and urea is regulated under TSCA.

Aromatic esters

This category was comprised of two compounds found in UV-cured inks. Dicyclohexyl phthalate was an additive (a plasticizer) and ethyl 4-dimethylaminobenzoate was a photoinitiator. Dicyclohexyl phthalate has been subjected to toxicological testing and presented a low concern for both human health hazard and occupational risk, but a high concern for aquatic hazard. The other, ethyl 4-dimethylaminobenzoate, was analyzed by the SAT and was given a low-moderate human health hazard level and a potential concern for risk via both dermal and inhalation pathways, a medium aquatic hazard level, and a low-moderate cancer hazard level. Dicyclohexyl phthalate is regulated under CWA, CERCLA, and TSCA.

Aromatic ketones

The seven compounds in this category were used as photoinitators in the UV-cured inks of this CTSA. One compound, 2-hydroxy-2-methylpropiophenone, presented a moderate hazard and a potential concern for risk via both inhalation and dermal exposure based on toxicological data. For the other compounds, the concern was limited to dermal exposure. 2-methyl-4'-(methylthio)-2-morpholinopropiophenone presented moderate hazard concern and potential risk concern via dermal exposure based on toxicological data. The other compounds had low human health hazard and low or potential concern for dermal occupational risk. 2-Isopropylthioxanthone, 4-isopropylthioxanthone and thioxanthone derivative were found by the SAT to have a high aquatic hazard concern; three others had a medium aquatic hazard concern. None of the compounds were known to present a cancer hazard or are explicitly regulated under the federal regulations discussed in this document.

Ethylene glycol ethers

These compounds were used as solvents in water-based inks. Two compounds — butyl carbitol and ethyl carbitol — present a clear concern for occupational risk via both dermal and inhalation exposure based on toxicological data. The three other compounds were analyzed by the SAT. Ethoxylated C11-C15 secondary alcohols was assigned a moderate hazard level and a clear concern for occupational risk via dermal exposure, and no inhalation exposure was expected. The other two compounds, ethyoxylated tetramethyldecyndiol and polyethylene glycol, were given ratings of moderate hazard and potential concern for dermal occupational risk. Ethoxylated C11-C15 secondary alcohols presented a medium aquatic hazard; all others had a low aquatic hazard level. None of the compounds were known to present a cancer hazard.

Both butyl and ethyl carbitol are regulated under CAA, CERCLA, EPCRA, and TSCA.

Hydrocarbons — high molecular weight
The four compounds included in this category were used as additives in solvent- and water-based inks. Based on toxicological data, solvent-refined light paraffinic distillates and paraffin wax were found to pose a potential concern for occupational risk by dermal exposure, and solvent-refined light paraffinic distillates also posed a potential concern for occupational risk by inhalation exposure. Hydrotreated light distillates were found by the SAT to present a potential concern for occupational risk by both dermal and inhalation exposure. Hydrotreated light distillates and mineral oil both presented high aquatic hazard, and hydrotreated light distillates and solvent-refined light paraffinic distillates have shown evidence of carcinogenicity in animals (but have not been evaluated formally by IARC or EPA).

Mineral oil has been assigned an OSHA PEL of 5 mg/m^3.

Hydrocarbons — low molecular weight
The three compounds included in this category were found in solvent- and water-based inks and performed different functions. Heptane, though it posed only a low hazard concern for both dermal and inhalation exposure based on toxicological data, presented a clear concern for occupational risk via inhalation, in part because of its greater concentration in some formulations. In contrast, styrene posed a high concern for developmental effects via inhalation based on toxicological data, but its relatively low concentration resulted in just a rating of potential concern for risk via inhalation effects. Light aliphatic solvent naphtha was found to be a low-moderate hazard and a potential concern for occupational risk for both dermal and inhalation exposure by the SAT. Heptane and styrene presented a high aquatic hazard concern, and light aliphatic solvent naphtha presented a medium aquatic hazard. There is evidence in animals that styrene may be carcinogenic, but it has not been evaluated by IARC or EPA.

Two compounds are regulated under multiple federal acts. Heptane is regulated under TSCA and has an OSHA PEL of 500 ppm. Styrene is regulated under CAA, CWA, SDWA, CERCLA, SARA, EPCRA, TSCA, and has an OSHA PEL of 100 ppm.

Inorganics
The compounds in this category perform a diverse set of functions in solvent- and water-based inks and have all been subjected to toxicological testing. One of the compounds, barium, is of particular concern. It had a high hazard concern for developmental effects via dermal exposure, and had a clear concern for occupational dermal risk. The other two compounds, kaolin and silica, had low human health hazard and occupational risk concern ratings, and all three compounds had low aquatic hazard ratings. Two of the compounds may present a cancer hazard: amorphous silica is classified as an IARC Group 3 compound (not classifiable as to its carcinogenicity in humans), and kaolin has been reported to cause cancer in animals but has not been evaluated formally.

Barium and kaolin have OSHA PELs of 0.5 mg/m^3 and 15 mg/m^3 (total dust), respectively. Barium is also regulated under RCRA, SDWA, SARA, and EPCRA.

Olefin polymers
The two compounds in this category, polyethylene and polytetrafluoroethylene, were used as additives (waxes) in solvent-based and UV-cured inks. Polytetrafluoroethylene presented low dermal hazard and risk concern based on toxicological information. Polyethylene was determined through SAT evaluation to have a low hazard and a low concern for dermal risk. Both have been studied by IARC for cancer hazards and found to be Group 3 compounds (not classifiable). No inhalation exposure was expected from these compounds, both presented a low aquatic hazard, and neither is explicitly regulated under the federal acts discussed in this report.

Organic acids or salts
These compounds performed a variety of functions as additives in solvent- and water-based inks. Citric acid, the only compound for which toxicological data were available, presented low concern for human health hazard and occupational risk via dermal exposure. The other two compounds, dioctyl sulfosuccinate sodium salt and methylenedisalicylic acid, were analyzed by the SAT and found to present low-moderate hazard and potential risk concern via dermal exposure. All three presented a moderate aquatic hazard. None of the compounds were expected to result in inhalation exposure, and none are explicitly regulated under the federal acts discussed in the CTSA.

Organophosphorous compounds
The three compounds included in this category were used in solvent-based and UV-cured inks as either plasticizers or initiators and have been subjected to toxicological testing. One compound, bis(2,6-dimethoxybenzoyl)(2,4,4-trimethylpentyl) phosphine oxide, had a moderate dermal hazard and a clear concern for occupational dermal risk. The other two, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide and 2-ethylhexyl diphenyl phosphate, presented low and low-moderate dermal hazard, respectively, and a potential concern for occupational risk by dermal exposure. 2-Ethylhexyl diphenyl phosphate presented a high aquatic hazard and the other two presented a medium aquatic hazard. None of the compounds were expected to result in inhalation exposure. One compound, 2-ethylhexyl diphenyl phosphate, is regulated under TSCA.

Organotitanium compounds
These three compounds were used in solvent-based inks as additives (adhesion promoters). Each was studied by the SAT and found to have medium human health hazard and clear occupational risk concern levels for dermal exposure. Isopropoxyethoxytitanium bis (acetylacetonate) and titanium diisopropoxide bis (2,4-pentanedionate) presented a medium aquatic hazard concern. Isopropoxyethoxytitanium bis (acetylacetonate) also presented a low-moderate cancer hazard concern. Inhalation exposure was not expected from any of the compounds. None of the compounds are explicitly regulated under the federal regulations discussed in this document.

Pigments — inorganic
This category was comprised of two chemicals and was seen in all three ink systems. C.I. Pigment White 6 had a low dermal hazard rating but a potential dermal risk concern rating based on toxicological data. C.I. Pigment White 7 was analyzed by the SAT and found to have a low-moderate hazard and a potential concern for risk via dermal exposure. Both compounds had a low aquatic hazard rating, but C.I. Pigment White 6 has displayed evidence of carcinogenicity in animals. Inhalation exposure was not expected from either of the compounds. C.I. Pigment White 6 has an OSHA PEL of 15 mg/m^3 (total dust).

Pigments — organic

This category was comprised of six compounds and were seen in all three ink systems. Toxicological data were available for only one compound, C.I. Pigment Red 23, which was found to have clear dermal concern. The other compounds in this category were analyzed by the SAT and found to have low or low-moderate human health hazard and low or potential concern for occupational risk. C.I. Pigment Blue 61 presented a medium aquatic hazard; the others had a low aquatic hazard concern. C.I. Pigment Yellow 14 was found to present a low-moderate cancer hazard concern. Inhalation exposure was not expected for any of these compounds, and none of the compounds are explicitly regulated under the federal regulations discussed in this document.

Pigments — organometallic

Nine organometallic pigments were used in all three ink systems. One compound, D&C Red No. 7, presented medium dermal systemic hazard and a clear concern for dermal risk based on toxicological data. One other compound subjected to toxicological testing, C.I. Pigment Green 7, presented a potential concern for dermal risk. Most of the other compounds, as determined by the SAT, presented low-moderate dermal hazard and potential dermal occupational risk concern. Most of the compounds had a medium or high aquatic hazard level, and all of the SAT-analyzed compounds presented a low-moderate cancer hazard. Inhalation exposure was not expected for any of these compounds, and none of the compounds are explicitly regulated under the federal regulations discussed in this document.

Polyol derivatives

These compounds were used in solvent-based and UV-cured inks as resins. For nitrocellulose, the SAT assigned a low-moderate human health hazard and a potential concern for occupational risk by dermal exposure, and a low aquatic hazard level. Polyol derivative A had low human health hazard and occupational risk concern ratings via dermal exposure and a low aquatic hazard rating. Inhalation exposure was not expected for either compound, and neither of the compounds is explicitly regulated under the federal regulations discussed in this document.

Propylene glycol ethers

These compounds were used as solvents in solvent- and water-based inks, and have all been subjected to toxicological testing. Propylene glycol propyl ether, based on toxicological data, presented a moderate systemic human health hazard concern via both dermal and inhalation exposure routes, and had a potential concern for dermal and inhalation occupational risk. Propylene glycol methyl ether presented a low hazard concern but a clear concern for risk for both exposure pathways based on toxicological data. Dipropylene glycol methyl ether and propylene glycol methyl ether, presented a low hazard concern and a low concern for occupational risk for both exposure pathways at the concentrations observed in the inks used in this CTSA. All three compounds had a low aquatic hazard, and none were known to present a cancer hazard.

Two compounds, dipropylene glycol methyl ether and propylene glycol methyl ether, are regulated under TSCA. In addition, dipropylene glycol methyl ether has an OSHA PEL of 100 ppm.

Resins

Resins were found in solvent- and water-based inks. One compound, polymerized rosin, presented a low-moderate human health hazard and a potential risk concern as determined by the SAT. All other compounds in this category presented low human health hazard and a low concern for occupational risk for dermal exposure. One chemical — resin acids, hydrogenated, methyl esters — had a high aquatic hazard rating, and acrylic resin had a medium aquatic hazard rating. Acrylic resin also may pose a cancer hazard based on evidence of carcinogenicity in animals. Inhalation exposure was not expected for any of these compounds, and none of the compounds are explicitly regulated under the federal regulations discussed in this document.

Siloxanes

These compounds are used in all three systems as additives (defoamers and wetting agents). Silicone oil, as determined through toxicological data, was anticipated to have moderate developmental hazard concern via dermal exposure, and a potential concern for dermal risk. The other two compounds, 1,1,1-trimethyl-N-(trimethylsilyl)-silanamine hydrolysis products with silica and dimethyl 3-hydroxypropyl methyl siloxanes and silicones, ethers with polyethylene glycol acetate, were analyzed by the SAT and determined to have a low-moderate human health hazard and a potential concern for dermal risk. All of the compounds had a low aquatic hazard rating, and none were known to present a cancer hazard. No inhalation exposure is anticipated for any of these compounds. Silicone oil is regulated under TSCA.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[a,b]	Dermal	Inhalation	
Acrylic acid polymers									
Water	Acrylic acid-butyl acrylate-methyl methacrylate styrene polymer 27306-39-4	SAT	L		L/L		low	n.e.	
	Acrylic acid polymer, acidic (#'s 1 and 2)[e] CAS: NA	SAT	M		L/L		low	n.e.	
	Acrylic acid polymer, insoluble[e] CAS: NA	SAT	L		L-M/L-M		potential	n.e.	
	Butyl acrylate-methacrylic acid-methyl methacrylate polymer 25035-69-2	SAT	L		L/L		low	n.e.	
	Styrene acrylic acid polymer (#'s 1 and 2)[e] CAS: NA	SAT	M		L-M/L-M		potential	n.e.	
	Styrene acrylic acid resin[e] CAS: NA	SAT	M		L-M/L-M		potential	n.e.	
Alcohols									
Solvent Water UV	Ethanol 64-17-5	Tox	L	IARC Group 1[f]	H/M	L	clear	clear	OSHA PEL
	Isobutanol 78-83-1	Tox	L		L-M/NA	M	potential	clear	RCRA, CERCLA, TSCA, OSHA PEL
	Isopropanol 67-63-0	Tox	L	IARC Group 3[g]	L-M/H	M/L	clear	clear	EPCRA, TSCA, OSHA PEL
	Propanol 71-23-8	Tox	L	EPA Group C[h]	M/L	M/L	potential	potential	TSCA, OSHA PEL
	Tetramethyldecyndiol 126-86-3	SAT	M		L/NA		low	n.e.	
Alkyl acetates									
Solvent	Butyl acetate 123-86-4	Tox	M		L/L	L/L	clear	clear	CERCLA, CWA, TSCA, OSHA PEL
	Ethyl acetate 141-78-6	Tox	M		L/NA	M/NA	potential	clear	RCRA, CERCLA, TSCA, OSHA PEL
	Propyl acetate 109-60-4	SAT	M		L-M/L-M	L-M/L-M	potential	potential	OSHA PEL

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Amides or nitrogenous compounds									
Solvent Water UV	Amides, tallow, hydrogenated 61790-31-6	SAT	H		L/L		low	n.e.	
	Ammonia 7664-41-7	Tox	H		M/NA	L/NA	clear	clear	CAA, CWA, CERCLA, SARA, EPCRA, TSCA, OSHA PEL
	Ammonium hydroxide 1336-21-6	Tox	M		L/NA	L/NA	clear	clear	CWA, CERCLA, EPCRA
	Erucamide 112-84-5	SAT	L		L/NA		low	n.e.	
	Ethanolamine 141-43-5	Tox	M		L/H	L/H	clear	clear	OSHA PEL
	Hydroxylamine derivative CAS: NA	SAT	M		M/M	M/M	clear	clear	
	Urea 57-13-6	Tox	L		L/L	L/L	low	low	TSCA
Aromatic esters									
UV	Dicyclohexyl phthalate 84-61-7	Tox	H		L/L	L/L	low	n.e.	CWA, CERCLA, TSCA
	Ethyl 4-dimethylaminobenzoate 10287-53-5	SAT	M	low-moderate SAT concern	L-M/L-M	L-M/L-M	potential	potential	

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
L= Low; M = Medium; H = High; NA = No data or information are available; n.e. = No Exposure

[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).

[c] Dermal occupational risk concern ratings are applicable for press and prep room workers; inhalation risk concern ratings are applicable for press room workers.

[d] This column only lists federal regulations in which the chemical is listed explicitly. Other regulations may apply to each chemical.

[e] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.

[f] An IARC Group 1 compound is carcinogenic to humans.

[g] An IARC Group 3 compound is not classifiable as to its carcinogenicity to humans.

[h] An EPA Group C compound is a possible human carcinogen.

[i] Actual chemical name is confidential business information.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Aromatic ketones									
UV	2-Benzyl-2-(dimethylamino)-4'-morpholinobutyrophenone 119313-12-1	Tox	M		L/NA		low	n.e.	
	1-Hydroxycyclohexyl phenyl ketone 947-19-3	SAT	M		L/L		low	n.e.	
	2-Hydroxy-2-methylpropiophenone 7473-98-5	Tox	L		M/NA	M/NA	potential	potential	
	2-Isopropylthioxanthone 5495-84-1	SAT	H		L/L		low	n.e.	
	4-Isopropylthioxanthone 83846-86-0	SAT	H		L/L		low	n.e.	
	2-Methyl-4'-(methylthio)-2-morpholinopropiophenone 71868-10-5	Tox	M		M/M		potential	n.e.	
	Thioxanthone derivative[e] CAS: NA	SAT	H		L-M/NA		potential	n.e.	
Ethylene glycol ethers									
Water	Alcohols, C11-15-secondary, ethoxylated 68131-40-8	SAT	M		M/M	M/M	clear	n.e.	
	Butyl carbitol 112-34-5	Tox	L		L/L	M/L	clear	clear	CAA, CERCLA, EPCRA, TSCA
	Ethoxylated tetramethyldecyndiol 9014-85-1	SAT	L		L-M/NA	L-M/NA	potential	n.e.	
	Ethyl carbitol 111-90-0	Tox	L		M-H/L	M-H/L	clear	clear	CAA, CERCLA, EPCRA, TSCA
	Polyethylene glycol 25322-68-3	Tox	L		L/NA	L/NA	potential	n.e.	
Hydrocarbons - high molecular weight									
Solvent Water	Distillates (petroleum), hydrotreated light 64742-47-8	SAT	H	animal evidence	M/M	M/M	potential	potential	
	Distillates (petroleum), solvent-refined light paraffinic 64741-89-5	Tox	L	animal evidence	L/NA	L/NA	potential	potential	
	Mineral oil 8012-95-1	Tox	H		L/L	L/L	low	low	OSHA PEL
	Paraffin wax 8002-74-2	SAT	L		NA/NA		potential	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Hydrocarbons - low molecular weight									
Solvent Water	n-Heptane 142-82-5	Tox	H		L/NA	L/NA	low	clear	TSCA, OSHA PEL
	Solvent naphtha (petroleum), light aliphatic 64742-89-8	SAT	M		L-M/NA	L-M/NA	potential	potential	
	Styrene 100-42-5	Tox	H	animal evidence	M-L/L	M/H	low	potential	CAA, CWA, SDWA, CERCLA, SARA, EPCRA, TSCA, OSHA PEL
Inorganics									
Solvent Water	Barium 7440-39-3	Tox	L		M/H		clear	n.e.	RCRA, SDWA, SARA, EPCRA, OSHA PEL
	Kaolin 1332-58-7	Tox	L	animal evidence	L/L		low	n.e.	OSHA PEL
	Silica 7631-86-9	Tox	L	IARC Group 3	NA/NA		low	n.e.	
Olefin polymers									
Solvent UV	Polyethylene 9002-88-4	SAT	L	IARC Group 3	L/L		low	n.e.	
	Polytetrafluoroethylene 9002-84-0	Tox	L	IARC Group 3	L/NA		low	n.e.	
Organic acids or salts									
Solvent Water	Citric acid 77-92-9	Tox	M		L/L		low	n.e.	
	Dioctyl sulfosuccinate, sodium salt 577-11-7	SAT	M		L-M/L-M		potential	n.e.	
	Methylenedisalicylic acid 27496-82-8	SAT	M		L-M/L-M		potential	n.e.	

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
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[b] Inhalation hazard information was not included for compounds that are not expected to be volatile (i.e., that have a vapor pressure <0.001 mmHg).

[c] Dermal occupational risk concern ratings are applicable for press and prep room workers; inhalation risk concern ratings are applicable for press room workers.

[d] This column only lists federal regulations in which the chemical is listed explicitly. Other regulations may apply to each chemical.

[e] Some structural information is given for these chemicals. For polymers, the submitter has supplied the number average molecular weight and degree of functionality. The physical property data are estimated from this information.

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[h] An EPA Group C compound is a possible human carcinogen.

[i] Actual chemical name is confidential business information.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Organophosphorus compounds									
Solvent UV	Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 75980-60-8	Tox	M		L/NA		potential	n.e.	
	2-Ethylhexyl diphenyl phosphate 1241-94-7	Tox	H		L-M/M		potential	n.e.	TSCA
	Phosphine oxide, bis(2,6-dimethoxy-benzoyl) (2,4,4-trimethylpentyl)- 145052-34-2	Tox	M		M/NA		clear	n.e.	
Organotitanium compounds									
Solvent	Isopropoxyethoxytitanium bis (acetylacetonate) 68586-02-7	SAT	M	low-moderate SAT concern	M/M	M/M	clear	n.e.	
	Titanium diisopropoxide bis(2,4-pentanedionate) 17927-72-9	SAT	M		M/M	M/M	clear	n.e.	
	Titanium isopropoxide 546-68-9	SAT	L		M/M	M/M	clear	n.e.	
Pigments - inorganic									
Solvent Water UV	C.I. Pigment White 6 13463-67-7	Tox	L	animal evidence	L/NA		potential	n.e.	OSHA PEL
	C.I. Pigment White 7 1314-98-3	SAT	L		L-M/L-M		potential	n.e.	
Pigments - organic									
Solvent Water UV	C.I. Pigment Blue 61 1324-76-1	SAT	M		L/L		low	n.e.	
	C.I. Pigment Red 23 6471-49-4	Tox	L		L/NA		clear	n.e.	
	C.I. Pigment Red 269 67990-05-0	SAT	L		L/L		low	n.e.	
	C.I. Pigment Violet 23 6358-30-1	SAT	L		L/L		low	n.e.	
	C.I. Pigment Yellow 14 5468-75-7	SAT	L	low-moderate SAT concern	L-M/L-M		potential	n.e.	
	C.I. Pigment Yellow 74 6358-31-2	SAT	L		L/L		low	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Pigments - organometallic									
Solvent Water UV	C.I. Basic Violet 1,molybdatephosphate 67989-22-4	SAT	H	low-moderate SAT concern	L-M/L-M		potential	n.e.	
	C.I. Basic Violet 1, molybdate-tungstatephosphate 1325-82-2	SAT	H	low-moderate SAT concern	L-M/L-M		potential	n.e.	
	C.I. Pigment Blue 15 147-14-8	Tox	L		L/NA		low	n.e.	
	C.I. Pigment Green 7 1328-53-6	Tox	L		L/NA		potential	n.e.	
	C.I. Pigment Red 48, barium salt (1:1) 7585-41-3	SAT	M	low-moderate SAT concern	L-M/NA		potential	n.e.	
	C.I. Pigment Red 48, calcium salt (1:1) 7023-61-2	SAT	M	low-moderate SAT concern	L-M/NA		potential	n.e.	
	C.I. Pigment Red 52, calcium salt (1:1) 17852-99-2	SAT	M	low-moderate SAT concern	L-M/L-M		potential	n.e.	
	C.I. Pigment Violet 27 12237-62-6	SAT	H	low-moderate SAT concern	L-M/L-M		potential	n.e.	
	D&C Red No. 7 5281-04-9	Tox	M		M/L		clear	n.e.	
Polyol derivatives									
Solvent UV	Nitrocellulose 9004-70-0	SAT	L		NA/NA		potential	n.e.	
	Polyol derivative A[i] CAS: NA	SAT	L		L/L		low	n.e.	
Propylene glycol ethers									
Solvent Water	Dipropylene glycol methyl ether 34590-94-8	Tox	L		L/NA	L/NA	low	low	TSCA, OSHA PEL
	Propylene glycol methyl ether 107-98-2	Tox	L		L/L	L/L	clear	clear	TSCA
	Propylene glycol propyl ether 1569-01-3	Tox	L		M/L	M/L	potential	potential	

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[i] Actual chemical name is confidential business information.

Table 8.13 Summary of Hazard and Risk Data by Chemical Category (continued)

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Resins									
Solvent Water	Fatty acid, dimer-based polyamide[e] CAS: NA	SAT	L		L/L		low	n.e.	
	Fatty acids, C18-unsatd., dimers, polymers with ethylenediamine, hexamethylenediamine, and propionic acid 67989-30-4	SAT	L		L/L		low	n.e.	
	Resin acids, hydrogenated, methyl esters 8050-15-5	SAT	H		L/L		low	n.e.	
	Resin, acrylic[e] CAS: NA	Tox	M	animal evidence	L/L		low	n.e.	
	Resin, miscellaneous[e] CAS: NA		NA					n.e.	
	Rosin, fumarated, polymer with diethylene glycol and pentaerythritol 68152-50-1	SAT	L		L/L		low	n.e.	
	Rosin, fumarated, polymer with pentaerythritol, 2-propenoic acid, ethenylbenzene, and (1-methylethylenyl)benzene[e] CAS: NA	SAT	L		NA/NA		low	n.e.	
	Rosin, polymerized 65997-05-9	SAT	L		L/L		potential	n.e.	

Ink System	Chemicals	Data Source	Hazard				Occupational Risk[c]		Regulatory Requirements[d]
			Aquatic	Cancer	Dermal[a]	Inhalation[ab]	Dermal	Inhalation	
Siloxanes									
Solvent Water UV	Silanamine, 1,1,1-trimethyl-N-(trimethylsilyl) -, hydrolysis products with silica 68909-20-6	SAT	L		L/L		potential	n.e.	
	Silicone oil 63148-62-9	Tox	L		L/M		potential	n.e.	TSCA
	Siloxanes and silicones, di-methyl, 3-hydroxypropyl methyl, ethers with polyethylene glycol acetate 70914-12-4	SAT	L		NA/NA		potential	n.e.	

[a] The first letter(s) represents systemic concern, the second represents developmental concerns.
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Suggestions for Evaluating and Improving Flexographic Inks

As this CTSA shows, several factors are involved in the selection of a flexographic ink. Because flexographic printing facilities are different, the criteria for identifying the best ink for each facility inevitably will vary. Therefore, the ultimate decision will have to be made based on considerations as they apply to the specific facility.

Likewise, ink formulators will have different considerations. In the process of improving the performance of inks, formulators will encounter the opportunity to substitute ink components that pose health concerns with those that are safer for press workers and the environment.

The following sections describe some of the steps that can help printers in identifying, and formulators in creating, safer flexographic inks. They range from steps that relate directly to information and ideas contained in the CTSA to those that will require processes outside of those considered in this analysis.

Printers

The selection of a specific ink is a complex process that is highly dependent on facility-specific factors. Some general considerations are presented below.

- *Know your inks:* Evaluate your current ink system by considering all aspects of its use, including performance, worker and environmental risk, and costs. You can use this CTSA to determine whether chemicals present in your inks may present hazards and risks to your workers and the environment. Consider that choices of an ink system, and within that, the specific product lines and formulations, have many implications, some of which you may not have considered in the past. Another important source that can help provide this information is your ink supplier, who may be able to provide safety information specific to your inks.

- *Consider alternatives:* Use this CTSA to identify possibly safer ink alternatives and to help you determine whether you are using the best, safest, and most cost effective ink system for your facility's situation. You may also wish to discuss your options with ink suppliers, trade associations, technical assistance providers, other printers, and your customers.

- *Evaluate your current practices:* Even if you are using the safest ink possible, you may be increasing the risk to workers by using it inefficiently. As seen with the solvent- and water-based inks in this CTSA, solvent and additives added at press side increased the number of chemicals of clear worker risk. By minimizing or eliminating the need for these materials — using enclosed doctor blades and ink fountains, minimizing ink film thickness, and closely monitoring ink pH and viscosity — the risk to workers can be reduced. For presses with an oxidizer system, it is important to clean the catalyst when necessary and to keep the equipment operating at the optimum temperature so that it destroys as much VOC material as possible.

- *Protect workers:* Experienced and responsible employees are essential to a successful printing operation. Maintain their health and motivation by maximizing air quality and reducing the presence of hazardous materials. These steps may also yield savings with respect to regulatory and storage costs. You can also protect workers by ensuring that people who handle ink use gloves. Butyl and nitrile gloves are considered best for inks, and will minimize exposure to chemicals that may pose a health risk.

- *Look at all aspects of your printing operation:* Though this CTSA focuses on ink, several other steps in the flexographic printing process are sources of waste and candidates for process improvement. Read Chapter 7: Additional Improvement Opportunities for pollution prevention ideas that range from measures for particular process steps to facility-wide concepts. Systematic approaches, such as an Environmental Management System (EMS) or full-cost accounting, can help flexographers identify areas for improvement in their management of resources.

Ink Formulators and Suppliers

Ink companies have several important resources at their disposal: knowledgeable researchers, financial resources, and a communication network of sales representatives. Ink formulators have the ability to evaluate the feasibility of the substitution of different and safer chemicals, and can thoroughly test new formulations for performance characteristics. Supplier representatives have the ability to articulate the benefits of safer, better performing or less costly inks to printers.

- *Support environmental and health risk research:* Research is needed on several categories of chemicals:
    - ◊ those that are not regulated and pose risks
    - ◊ new chemicals (usually not regulated and not tested)
    - ◊ chemicals that have not undergone toxicological testing and have clear or potential risk concerns
    - ◊ high production volume chemicals[f]

  The point of such research is to ensure that the flexographic industry has access to as much information as possible about the chemicals they work with. Information is the most important key to improving inks.

- *Make improved ink safety a top goal of research and development:* The flexographic printing industry constantly demands new inks that can meet increasing performance needs. In addition to performance research, ink formulators can meet the needs of printers by looking for substitute ingredients that are less harmful to workers and the environment.

- *Communicate the safety aspects of inks with printers:* When sales representatives discuss different ink options with printers, inform the printers of any improvements in the environmental and worker risks associated with each product line. Because inks with minimized environmental and worker risk concerns can result in cost savings as well as improved working conditions and less liability, printers may be interested in this information. Research has indicated that for printers, environmental and health risk issues are an important criteria when selecting an ink — second only to performance.[9]

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[f] High production volume (HPV) chemicals are manufactured in or imported into the United States in amounts greater than one million pounds per year. EPA has initiated a HPV Challenge Program to gather test data for all these organic chemicals (about 2,800). The CTSA includes 39 chemicals that appear on the HPV Challenge Program Chemical List.

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