I. INTRODUCTION AND BACKGROUND

The printing industry is one of the largest manufacturing industries in the United States. The industry is dominated by small and medium-sized businesses, most of them with fewer than 20 employees. In 2002, according to the Bureau of Census, approximately 83 percent of the screen printing industry was comprised of small businesses. The Info USA Power Business Database estimates the number of screen printers in 2002 in the U.S. at 16,341. California has 1,886 screen printing establishments.

Volatile Organic Compound (VOC) emissions from solvent cleaning operations contribute significantly to the South Coast Air Basin's emission inventory. The South Coast Air Quality Management District (SCAQMD or District) periodically adopts an Air Quality Management Plan (AQMP). This AQMP calls for significant reductions in VOC emissions from cleaning and degreasing operations by 2010 to achieve attainment status.

The SCAQMD regulates VOC emissions from businesses located in the four county area including Los Angeles County, Orange County, San Bernardino County and Riverside County. One of the SCAQMD rules, Rule 1171 "Solvent Cleaning Operations," regulates the VOC content of screen printing cleanup solvents. The VOC content of screen printing cleanup solvents is currently set at 500 grams per liter. The District plans to reduce the allowed VOC content to 100 grams per liter on July 1, 2006. Lowering the VOC content to 100 grams per liter would reduce emissions of these solvents by about 1.3 tons per day. By July 1, 2006, screen printers in southern California must convert to alternative low-VOC cleanup materials.

The Institute for Research and Technical Assistance (IRTA), a nonprofit organization, was established in 1989 to assist industry in adopting safer alternatives to ozone depleting, chlorinated, other toxic and VOC solvents. IRTA staff have worked with hundreds of facilities in the South Coast Basin to identify, test and develop alternatives. IRTA runs and operates the Pollution Prevention Center (PPC), a loose affiliation of local, state and federal governmental organizations and a large electric utility.

The SCAQMD contracted with IRTA to work with three textile printers to test and demonstrate low-VOC alternatives that would meet the 100 gram per liter VOC limit. IRTA worked on three earlier projects that focused on finding alternative cleanup materials in screen printing. First, Cal/EPA's Department of Toxic Substances Control (DTSC), with DTSC and U.S. EPA Region IX funding, contracted with IRTA to work with screen printers to identify, test, develop and demonstrate alternative low-VOC, low toxicity cleanup solvents. Second, IRTA worked with U.S. EPA on a project that involved working with a few screen printers. Third, IRTA worked on an earlier project with SCAQMD that included screen printers. In the earlier SCAQMD project, IRTA was not able to complete the work with textile printing, one category of screen printing.

IRTA undertook the current SCAQMD project to conduct testing of alternatives with three additional textile printing companies. This document presents the results of the project sponsored by Cal/EPA's DTSC and U.S. EPA and the results of the testing with the three new textile printers.

Screen Printing

Screen printing is a short-run process that prints on almost any substrate including fabric, paper, leather, metal, glass, wood, ceramic and plastics. It is used for printing art prints, posters, greeting cards, labels, menus, program covers, wallpaper and textiles such as clothing, tablecloths, shower curtains and draperies. Some screen printing is done by hand with very simple equipment consisting of a table, screen frame and squeegee. Most commercial printing is performed on automated presses. One type of automated press uses flat screens that move in an indexed manner so that ink of different colors can be applied. Another type uses rotary cylindrical screens with the squeegee mounted inside the cylinder. The ink is pumped in automatically.

Screens are prepared before printing by the screen printers. The screens can be various sizes and they are generally made of polyester material with a wood or metal frame. A light sensitive emulsion is put onto the screen and it is cured with light. The emulsion forms a so-called stencil which serves as the pattern for printing. During printing, ink is forced through the screen and a pattern is printed on the substrate. The emulsion masks the part of the screen so that ink cannot pass through. Some companies also use a material called blockout to touch up the emulsion.

Most companies save the screens after a printing run so they can be used next time the customer orders a job. The emulsion is not removed from these screens and the screens are stored for future use. Some companies remove the emulsion each time the screen is used for printing.

Four types of inks are commonly encountered in screen printing. One type of ink is solventborne ink which is used by many printers. Another type of ink, called Plastisol ink, is used in textile printing applications; this ink is also solventborne. Textile printers account for about two-thirds of the screen printers. Some screen printers use ultraviolet (UV) curable ink which contains photoinitiators that are cured using light. Finally, a few screen printers use waterborne inks.

There are two places in the process where solvents are used to clean ink from the screens. During printing, many companies clean the screens periodically when the ink builds up. After printing when the screens are recycled or completely cleaned, solvents are used to remove the ink from the screens. Plain water or water-based cleaners are used to clean waterborne ink from the screens. Other materials are used to remove the emulsion, blockout and ghost image.

Participating Facilities

Nine facilities that have screen printing operations participated in the DTSC/EPA sponsored project and three additional facilities participated in the SCAQMD sponsored project. Table 1-1 shows a list of these facilities together with a description of the type of printing they perform and the type of ink they use. The results of the testing for the first nine facilities were reported in the final report for the DTSC/EPA project; the results for the last three facilities are reported here for the first time.

Table 1-1
Facilities Participating in Project

Company	Printing Description	Ink Type
Owens-Illinois	Prints on plastic cosmetic bottles	UV
Southern California Screen Printing	Prints on paper and plastic	UV
Com-Graf	Prints on variety of different substrates	Solventborne
Serendipity	Prints on variety of different substrates	Solvent and waterborne
Oberthur	Prints on plastic credit cards	Solvent and waterborne
Texollini	Prints on fabric	Waterborne
Hino Designs	Prints on textiles	Plastisol
Quickdraw	Prints on textiles	Plastisol
LCA Promotions	Prints on textiles	Plastisol
Totally Ink	Prints on textiles	Plastisol
Applied Pressure	Prints on textiles	Plastisol
Powerhouse	Prints on textiles	Plastisol

The facilities have a variety of different processes. Some, like Oberthur and Texollini manufacture goods and perform screen printing as part of their operations. Six of the facilities, Hino Designs, Quick Draw, LCA Promotions, Totally Ink, Applied Pressure and Powerhouse, are small textile printers who primarily print on T-shirts. Com-Graf prints on a variety of different products including glass and ceramics. Serendipity is a small one-person shop that does various printing jobs. Owens-Illinois prints on a range of different plastic cosmetic bottles. Southern California Screen Printing prints very large plastic and paper banners. Plastisol ink is used by the six T-shirt printers. UV curable ink is used by two of the participating facilities. Three facilities use waterborne ink, three facilities use more traditional solventborne ink.

Project Approach

The first step in the project was to visit each of the participating facilities. During these visits, IRTA toured the facility and focused particularly on the screen printing process. IRTA discussed the substrates and ink types used by each facility. IRTA also discussed the types of emulsions and blockouts used by the facilities. These are the parameters that affect the type of cleaner that can be used. IRTA requested a sample of ink or inks from the facilities.

The second step in the project was to perform preliminary tests at the IRTA office using the ink and several alternative cleaning agents. At this stage, IRTA wanted to screen alternative cleaning materials to see if they could clean the ink. IRTA obtained a typical screen from a screen printer and this screen was used in the preliminary testing. The ink was applied to the screen and different cleaning agents were rubbed on the screen with a wipe cloth to determine if they could effectively remove the ink. This test procedure allowed IRTA to determine which alternatives might be effective in cleaning ink at each facility.

The third step in the project was to visit the facilities and conduct initial tests with the alternatives that appeared effective in the preliminary testing to clean the ink in the screen printing process. The initial testing generally involved limited testing by hand cleaning screens that did not need to be saved for a future job. Some of the alternative cleaners can remove emulsion or blockout, depending on the type of emulsion or blockout used by the facility. Most facilities do not want the emulsion or the blockout to be removed so they can save the screens for the same customer with future jobs.

The initial facility testing generally involved testing two to 15 cleaning alternatives that have low-VOC and are relatively low in toxicity. If a cleaning agent cleaned the ink effectively but removed the emulsion or the blockout in cases where the facilities wanted to preserve the screen, it was eliminated from consideration. In almost all cases, IRTA tested the alternatives in the same manner the facility used the current cleaning agent. In some cases, however, it was necessary to modify the conditions. Water-based cleaners work much more effectively when they are heated and the initial facility testing was generally performed with a heated cleaner.

The fourth step in the project was to perform more extensive or scaled-up testing of the alternative cleaning agents that appeared to effectively remove the ink. IRTA provided the facilities with a week's supply or more of the cleaning agents so they could test them under production conditions. In some cases, IRTA provided equipment to the facility for the scaled-up testing which lasted for several weeks.

The fifth step in the project was to analyze and compare the cost and performance of the alternative and currently used cleaners. Section II of this document presents this analysis for the twelve facilities participating in the project.

Current Cleanup Solvents

Solvents used by the screen printing industry for cleanup in the U.S. include mineral spirits, methyl ethyl ketone, toluene, xylene, glycol ethers, terpenes, heptane and hexane. All of these solvents are classified as VOCs and many of them are toxic. Mineral spirits contain trace quantities of benzene, toluene and xylene. Benzene is an established human carcinogen; toluene and xylene are listed on California's Proposition 65. Hexane causes peripheral neuropathy, a nervous system disease.

SCAQMD is concerned about the VOC emissions from the solvents. The DTSC/EPA project sponsors were concerned about VOCs and exposure of workers and community members to the cleanup materials. The aim of the project was to identify, develop, test and demonstrate low-VOC, low toxicity alternative cleanup materials.

Alternative Cleanup Materials

The alternative low-VOC, low toxicity cleanup materials IRTA tested during this project can be classified into three categories. The first category is water-based cleaners. The second category is solvents that are exempt from VOC regulations. The third category is methyl esters which are vegetable based cleaners with a very low VOC content. Each of these categories of cleaners is discussed in more detail below.

Water-Based Cleaners. These cleaners generally contain a certain amount of water. They are sometimes diluted further with water when they are used for cleaning. Some water-based cleaners are based on surfactants; others contain a small amount of solvent. Water-based cleaners are most applicable for cleaning the plastisol ink used by the textile printers or ultraviolet (UV) curable ink used by some printers.

IRTA tested one water-based cleaner, called Ardrox 405-V and made by Chemetall Oakite, at two textile printing facilities. Both Hino Designs and LCA Promotions tested the water-based cleaner in a heated parts cleaner at 50 percent concentration. This water-based cleaner cleaned the ink effectively when the screens were being recycled.

IRTA tested another water-based cleaner, called Experimental Commercial Printing Cleaner NP 2520, which is made by Mirachem. This cleaner was tested at Southern California Screen Printing in a recirculating brush application system at full concentration. It worked very effectively in cleaning the UV curable ink when the screens were being recycled. The same water-based cleaner was tested at three textile printing facilities, Totally Ink, Applied Pressure and Powerhouse. At Totally Ink, the cleaner was applied by hand in concentrate form; at Applied Pressure and Powerhouse, the cleaner was used in a heated parts cleaner at 50 percent concentration. Powerhouse has since converted to this cleaner and has been using it for several months.

IRTA tested a third water-based cleaner, called GD 1990 and made by Brulin, during the project. The cleaner worked effectively for cleaning the semi-cured water-based ink at Texollini. The company converted to the cleaner and it is used in a high pressure spray process at about one-third concentration.

Exempt Solvents. There are a number of solvents that have been specifically deemed exempt from VOC regulations by U.S. EPA and local California air districts. Some of these contribute to ozone depletion and their production has been banned. The use of others, perchloroethylene and methylene chloride, is severely restricted because they are classified as carcinogens. Still others, one of the volatile methyl siloxanes and parachlorobenzothrifluoride, have potential toxicity problems.

One solvent that is exempt from VOC regulations was tested during the project. Acetone is an aggressive solvent that is very low in toxicity compared to other organic solvents. It evaporates readily and its disadvantage is its low flash point. IRTA tested acetone extensively during this project and it is a very effective ink cleaner.

Acetone evaporates too quickly to effectively remove ink from the screens when it is used by itself. When IRTA tested acetone during this project, it was combined with small quantities of other VOC solvents to prevent such rapid evaporation. A blend of acetone was tested for on-press cleaning at three printers, Hino Designs, Quick Draw and LCA Promotions. It effectively cleaned the ink at two of these facilities. An acetone blend was also tested at Com-Graf, Oberthur and Serendipity and it worked effectively on the ink at those facilities.

<u>Methyl Esters.</u> This class of chemical generally contains methyl esters that have a 16 to 18 carbon chain length. Materials like soy, canola oil, rape seed oil and coconut oil are composed of methyl esters. These materials clean most types of inks very effectively. During this project, IRTA relied heavily on soy based cleaners and soy was selected because it is more widely available and lower cost than some of the other methyl esters. Several different formulations were tested for VOC content by SCAQMD and the VOC content ranged from five to 25 grams per liter.

Two soy based cleaners were tested with the six of the textile printers. One of the cleaners, called Soy Gold 2000 and made by Ag Environmental, effectively cleaned the plastisol ink. A second soy based cleaner, designed to be rinsed more easily, called Soy Gold 2500, was effective at ink removal at Totally Ink, Applied Pressure and Powerhouse. Use of the soy cleaners did, however, require an additional rinsing step for the textile printers. Soy cleaners are oily and they must be rinsed before the screens are ready for printing. Soy Gold 2000 was also effective for cleaning the UV curable ink at Owens-Illinois and the company converted their operation to use the vegetable based cleaner. Another soy based cleaner, called Autowash #3 and made by Seibert, was tested for cleaning the UV curable ink at Southern California Screen Printing. This cleaner worked almost as effectively as the current cleaner at that facility.

<u>Cleaner Performance</u>

Performance of the alternative cleaning agents at each facility was evaluated on a case-by-case basis. In each instance, the plant personnel provided information on their requirements for the cleaning process. In all cases, it was important for the cleaning agent to effectively clean the ink from the screens in a reasonable period of time. The facility personnel were the judges of which cleaners cleaned effectively. In addition, when cleaners were tested during printing, IRTA insisted that the facility print after cleaning to make sure the print quality was acceptable.

<u>Cost Analysis</u>

IRTA performed cost analysis for each of the alternatives that was successfully tested at each of the facilities participating in the project. The types of costs that were evaluated included:

- capital cost
- cleaner cost
- labor cost
- utilities cost
- disposal cost

These costs were evaluated and compared when the costs were different for the current solvent and the alternative cleaners.

In some of the cases, it was assumed that there would be a capital equipment requirement. In these instances, the cost of the capital equipment was spread over a 10 year period, which was assumed to be the life of the equipment. The interest rate for the cost of capital was assumed to be four percent.

In virtually all cases, there was a difference in the cost of the current solvent and the cost of the alternative cleaner. In some cases, there was a difference in labor costs and, in these instances, the different costs were compared. In a few cases, there was a difference in electricity costs and these were noted and compared. Finally, in some instances, there was a difference in disposal costs and these were analyzed where appropriate.

Report Organization

Section II of this report provides detailed information on the analysis that was performed for each of the companies participating in the project. The cost of the current and alternative process was evaluated and compared. Section III summarizes the results of the tests and demonstrations at the facilities. Appendix A includes MSDSs for the alternative products that were tested or adopted by the participating facilities. Appendix B provides the stand alone case studies for three of the facilities that opted to convert to alternatives.