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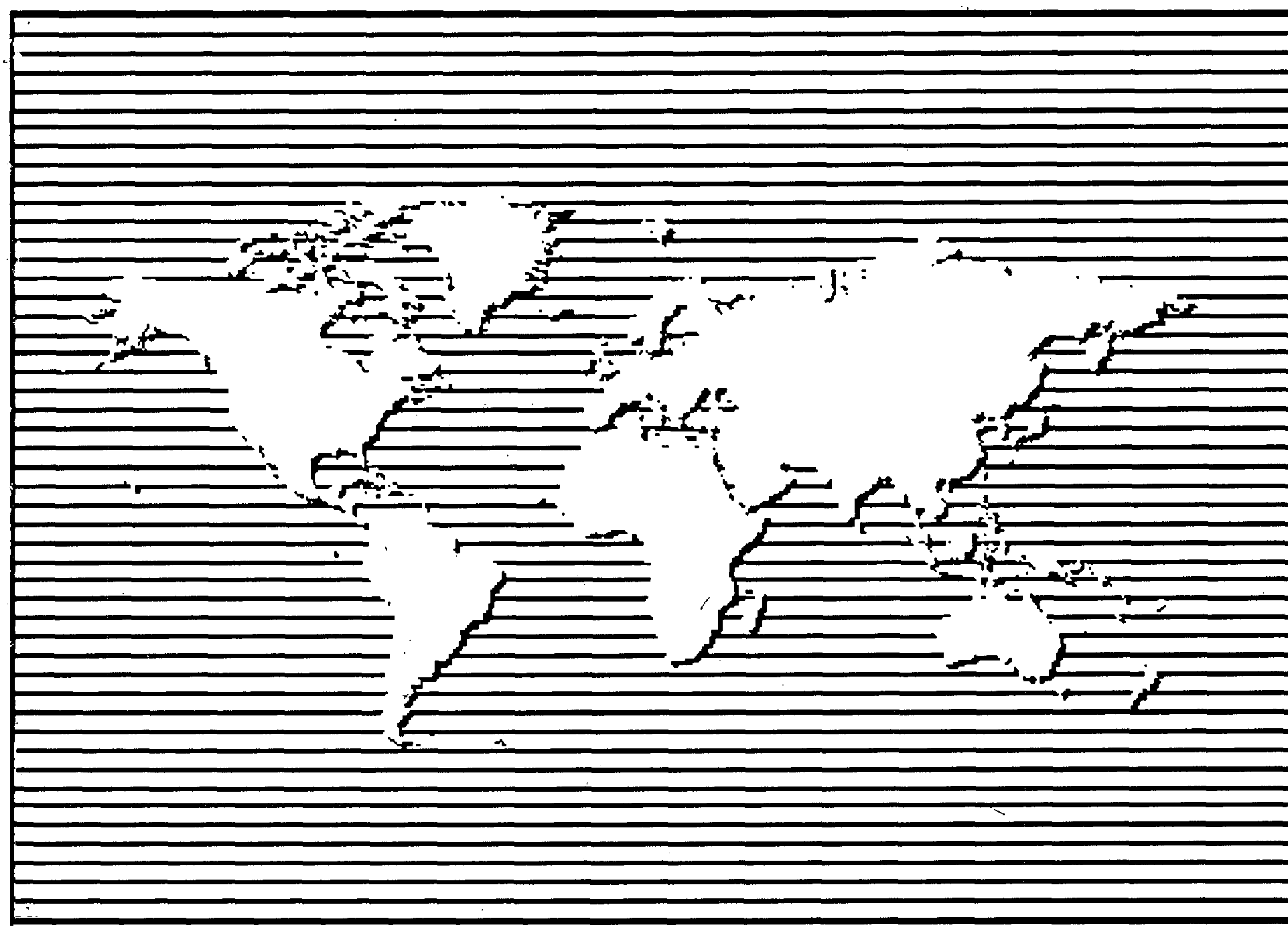
Manual Of Practices To Reduce And Eliminate CFC-113 Use In The Electronics Industry



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MANUAL OF PRACTICES

TO REDUCE AND ELIMINATE

CFC-113 USE IN THE ELECTRONICS INDUSTRY

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Disclaimer

Northern Telecom and the U.S. Environmental Protection Agency do not endorse the cleaning performance, worker safety, or environmental acceptability of any of the technical options discussed. Every cleaning operation requires consideration of worker safety, proper disposal of contaminants, and waste products generated from cleaning processes. Moreover, as work continues, more information on the health and safety of the alternatives will become available for use in selecting among alternatives discussed in this document.

FOREWORD

The Montreal Protocol on Substances that Deplete the Ozone Layer restricts the production and consumption of some ozone-depleting chemicals. Chlorofluorocarbon (CFC) 1,1,2-trichloro-1,2,2-trifluoroethane, commonly referred to as CFC-113, is one of these chemicals. Recent scientific evidence suggests that the measures outlined in the Montreal Protocol to reduce the production of CFCs to 50 percent of the 1986 levels by 1998 will not be sufficient to prevent further depletion of the stratospheric ozone layer. This has led some member nations to the Montreal Protocol to call for a complete phase out of CFCs by year 2000. There is a good possibility of this happening.

The time has come to seriously consider alternatives that could be used to replace the use of CFC-113 in the electronics industry. The situation provides us with a unique opportunity to rethink and reevaluate the processes and technologies that have been used for decades. It is a time to innovate and commercialize new technologies and processes. The inevitable price increases in CFC-113 as production drops may create a de facto situation in which CFC-113 becomes economically less desirable and a more rapid phase out of CFC-113 may occur than is currently foreseen. Thus, processes and technologies that currently do not seem economically viable might become cost competitive or economically more attractive than current CFC-113 processes.

You, as a manufacturer of printed circuit boards (PCBs) and printed wiring assemblies (PWAs), need to quickly find ways to reduce and eliminate your use of CFC-113. You can meet these challenges through conservation programs followed by adoption of one or more choices of alternate technologies.

In response to this important CFC issue and the need to identify and develop alternative strategies to reduce the use of CFC-113 in the electronics industry, Northern Telecom and the U.S. EPA have undertaken a joint program to provide users of CFC-113 with help to reduce and/or eliminate the use of CFC-113. This effort resulted in the publication of this manual, which is intended to provide company personnel involved with the CFC issue with guidelines and strategies to minimize/eliminate the use of CFC-113. Information provided in this manual is based on practices that have been adopted at Northern Telecom, and it is intended that the procedures and practices adopted by Northern Telecom will serve as an example for plant personnel in companies worldwide.

This manual of guidelines takes you through a simple structured program. It focusses first on conservation programs where reductions of up to 70-85 percent of your current use can be attained. Then it outlines for you the alternate technology and process options that are available to eliminate the remainder of your CFC-113 use. North American use of CFC-113 in PCB and PWA manufacturing appears to be in the order of 2.0 kg/m^2 of boards produced. Simple and inexpensive conservation techniques will reduce this use by 40-50 percent, and the addition of solvent vapor carbon adsorption will net an overall reduction of up to 80-85 percent. Alternate technologies such as aqueous cleaning, low solids fluxes/"no clean" assembly, controlled atmosphere soldering, alcohols and hydrochlorofluorocarbons (HCFCs), and hydrocarbon/surfactants will be needed to eliminate the remaining 15-20 percent.

Although this manual will primarily benefit manufacturers of PCBs and PWAs, others who process small electronic parts, for example, will also find this manual helpful.

The success of your CFC-113 elimination program will depend upon how effectively you coordinate your program. Management commitment is needed at all levels.

STRUCTURE OF MANUAL

This manual is divided into the following sections:

- Process Characterization: In this section, it is stressed that you need to understand how you manufacture your product (design, assembly, soldering, and cleaning), and where and how CFC-113 is used in this process;

- Conservation Practices & Strategies: In this section, discrete conservation projects are ranked so that you can choose the project(s) that will give you the biggest reduction of CFC-113 for the least amount of time and money;

- Non-CFC Processes: This section presents the choices of alternate non-CFC processes and technologies; and

- Methodology to Select Non-CFC Processes: This section outlines a methodology for the decision making criteria that can be used to select a non-CFC process.

REQUIREMENTS FOR PROGRAM SUCCESS

You can reduce the use of CFC-113 by up to 70-85 percent in your cleaning processes through conservation, and you can eliminate the remainder by adopting technologies that are now available.

This program will only be successful if you:

- gain management commitment at all levels and all functions;
- make your staff aware of and get them involved in the program;
- understand how and where you use CFCs;
- identify individuals who will monitor the program and be responsible for its implementation through to completion;
- adopt conservation programs;
- set realistic targets and achieve them; and
- evaluate and adopt non-CFC processes.

PROCESS CHARACTERIZATION

To develop an effective program to reduce and eliminate CFC-113 use, it is vital that you develop a good knowledge of your plant operations.

> Understanding Plant Operations:
>
> - Who purchases CFC-113?
> - Who takes delivery?
> - How it is handled from arrival to ultimate use?
> - How it is CFC-113 used? and
> - Where do losses take place?

Have the manager of your CFC-113 elimination program start with a survey. A copy of a questionnaire that can be used is shown in Exhibits 1 and 2. This survey form should be sent to individuals in different plant locations who are responsible for, and who understand, Material Safety Data Sheets (MSDS). All MSDS should be checked for 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113) to help identify the trade name. Identify the quantities bought in the previous calendar year and start reporting on a regular basis (monthly or quarterly).

The following steps should then be followed:

(1) For a given time period (year, quarter, month) determine total production of boards in square meters of surface area. Only measure the area of one side of the board regardless of whether it is single sided, two sided, or multiple layer in configuration.

(2) Now you can, for a given period of time, divide total quantity of CFC-113 purchased by total manufactured board area for the same period to determine the ratio of kilograms of CFC-113 used per squaremeter of board produced, expressed as kg/m^2.

In North American industry this ratio appears to be in the order of 2.0 kg/m^2 for a production facility operated with today's technology and minimal attention to chemical handling. Determine your ratio first before you start your conservation and elimination programs.

> At this point you have to make the following decision:
>
> - If you are already at 0.5 kg/m^2 then you likely have good conservation practices in place and you will be ready to focus more of your time and effort on exploring alternate processes and technologies.
> - If your ratio is higher than 0.5 kg/m^2 you can benefit from conservation programs.

Calculate this ratio and report it on a regular basis - monthly is recommended. It is important because you will be able to monitor success as your conservation programs go into effect, and your employees will take an interest and participate in the drive towards reaching the objectives of reducing CFC-113 use.

Next, do an assessment of where you are losing CFC-113. Do this for the whole plant beginning with the delivery of CFC-113. You may wish to develop a simple flow schematic as is shown in Figure 1. This will give your project manager and your technical staff an understanding of the areas to focus on first. If you have more than one cleaning machine you should do an analysis of each since CFC-113 losses may vary significantly from machine to machine.

With your knowledge of consumption and where your losses are occurring you can now select the appropriate conservation programs. These are described in the next section.

Figure 1: CFC-113 LOSSES IN A TYPICAL PLANT

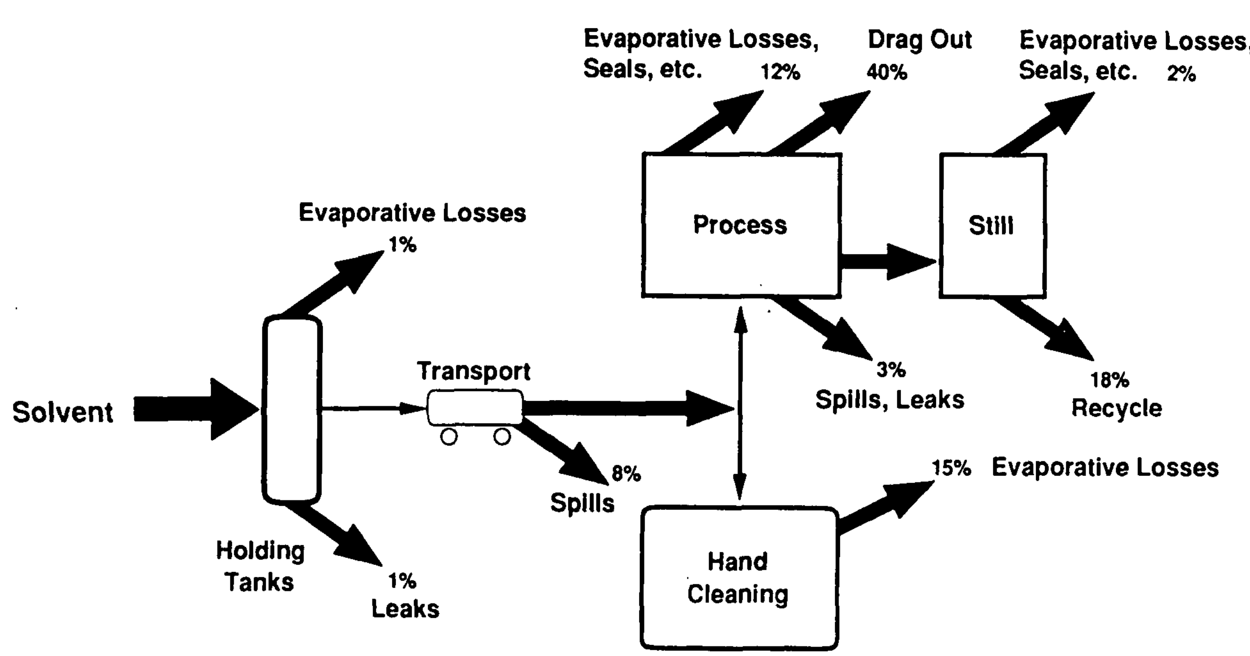


EXHIBIT 1. CFC USAGE PROFILE

A. Identification

Name of Product: ______________________

Manufacturer: ______________________

Purchase Number: ______________________

CFC Components:

	Chemical Name	Percent or Concentration
1.	______	______
2.	______	______
3.	______	______

B. Quantification of Usage Patterns

Quantity Purchased: (please specify units)

1988: ______ 1990: ______

1989: ______ 1991: ______

C. CFC Disposal Practices

	1988	1989	1990	1991
Annual quantity shipped out as waste for disposal: (please specify units)	____	____	____	____
Annual disposal costs:	____	____	____	____
Annual quantity shipped out for reclamation: (specify units)	____	____	____	____
Annual cost of reclamation:	____	____	____	____
Annual quantity lost to the environment: (specify units)				
Through leakage:	____	____	____	____
Through spillage:	____	____	____	____
Through testing:	____	____	____	____
Through drag-out and evaporation:	____	____	____	____
By other means (specify) ______	____	____	____	____
Unaccounted for:	____	____	____	____

EXHIBIT 2. PRINTED CIRCUIT BOARD CLEANING EQUIPMENT PROFILE

A. Identification

Equipment Name: ____________________

Model Number: ____________________

Manufacturer: ____________________

Year Purchased: ____________________

Trade Name of Chemicals Used: ____________________

Annual Quantity of CFC Purchased for Use in this Equipment (specify units): ____________________

Annual Quantity of CFC Waste Requiring Disposal or Off-site Recycling: ____________________

B. Equipment Usage Pattern

Annual Board Production (please specify units): ____________________

Average Board Area: (please specify units): ____________________

Check appropriate blanks:

Single sided ______
Double sided ______
Multilayered ______
Number of layers______

Average Number of Solder Connections per Board: ____________________

C. Emission Controls

Do you practice the following? If you do, briefly describe the procedures:

Leak Testing:

Alternate Testing Methods:

On-site Recovery/Recycling:

Improved Loss Control Procedures:

Operator Awareness/Guidelines:

CONSERVATION PRACTICES AND STRATEGIES

Once you have characterized your current use of CFC-113, you can begin to develop a conservation strategy. At first, you should choose conservation options that are easy to put into place in the short-term. These will give immediate results and will provide encouragement to employees to continue and accelerate their efforts.
Conservation practices are divided into two categories: in-line cleaning and batch cleaning.

Operator Awareness of the CFC Issue and Training in the Handling of CFC-113:

In general, it has been found that operators are unaware of the financial or the environmental costs associated with the use of CFCs. Increased operator awareness and respect for chemicals translates into a reduction in consumption, since operating practices and methods can usually be improved.

Operators, once educated, are able to change the methods and practices. For instance: keeping lids and windows closed, turning off the cleaner when not in use, conducting maintenance regularly, and exercising care while working with machines and equipment.

You may also wish to review chemical handling procedures and restrict access to CFC-113 to a few employees.

IN-LINE CLEANING PRACTICES

Choices for in-line cleaning are listed and ranked starting with the easiest to do. These options include:

(1) **Examine and Replace, Repair or Upgrade the Seals and Gaskets on Pumps, Valves, Pipe Joints, Covers, Lids, and Elsewhere:**

Pump seals deteriorate when not in contact with CFC-113. A "running dry" condition erodes the seal surface and the seal prematurely fails.

The design and maintenance of cleaners and stills requires a focus on the seals and gaskets on covers, lids, and panels. High volume leaks often occur around corners and joints where two seals meet.

Check for compatibility of new and replacement materials.

(2) **Reduction of Air Currents:**

Excessive air currents outside in-line solvent cleaners disturb the vapor blanket within the equipment and losses increase. When excessive air movement is a problem, remove the source or consider the installation of baffles or partitions on the windward side to divert the draft away from the cleaning unit.

(3) **Cleaning Machine Optimization:**

Take advantage of services often offered by the machine manufacturers; they have experience in fine tuning the cleaner to minimize losses. You may wish to complement this with services offered by CFC-113 suppliers who often have programs and information that also can help operators better manage the process.

In optimizing the machine, examine the potential for reducing the conveyor belt speed. This will keep the board in the vapor zone longer for more complete evaporation of solvent, thus reducing drag-out to a minimum.

Check all temperature measuring devices and controls. Correctly calibrated instruments will optimize machine performance and reduce solvent losses.

(4) **Board Cooling:**

Solvent cleaners often are placed immediately following wave solder machines. This reduces the cooling time before cleaning. If the boards are entering the cleaner at a temperature greater than the vapor temperature, the heat will be transferred to the vapor and liquid CFC-113. This creates a super heated vapor and an elevated temperature in the various chambers of the cleaner, resulting in a less efficient operation which may increase solvent losses.

A solution is to mount small fans above and below the conveyor to cool the boards before they enter the cleaning machine. Fans should be directed away from the opening(s) of the equipment to prevent disturbing the vapor blanket within the machine which could result in increased solvent loss.

(5) **Board Orientation:**

Orientation of the board plays a key role in the volume of CFC-113 dragged-out of the cleaners. In many instances it has been found that CFC-113 adheres to the underside of components and connectors. This could be minimized through reorientation.

Reorientation can be as simple as changing the method by which the boards are processed. This may require an intelligent controller interfaced with a turntable located after the wave solder machine. The turntable may require a faster cycle time to reduce the adverse effects on production.

(6) **Solvent Recycling:**

CFC-113 often is used to clean flux residue from washers and stills when preventative maintenance is carried out. External reclamation and recycle facilities are often available which will provide a reclamation and reconstitution service for this contaminated solvent. You may have the choice between having the solvent returned to you for re-use or receiving credit with the solvent being made available for resale to others.

(7) **Filter Improvements:**

Original filters reach the limit of their usefulness relatively quickly under normal operating conditions. The use of more effective filters results in fewer changes over time and less solvent loss.

For example, the use of an engine oil filter and a pump can filter out additional impurities in the solvent distillation process. This can be used to increase the time between preventative maintenance requirements, which in turn decreases solvent losses.

(8) **Machine Rationalization:**

Consider using one solvent cleaner to handle the boards from two or more solder machines. Large losses are seen in cleaners that are under utilized and have an extended idle mode or cycle through frequent start-ups and shut-downs.

This will require reworking equipment placement, conveyor lines, controllers, and other features. If successful, benefits include not only reduction of losses of solvent but also removal of extra equipment with a reduction in operating and maintenance costs.

(9) **System Enhancements:**

There are a number of enhancements that can be made to the solvent cleaner which you may wish to consider. These are hardware add-ons or modifications that require capital expenditures and are not the machine optimization aspects previously described. System enhancements include:

- increased freeboard height;
- increased cooling system compressor capacity; and
- additional cooling coils on inlets and outlets.

Cleaner manufacturers and experts in chilling/refrigeration should be consulted for their expertise. Consider reviewing the condensing effectiveness of your chiller/refrigeration system with the assistance of a knowledgeable contractor. Improved condensing efficiency through additional cooling coils at the entrance and exit of the wash and perhaps through compressor resizing will reduce evaporative and drag-out solvent losses.

Use gas detectors to give accurate information on where leaks are and how effective your efforts are.

(10) **Bulk Solvent Handling:**

A bulk CFC-113 handling system, shown in Figure 2, reduces CFC-113 losses in drum handling, in transferring to small containers, and in filling the cleaners. With appropriate real time alarms, personnel are alerted to possible leak conditions by monitoring consumption or loss in each cleaner as CFC-113 is supplied.

Solvent is delivered by bulk tanker and is then pumped into a bulk storage tank where it is held until needed. The tank is non pressurized and, in the example, is within the plant. Distribution to the cleaners is provided through a series of pumps and PVC pipes. Therefore, the system eliminates all manual handling of CFC-113 and minimizes losses. Control is provided by float switches within individual washer units.

A microprocessor can be used to monitor the consumption of CFC-113. This allows for daily collection of consumption data for each cleaner. The computer also can adjust for excessive consumption. In addition, if an alarm condition occurs, the cleaning system is checked for leaks.

(11) **Solvent Vapor Recovery:**

Drag-out losses are a major contributor to the overall loss of solvent in the system and vapor capture systems should be considered. These systems adsorb the non-polar CFC-113 molecule on an activated carbon bed, which is then extracted by steam for blending with additives and re-use in the system.

The intake and exhaust ports of the cleaner are vented to hoods where vapors are drawn under negative pressure through the activated carbon bed. It is vital to properly design the collection hood at the cleaner discharge since this is where drag-out and drying losses are most significant.

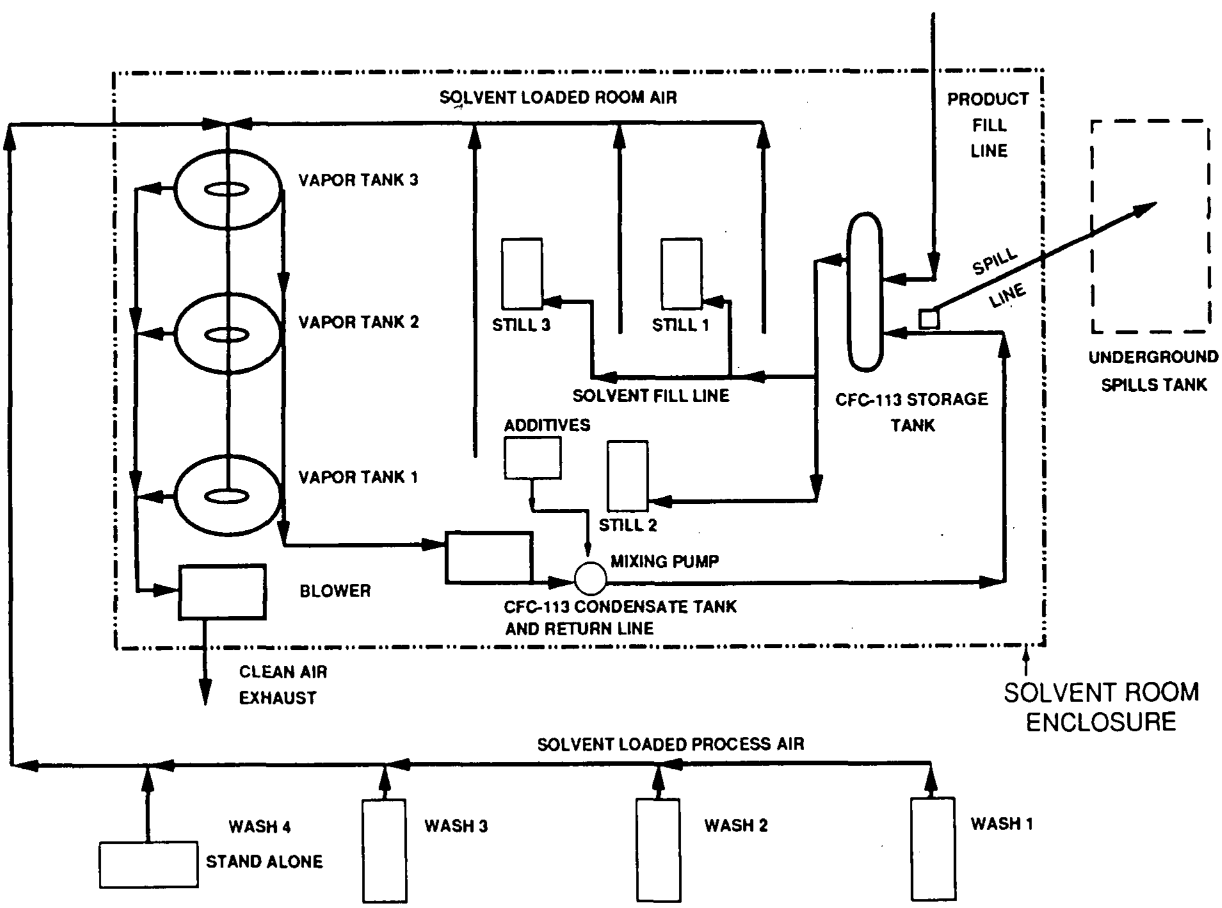
Adsorption continues until the carbon bed is saturated at which time the bed is steam injected to strip off the CFC-113 for condensing and water separation.

Three streams are produced: pure CFC-113, clean air, and wastewater. Waste water is treated and released to the sewer system; the air is returned to the plant or exhausted into the atmosphere; CFC-113 is reblended/reconstituted with additives and reused in the process. There will be some methanol in the waste water streams and local legislation should be considered in specifying equipment.

Systems can be sized to suit large and small applications, and one adsorption system can service more than one cleaner. In the example developed in this manual, four cleaners are handled by one adsorption system.

It should be noted that in this example the bulk storage tank, the stills, and the adsorption system are all located in an enclosed room. The room air itself also passes through the adsorption system which captures and recycles any fugitive CFC-113 losses.

Figure 2: CFC-113 VAPOR RECOVERY SYSTEM



BATCH CLEANING OPERATING PRACTICES[1]

Operating practices that can reduce losses from batch cleaning process are described below.

(1) **Location of Cleaning System (Air Current Reduction):**

As with the case for in-line equipment, batch cleaners should be placed in an area that is as draft-free as possible. Turbulence caused by drafts from adjacent windows, doors, fans, unit heaters, ventilators or spray booths will greatly increase the rate of evaporation of solvent vapor.

To avoid excessive air movement, consider installing baffles or partitions on the windward side to divert drafts away from the cleaning unit.

For open-top equipment, problems with drafts can be avoided or corrected by using hooded enclosures with automated work-handling facilities.

(2) **Size of Workload:**

Decrease the loss of solvent vapor by avoiding the processing of workloads that exceed the cleaning system's design capabilities.

A workload that is too large in physical size can displace vapor from the cleaning unit by the "piston effect." Losses caused this way can be minimized by making sure that the area of the workload is not greater than 50 percent of the horizontal cross-sectional area of the sump into which it is being introduced.

Also, the introduction of a workpiece that is too large in mass will cause condensation of too much of the vapor blanket. This will cause air to infiltrate the cleaner.

During reestablishment of the vapor blanket, the infiltrated air saturated with solvent vapors will be expelled from the cleaning unit. If this occurs on a regular basis, contact the equipment manufacturer to determine if additional heating and condensing facilities can be incorporated into the cleaning unit.

(3) **Start-Up/Shutdown Procedures:**

Solvent emissions during start-up can be minimized through the following steps in the order shown:

- Start-up the condenser cooling system and make sure that it is operating properly.
- Start-up any auxiliary emission control equipment.
- Check and adjust solvent levels in all compartments.
- Turn-on heaters.
- Start-up the spray pumps once a stable vapor blanket is established.
- Process work pieces only after the vapor blanket has been stabilized.

Use the following steps, in the sequence shown, when shutting down the system:

- Stop work processing and clear the machine of all work.
- Turn-off the heaters.
- Activate sump cooling coils where provided.
- Allow the vapor blanket to collapse completely.
- Turn-off the condenser cooling system.
- Close the cover on open-top units.

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[1]This section was prepared using information from the DuPont Company

(4) **Consolidation and/or Work Scheduling:**

Start-up always results in some solvent vapor loss as air is purged from the system. When the cleaner is used on an intermittent basis, emissions caused by frequent start-ups and shut-downs can be minimized by deferring cleaning until a full day's cleaning work is accumulated for processing. Thus, there will only be one start-up of the cleaning equipment.

As well, you can reduce vapor emissions by consolidating operations of several open-top units into a single, enclosed unit designed for continuous operation.

(5) **Positioning Work To Reduce Drag-Out Loss:**

You can reduce drag-out losses if the work being cleaned, whether contained in baskets, suspended from hooks or racks, or conveyed on a belt, is always positioned so that it permits maximum liquid drainage. Solvent trapped in pockets and recesses results in excessive drag-out losses.

(6) **Cover Design:**

Hinged covers, if opened too quickly, tend to drag some of the solvent vapor with them. Consider an alternate design such as a cover which slides open.

(7) **Vapor Dwell Time:**

If possible, hold the workload in the vapor zone after the final cleaning step until its temperature equals that of the vapor zone and vapor stops condensing on the part. Work taken out earlier will emerge wet with solvent condensate.

Dwell times that are too short are most often seen in open-top units where the work is manually moved into and out of the unit. Automatic hoists can help reduce excessive drag-out due to insufficient dwell time.

(8) **Movement of Workload:**

A recommended maximum speed for work entering and leaving the cleaner is three meters/min. Higher throughput rates can cause vapor/air interfacial disturbances that result in high vapor losses.

Again, the use of automatic hoists and programmed work transporters is recommended. The speed of the piece entering and leaving should be optimized.

(9) **Spraying:**

Spraying of work pieces by spray-lance or spray headers should be performed deep within the vapor zone. This avoids excess disturbance of the vapor/air interface.

Take care to avoid having the liquid solvent ricochet into the free-board zone or out of the machine when lance spraying.

Avoid spraying cold solvent vapor because this results in the loss of heat from the vapor blanket, which increases the potential risk of collapsing the vapor blanket. Use warm solvent (100° F to 112° F) for spray washing. This minimizes the potential for vapor blanket collapse, and the loss of solvent that takes place when the vapor blanket is reestablished.

(10) **Integrated Cover/Hoist Designs:**

The inclusion of an integrated degreaser cover and hoist design is effective in reducing working solvent loses. The presence of a motorized, horizontal sliding, two-piece lid can be integrated with an automated programmable hoist. As the hoist lowers the workload to the degreaser, the lid slides open to allow entry of the product into the vapor zone. When the workload clears the lid on its downnward descent, the lid closes. Subsequeent losses due to the "piston effect" or sprayers disturbing the vapor blankket are minimized. After vapor condensation ceases or spraying is terminated, the workload can be raised into the cooling coil zone of the degreaser with the lid still closed. Again disturbed vapor zone and potential workload drag-out losses are minimized. When the solvent has vaporized and the product is free of liquid solvent (dry), the hoist begins raising the product out of the degreaser, the lid opens and then closes after exiting.

Such designs can be purchased as an integral part of many new degreaser designs. Retrofit kits consisting of a lid, hoist or a combination of the two are also available to convert existing degreasers.

(11) **Handling of Solvent:**

Add solvent to the cleaner carefully to minimize disturbing the vapor/air interface. Solvent should be pumped into the cleaner through a liquid-submerged fill connection. Makeup solvent should be added to a rinse compartment, or better yet, to the cleaner's condensate collection tank. Cold solvent definitely should not be added to a boiling sump; it may stop the boiling and cause the vapor blanket to collapse.

Avoid overhead pouring of solvent via buckets and drums to an open-top cleaner. This produces turbulence at the vapor/air interface and increases the possibility of the vapor blanket to collapse. Solvent handling in open-top containers should be avoided because it offers the opportunity for solvent evaporation and spillage.

Keep drums containing solvent tightly sealed between transfer operations to prevent unnecessary evaporation losses. And store drums with the bung end up to eliminate the possibility spillage of solvent through a leaky bung. Consider a bulk storage system for solvent and delivery of the solvent through a piping system to the batch cleaners.

RECAP ON PROGRAM TO THIS POINT

Following the recommendations presented above, your program at this point will have consisted of the following sequence of activities:

- management's commitment to a successful reduction of CFC-113;
- designation of an individual with a mandate to proceed with the project;
- a survey of your CFC-113 purchases and uses;
- establishment of your CFC-113 use per area of board manufactured (kg/m^2) and procedures to calculate and monitor this ratio on a regular basis; and
- execution of conservation projects in the most appropriate order.

You are urged to follow these steps in this sequence before pursuing new replacement technologies and processes. The benefits of doing so include:

- employees learn about the issues;
- a cultural change takes place in the location and elsewhere in the company which is essential for the program's success;
- employees develop a deep understanding of the manufacturing process and equipment; and
- significant reductions in CFC-113 use are achievable in a short period of time.

NON-CFC PROCESSES

In addition to conservation procedures, you want to evaluate non-CFC processes. There are a number of alternatives to CFC-113 now available for cleaning of PCBs and PWAs. It is important, however, that your customer requirements be closely examined before moving toward implementing these alternatives. This is necessary because traditionally cleanliness of PCBs and PWAs is cited as a reliability requirement. Studies have shown, however, that this may not be so, and therefore, the application of any alternate is now dependent on addressing cleanliness and reliability issues.

It is important that you determine and establish on paper what tests and standards will be applied for cleanliness and reliability. For example, while cleaning may not be required for final product reliability, it may still be required to do tests on the boards; therefore, testing methods would have to be specified. You will need to take into account your customers' perception of what constitutes an acceptable product in terms of reliability and testing. This approach will be a new way of thinking for many manufacturers.

Once your criteria are established, consider one or more of the following options which are available today:

- aqueous cleaning;
- low residue fluxes/"no-clean" assembly;
- controlled atmosphere soldering;
- alternate solvents (chlorinated solvents, alcohols, and hydrochlorofluorocarbons (HCFCs)); and
- hydrocarbon/surfactant cleaning.

Each of these offers advantages and disadvantages.

AQUEOUS CLEANING

Water is an excellent solvent for removing ionic contaminants and water soluble fluxes. Water, in combination with a saponifier, can remove non-polar substances such as oil and rosin fluxes. Aqueous cleaning systems generally consist of a wash, rinse, and a dry stage (See Figure 3). In the wash stage, contaminants such as oils, grease, and rosin react with the alkaline saponifiers (most commonly alkanolamines) to form a water soluble soap via a saponification process. Following exposure to saponifier, the boards are rinsed. The rinse step is important to remove saponified contaminants, residual saponifier solution, and other water soluble residues remaining. The rinse step is generally carried out with deionized water to maintain a high degree of purity. Aqueous cleaning is most effective when combined with high pressure and/or high volume sprays.

Aqueous cleaning offers several potential advantages:

- aqueous cleaning can be used to remove water soluble fluxes, and in conjunction with saponifiers, rosin fluxes;
- suitable for cleaning through hole and surface mount assemblies;
- no distillation equipment is required to recycle the solvent;
- no costs of disposing spent solvents;
- reduced pretreatment costs can be realized if water treatment (e.g., distillation, reverse osmosis, heating, etc.) is not required.

Prior to the use of aqueous cleaning the following items should be considered:

- Because surface mounted components are placed closer to the board than traditional through-hole components, adequate cleaning in the small gaps underneath surface mounted components is more difficult. Aqueous cleaning of surface mounted assemblies (SMAs) depends on a number of physical properties including (1) surface tension, (2) viscosity, (3) mechanical energy, and (4) temperature. You have to keep these important parameters in mind when designing aqueous cleaning processes for SMAs.
- Most newly designed aqueous cleaning systems are based on a closed loop recirculating wash and rinse stages, as opposed to a continuous discharge system. The wash and rinse water is continuously used for weeks or months without being discharged. This reduces the amount of wastewater being used, and therefore, reduces the energy and disposal cost (See Appendix 1 for a list of vendors).
- "Zero-discharge" aqueous cleaning systems are available that use closed loop recycling systems to minimize the discharge of process water (See Figure 4). Such systems reduce water, energy, and disposal costs significantly. Currently these systems are available for aqueous cleaning systems that use water soluble fluxes (See Appendix 1 for vendor). Systems for other types of fluxes (i.e., rosin and organic acid fluxes) are being developed.

Figure 3: TYPICAL AQUEOUS CLEANING CONFIGURATION

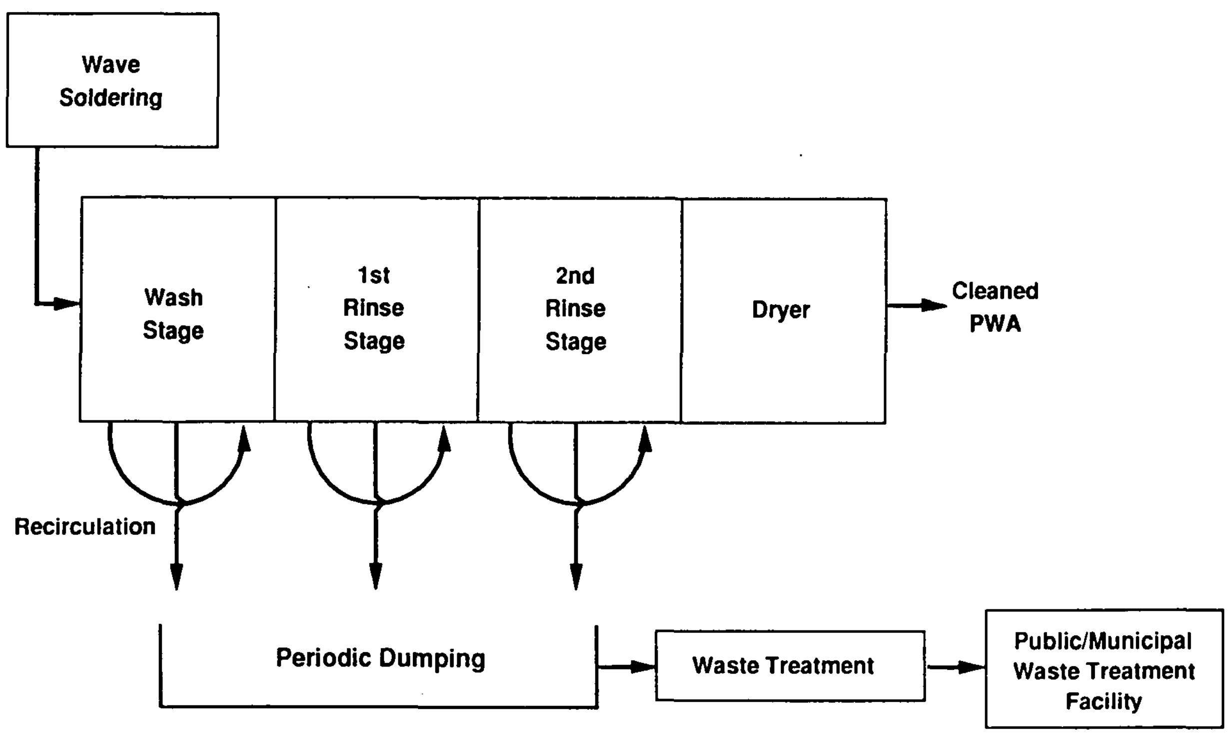
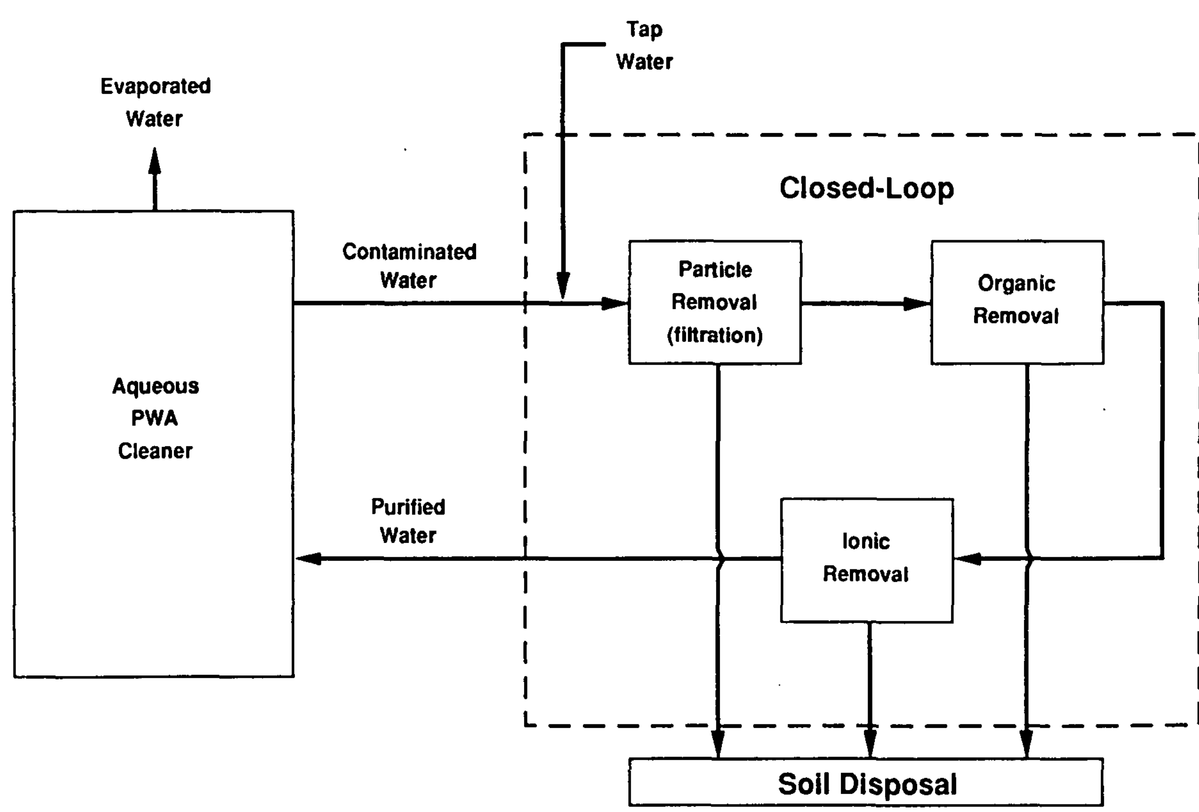


Figure 4. "ZERO DISCHARGE" WATER RECYCLING SYSTEM CONCEPT



LOW SOLIDS FLUXES/"NO-CLEAN" ASSEMBLY

By carefully evaluating and selecting components and assembly processes, benign low solids fluxes can be used to eliminate cleaning in some instances. Traditionally, the electronics industry has used, and is still using, rosin fluxes containing between 15 to 35 percent solids content for wave soldering electronics assemblies (through-hole, single-sided, and double-sided printed circuit boards). Numerous low solids fluxes containing 1 to 10 percent rosin (or resin, or both) have been formulated and tested.

Low solids fluxes have the following advantages:

- "bed of nails" testing on printed circuit board assemblies can be carried out immediately after wave soldering, without the problems created by the presence of rosin residues; and
- the need for defluxing can be eliminated.

Depending on the solder mask or resist and the low solids flux used, little or no visible residue remains on the boards after soldering. The remaining residues, if any, dry and rapidly harden. Automatic testing can be done without cleaning the boards. Because low solids fluxes are generally considered non-corrosive and have high insulation resistance, in most cases it is unnecessary to remove them, even for cosmetic reasons.

Prior to using this process, you should note that:

- These fluxes may have to be removed to meet military specifications and are relatively difficult to remove by traditional CFC-113 methods.
- The use of incompatible cleaners can result in the formation of white residues or cosmetic imperfections on the fluxed surface. It is important that you consider the compatibility of these fluxes with cleaning media and cleaning equipment.
- One company has performed additional tests on low solids fluxes. The test results demonstrated an inverse relationship between surface insulation resistance (SIR) and the quantity of low solids flux applied and revealed the importance of process selection and process control in the application of a number of low solids fluxes.
- Aging studies showed that large quantities of some, but not all, post-solder low flux residues can be detrimental.

To minimize excessive flux build-up a new fluxing system has been designed that uses an ultrasonically-controlled spray to disperse the flux (U.S. Patent #4,821,948, April 18, 1989). This system is commercially available. Other commercial spray fluxes are also available (see Appendix 1 for list of vendors). Other advantages of this system include minimal deposition of flux on the topside of circuit boards which can be detrimental, and a closed flux reservoir system that prevents alcohol evaporation (specific gravity changes) and water absorption.

Conventional fluxes are more tolerant of minor variations in the process parameters because of their high solids content. The choice of solder mask is a prime concern, as a poor choice results in unacceptable levels of solder ball formation.

You should not expect the conversion of a soldering line from a conventional to a low solids flux to be easy. Some adaptation of the process parameters and possibly the soldering machine itself will be needed. Some users have experienced initial difficulties when starting up with these fluxes, but a little perseverance generally resolves problems such as maintaining an adequate foam head, measuring and adjusting the flux solids, preventing water from entering the flux, regulating the quantity of applied flux, and adjusting the preheaters to a more critical degree.

Fluxes are now available in foam, wave, and spray application. Wave application of low solids flux presents minimal cost and retrofit difficulties. As these processes all utilize low solids fluxes diluted with isopropanol, you must consider adequate ventilation and fire suppression. Optimization of the process parameters using low solids flux can be assisted by using applied statistical quality/process control techniques (e.g., the Taguchi method).

CONTROLLED ATMOSPHERE SOLDERING

A new soldering process, inert gas wave soldering, recently has been developed by a large West German group who is licensing the manufacture of machines (See Appendix 1 for list of vendors). The process operates under a nitrogen atmosphere and applies finely divided activators via ultrasonic injection (See Figure 5). The carboxylic acid activators include formic acid, acetic acid, citric acid, and adipic acid. Other processes are also being developed that function on the same principle except that soldering is carried out in vacuum instead of a nitrogen atmosphere.

Inert gas wave soldering has been tested by a large West German electronics manufacturer with numerous conventional wave soldering systems in operation. Preliminary test results show no significant differences in the quality of solder joints. Boards tested by Northern Telecom after inert gas wave soldering found better solderability. These preliminary tests showed an order-of-magnitude decrease in solder defects. In addition, several European and North American companies will soon be using the inert gas process to wave solder both through-hole and surface mounted assemblies. Results are preliminary and tests are underway to further quantify the process. Processes are currently being developed and patented to allow blanketing of existing through hole equipment. SMT technology is about to see controlled atmosphere applications as well.

The particular features that make this process preferable to the well established and widely used method of soldering under atmospheric conditions (i.e., in the presence of oxygen) are:

- soldering takes place with metallically pure solder (i.e., in an oxide-free soldering module, oxygen levels in and above the bath are monitored by solid electrolytes at less than two ppm);
- oxide formation is greatly reduced on the printed circuit boards both before and after soldering (dross formation is reported to be only 10 percent of that generated in normal soldering machines, i.e., 0.5-1.0 kg/day);
- the system operates without conventional rosin or resin fluxes; and
- post-cleaning required for assemblies wave soldered on equipment currently in use and utilizing conventional fluxes (rosin, inorganic or synthetic fluxes) is eliminated for many applications. The residues remaining on the printed circuit boards after soldering have been reported to be less than 3.5 micrograms/square centimeter NaCl equivalent.

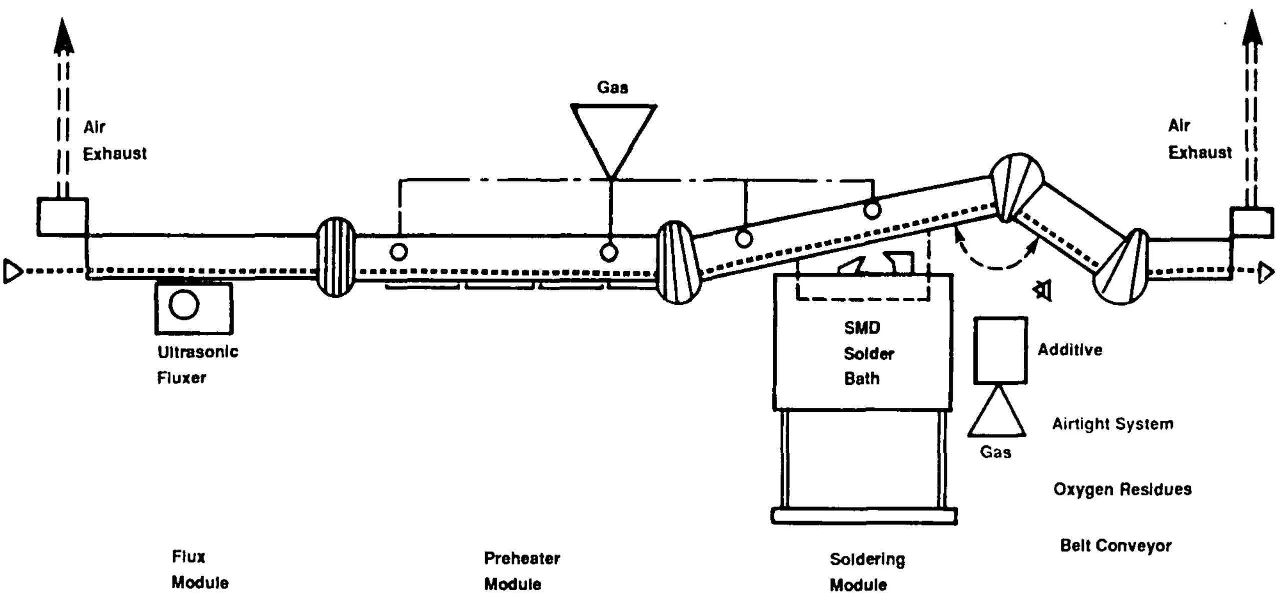


Figure 5. DIAGRAM OF A CONTROLLED ATMOSPHERE WAVE SOLDERING MACHINE

ALTERNATIVE SOLVENTS

There are a wide variety of alternative solvents that are considered as possible replacements for CFC-113. These include chlorinated solvents (1,1,1-trichloroethane), alcohols and hydrochlorofluorocarbons (HCFCs). These solvents are briefly discussed in the next section.

(1) **1,1,1,-Trichloroethane:**

1,1,1-Trichloroethane is an effective substitute for CFC-113 in electronics industry operations. Although a volatile organic compound, the U.S. EPA has exempted 1,1,1-trichloroethane from legal classification as a volatile organic compound (VOC). Furthermore, it is nonflammable. It is possible, therefore, that some substitution of 1,1,1-trichloroethane will occur as CFC-113 becomes less available and users face rising prices. However, 1,1,1-trichloroethane has been identified as an ozone depleting substance and may be added to the Montreal Protocol in 1990.

(2) **Chlorinated Solvents:**

Trichloroethylene, perchloroethylene,and methylene chloride also are effective cleaners. They are also volatile organic compounds. However, each of these solvents is considered a possible or probable carcinogen. The U.S. EPA has classified trichloroethylene in Category B2 as a "probable human carcinogen," while the International Agency for Research on Cancer (IARC) has classified this solvent in Group 3, a substance not classifiable as to its carcinogenicity in humans. The IARC has classified perchloroethylene in Group 2B as a substance considered "possibly carcinogenic to humans." Finally, the U.S. EPA has classified methylene chloride in Category B2 as a "probable human carcinogen," while the IARC has classified methylene chloride in Group 2B as a substance considered "possibly carcinogenic to humans". Chlorinated solvents will be selected substitutes for CFC-113 in some cases. For example, in the United States, trichloroethylene continues to be used even with new regulations that reduce the allowable worker exposure to the chemical.

(3) **Organic Solvents and HCFCs:**

Organic solvents such as alcohols and HCFCs are possible replacements for CFC-113. Five organic solvents and HCFCs have been proposed as possible CFC-113 substitutes: pentafluoropropanol (5 FP), isopropanol, HCFC-225ca, HCFC-225cb, and HCFC-141b/HCFC 123/Methanol blend (see Appendix 1 for list of chemical suppliers). Exhibit 3 summarizes their physical properties which are compared to CFC-113. Preliminary research suggests these solvents have good cleaning performance. However, long-term toxicity testing is still being conducted on several HCFCs.

Generally, the use of organic solvents in the past has been small primarily due to the flammability concern associated with the use of these solvents. For example, the use of isopropanol has been limited due to its flammability. A large European electronics manufacturer is operating a modified, conveyorized, in-line isopropanol cleaner. The machine, depicted in Figure 6, cleans both through-hole and surface mounted assemblies. The system has an on-line still for recycling, and the system is designed to be explosion resistant.

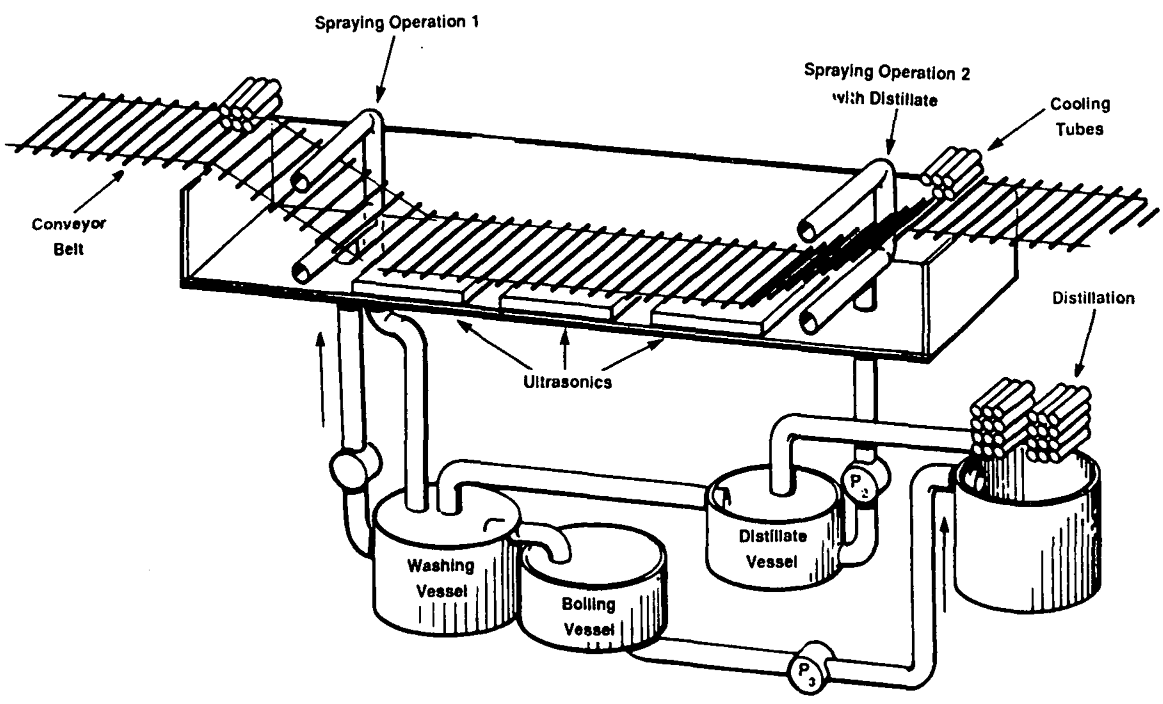


Figure 6. DIAGRAM OF A MODIFIED CONVEYORIZED IN-LINE CLEANING MACHINE USING ALCOHOL SOLVENT

These machines are currently commercially available and the equipment range covers:

- cold solvent cleaners with brush option;
- hot solvent cleaners with ultrasonic option;
- vapor phase batch cleaners with ultrasonic option; and
- in-line continuous cleaners with spray and ultrasonic option.

Ancillary equipment for solvent recycling is also available.

EXHIBIT 3. PHYSICAL PROPERTIES - HCFCS & OTHER SOLVENT BLENDS

	CFC-113	HCFC-225ca	HCFC-225CB	Pentafluoro Propanol	Isopropanol	HCFC-141b/ HCFC-123/ Methanol
Chemical Formula	CCl_2FCClF_2	$CF_3CF_2CHCl_2$	$CClFCF_2CHClF$	$CF_3CF_2CH_2OH$	$CH_3CHOHCH_3$	$CHCl_2F$/ $CHCl_2CF_3$/ CH_3OH
Ozone Depleting Potential	0.8	<0.5	<0.5	0.0	0	0.07-0.08
Boiling Point (°C)	47.6	51.1	56.1	81	82	30-32
Viscosity (cps) @ 25°C	0.68	0.59	0.61	--		0.42
Surface Tension (dyne/cm)	17.3	16.3	17.7	19.0	22.6	0.42
Kauri-Butanol Value	31	34	30	36	N/A	--
Flash Point °C	None	None	None	None	12	None
Toxicity	Low	Being Conducted	Being Conducted	Being Conducted	Moderate	Being Conducted

HYDROCARBON/SURFACTANTS

A number of hydrocarbon/surfactant cleaning solutions are being developed to clean PCBs (See Figure 7). One such solution, terpenes, is a naturally-derived solvent, which is considered a viable alternative for cleaning some electronics assemblies. Terpenes generally are isoprene oligmers, but may include derivatives such as alcohols, aldehydes, and esters.

Terpenes display the following characteristics:

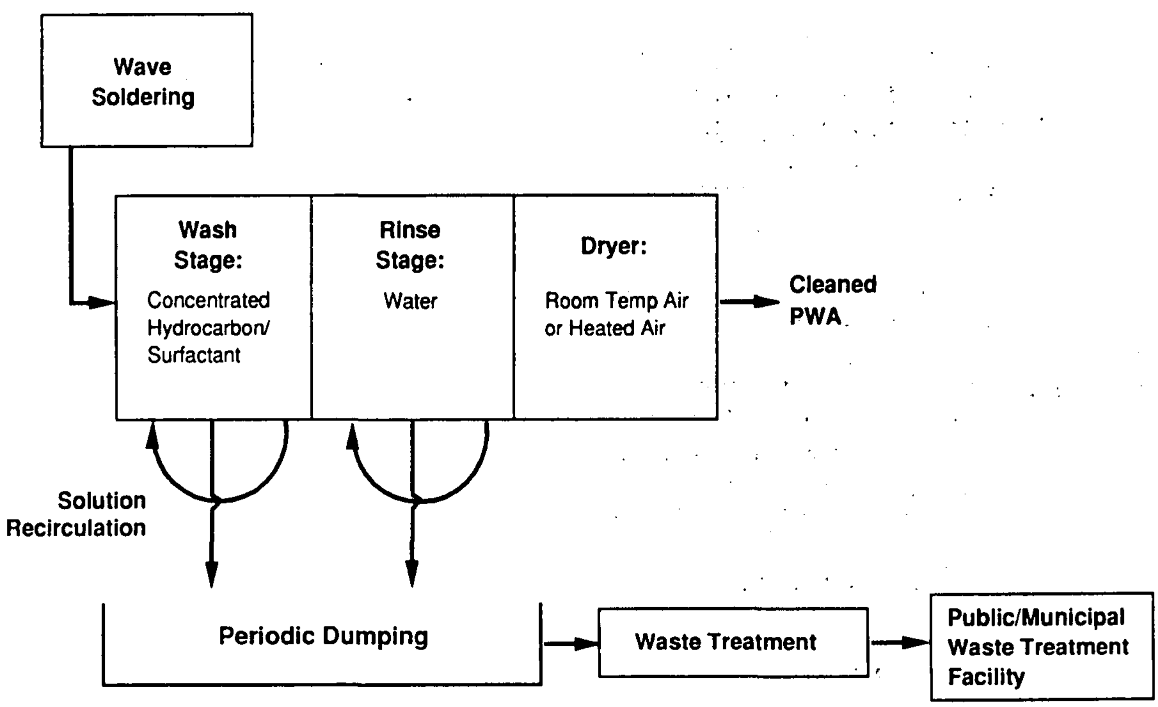
- work effectively in close spacing (clean SMDs);
- work at low (room or slightly higher) temperatures;
- are noncorrosive (pass the copper mirror test);
- have low viscosity and are low foaming; and
- remove both polar and non-polar contaminants.

Prior to the use of this process the following items should be noted:

- Equipment specifically designed for terpene cleaning is necessary because of material compatibility, combustibility, and odor concerns associated with terpenes (See Appendix 1 for list of equipment and chemical suppliers).
- Cleaning machines using terpene solvents must be "inerted" (purged with inert gas such as nitrogen) for safe operation because of low closed-cup flash point (47°C) and potential room temperature flammability associated with spray mist.
- Terpenes are considered VOCs, and therefore, adequate containment of terpene mist and vapors should be provided to control odor and minimize material losses.
- Only limited testing of these chemicals has been completed to date. More information on health and safety issues will become available as development of this option continues.

FIGURE 7

Configuration of Hydrocarbon/Surfactant Based Cleaning Process



METHODOLOGY TO SELECT NON-CFC PROCESSES

The methodology used to select a non-CFC process has to take into account a host of important considerations that might include the process compatibility, flexibility and performance, the capital costs (i.e., the costs of the cleaning equipment and waste treatment equipment if needed), operating costs, and safety and environmental issues. For each alternative non-CFC process these considerations have to be compared to the CFC-113 alternative to evaluate the technical and economic feasibility of substitution.

To evaluate the technical and economic feasibility of substitution, a methodology was developed at Northern Telecom that standardized the procedure used to compare alternatives. This methodology can be used as the basis for preliminary screening of various alternatives. The methodology is based on the principle that the two most important factors to be evaluated are the technical and economic feasibility for substitution. The technical feasibility criteria are evaluated by establishing a difficulty index that compares the difficulty of using a non-CFC process with a CFC-113 process. The economic feasibility is evaluated by estimating the net present value of the non-CFC process and comparing it with that of the CFC-113 process. The next sections describe this methodology in more detail.

TECHNICAL FEASIBILITY

The technical feasibility of a non-CFC process is evaluated by establishing a difficulty index. This is accomplished by first establishing a set of criteria that need to be considered to evaluate the merit of a substitute; second, each criterion is weighted based on its importance; and third, each criterion is assigned a value based on its feasibility. This is performed for the CFC-113 process as well as for the non-CFC processes that are being considered.

The factors that you might evaluate to determine the technical feasibility include:

- compliance to specification (e.g., military specifications);
- defect rate (i.e., the rate at which parts do not meet inspection standards);
- customer return issues;
- industry direction (i.e., likelihood of widespread commercialization and use);
- cosmetics of the PCBs cleaned;
- flexibility of the process;
- ability to clean surface mount assemblies (SMT);
- fallback position for the process;
- process control;
- throughput of the cleaning process;
- health, safety, and environmental concerns;
- future costs associated with the process;
- availability of the process;
- ease of process installability;
- process compatibility; and
- floor space requirements.

Next, a weight is assigned for each of the above criteria based on its importance (10 for the most important and 1 for the least important). Exhibit 4 summarizes the weights assigned to each criterion by Northern Telecom.

EXHIBIT 4. DIFFICULTY CRITERION WEIGHTS

Difficulty Criterion	Weight
Compliance to Specification	9
Defect Rate	9
Customer Return Issues	9
Industry Direction	8
Cosmetics of the PCBs	7
Flexibility of Process	7
Ability to Clean SMT	7
Fallback Position	7
Process Control	6
Throughput	6
Environment, Health, and Safety Concerns	5
Future Costs	4
Availability of the Process	4
Ease of Process Installation	2
Process Compatibility	1
Floor Space Requirements	1

Source: Northern Telecom

Next, each of the above criteria is ranked for the CFC-113 process and other non-CFC processes being evaluated. The ranking system is based on a scale of 1 to 10. One being the highest and 10 being the lowest ranking. Exhibit 5 presents the ranking for CFC-113 and an alcohol based process. Once the alternative has been ranked, the weighted difficulty criterion is calculated by multiplying the weight for each criterion by its rank and by adding up the weighted ranks for each factor. For example, for CFC-113 this is equivalent to:

$$\begin{aligned} \text{CFC-113} &= (\text{compliance})(9*1) \\ &+ (\text{defect rate})(9*1) \\ &+ \ldots\ldots + (\text{floor space})(1*1) \\ &= 235 \end{aligned}$$

Similarly, for the Alcohol Process, the value equals 236.

The difficulty index is calculated by taking the ratio of the weighted rank factor for the alcohol and the CFC-113 process which, in this case, is approximately one.

ECONOMIC FEASIBILITY

The economic feasibility is an important factor in determining which alternative non-CFC process is a viable substitute. This can be accomplished by calculating the net present value (NPV) of the CFC-113 process and the non-CFC alternative being considered. To calculate the net present value the costs associated with the process have to be determined over a period of time. One simple approach is to calculate NPV based on a five year period assuming that the capital investment for the process takes place in year zero and the return on investment is 20 percent. Based on this the NPV is calculated as follows:

$$NPV = Cost_{\phi} + Cost_1 / (1+i) + Cost_2 / (1+i)^2 + \ldots + Cost_5 / (1+i)^5$$

EXHIBIT 5. COMPARISON OF CFC-113 VS ALCOHOL PROCESS

Difficulty Criteria	CFC-113	Alcohol Rank	Comments
Compliance to Specification	1	2	Alcohols Not Yet Approved By Military Specifications
Defect Rate	1	1	
Customer Return Issues	1	1	
Industry Direction	10	3	Industry Moving Towards Alcohols
Cosmetics of the PCBs	1	1	
Flexibility of Process	1	1	
Ability to Clean SMT	1	1	
Fallback Position	10	10	
Process Control	1	4	
Throughput	1	1	
Environment, Health and Safety Concerns	1	6	Alcohols Combustible
Future Costs Increases	3	1	Future CFC-113 Price
Availability of the Process	1	1	
Ease of Process Installability	1	6	Major Equipment Installation
Process Compatibility	1	1	
Floor Space Requirements	1	4	Alcohol Process has Bigger Equipment

Source: Northern Telecom

The costs associated with the CFC-113 and the non-CFC processes have to include: (1) capital costs of equipment (including costs of waste treatment if needed), and (2) operating costs that includes material costs, labor costs, maintenance costs, and utilities costs. These cost estimates for the non-CFC process can be developed through a preliminary process design that estimates the design parameters of the process. This in turn will lead to preliminary cost estimates for the process and waste treatment equipment, if needed. Operating costs can also be determined from this initial conceptual design.

Exhibit 6 presents a comparison of the NPV calculation for a CFC-113 process and an alcohol process. It is assumed that the CFC-113 process has zero capital investment because the process is already installed and operational. However, this might not be the case if additional engineering controls need to be installed as part of conservation measures to reduce the use of CFC-113. Based on Exhibit 6, the NPV of the CFC-113 process is $329K and that of the alcohol process is $754K.

EXHIBIT 6. NET PRESENT VALUE CALCULATIONS - CFC-113 VS ALCOHOL PROCESS

	CFC-113 (Thousands of U.S. $)	Alcohol (Thousands of U.S. $)
Capital Costs		
Equipment	-	250
Waste Treatment	-	100
Total Capital	-	350
Operating Costs		
Solvent Costs	35	25
Labor Costs	30	30
Maintenance Costs	15	50
Utilities Costs	30	30
Total Operating	110	135
NPV	329	754

Note: These costs are indicative. They may not accurately reflect costs in specific situations.

Source: Northern Telecom

SELECTION OF NON-CFC PROCESSES

The selection of the non-CFC process can be made by:

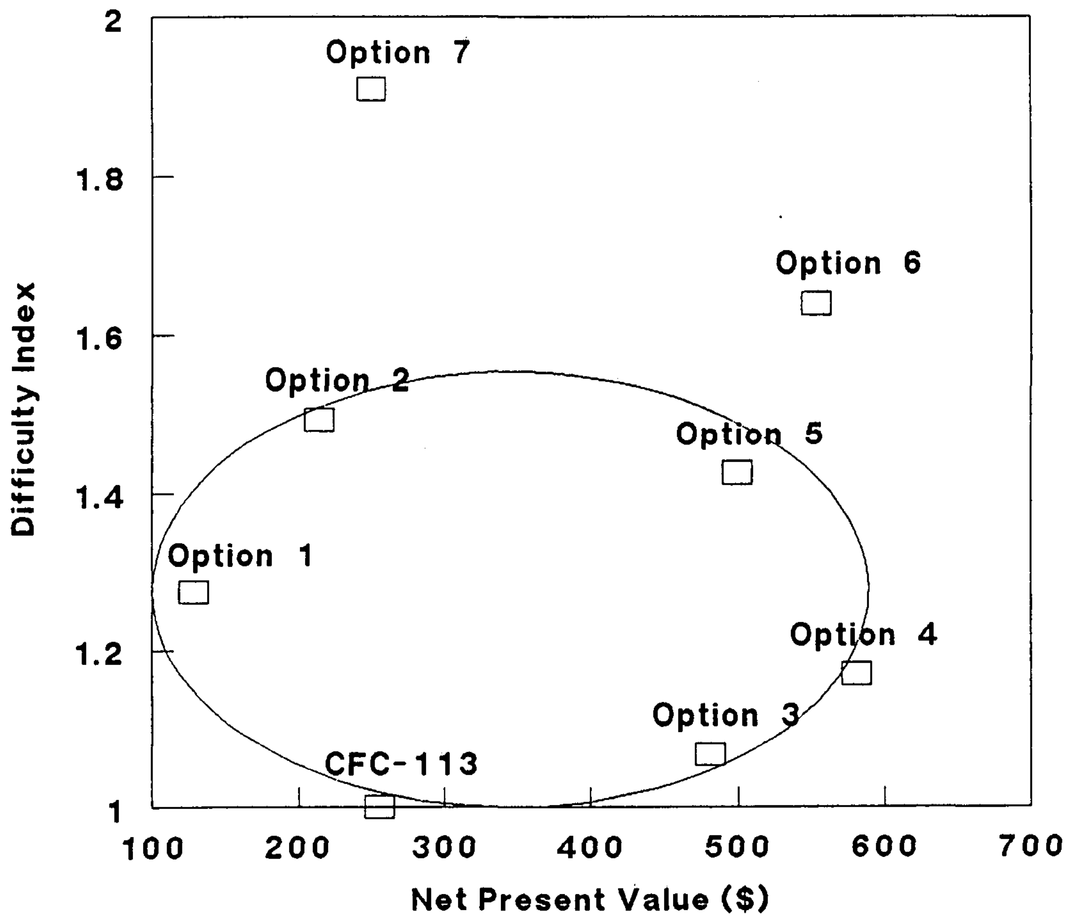
- Listing all feasible non-CFC processes;
- Performing a preliminary analysis for each process to determine the difficulty index and the NPV;
- Comparing the difficulty index and the NPV for the non-CFC process with the CFC-113 process;
- Once these have been determined for all the non-CFC processes being considered, plotting them on a graph that represents difficulty index versus NPV (See Figure 8).

This graph can be used to determine the range of difficulty index - NPV combinations that can be considered feasible. This range is represented by the oval shape region defined in Figure 8. This oval shape region has been defined using the rational that a non-CFC process that has a high difficulty index and low NPV, and a low difficulty index and a high NPV is not feasible.

Based on such an evaluation you can perform a preliminary screening of a wide variety of non-CFC processes. Once such a preliminary screening is completed, a more detailed evaluation of the promising processes can be performed. Such an evaluation will allow you to pin point more promising alternatives and thus direct more resources to evaluate them.

FIGURE 8

COMPARISON OF DIFFICULTY INDEX VS PRESENT VALUE



IN CLOSING ....

Northern Telecom has successfully implemented conservation practices at its divisions. It has designed, built and operated a state-of-the-art vapor adsorption system, and has used the methods described here to select non-CFC alternatives. These are the principal actions that will allow the company to eliminate the use of CFC-113 in its manufacturing operations worldwide by the end of 1991.

You may want to contact Northern Telecom for more information as you move forward with your CFC-113 reduction and elimination programs. The key contacts are:

A. D. FitzGerald
Director, Environmental Affairs
Telephone: 416-566-3048
Fax: 416-275-1143

M. Brox
Project Manager, CFC Elimination
Telephone 416-566-3232
Fax: 416-275-1143

Northern Telecom's address for both individuals is:

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3 Robert Speck Parkway
Mississauga, Ontario
Canada L4Z 3C8

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Washington, D.C. 20460
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Fax: 202-382-6344

Sudhakar Kesavan
Vice President
ICF Incorporated

Farzan Riza
Associate
ICF Incorporated

ICF's address for both individuals is:

409 12th Street, SW
Suite 700
Washington, D.C 20024
Telephone: 703-934-3000
Fax: 703-934-3590

The authors welcome comments on this manual.

APPENDIX 1 - VENDORS[2]

1. Solvent Cleaning Equipment

Baron Blakeslee
2001 No. Janice Ave.
Melrose Park, IL 60160
(312) 450-3900

Detrex
P.O. Box 501
Detroit, MI 48232
(313) 358-5800

Ultronix
RD2 Box 100D
Coopersburg, PA 18036
(215) 965-8009

2. Alternate Solvents

Allied-Signal
2001 North Janice Ave
Melrose Park, Illinois 60160
(312) 450-3880

Dow Chemical
2020 Dow Center
Midland, MI 48674
(517) 636-8325

DuPont Electronics
Wilmington, DE 19898
(302) 999-2889

ICI Americas Inc.
Wilmington, DE 19897
(302) 575-8669 or
ICI Chemicals
Solvents Marketing Department
P.O. Box 19
Runcorn, Cheshire, WA7 4LW
(0928) 512245

Pennwalt Corporation
Three Parkway
Philadelphia, PA 19102

3. Aqueous Cleaners

Advanced Chemical Company
Ben Franklin Technology Court
South Mountain Drive
Bethlehem, PA 18015
(215) 861-6921

Baron Blakeslee
2001 No. Janice Ave.
Melrose Park, IL 60160
(312) 450-3900

DuBois Chemicals, Inc.
511 Walnut Street
Cincinnati, OH 45202
(513) 762-6839

Indusco Chemicals
1806 Southeast Holgate Blvd.
P.O. Box 42194
Portland, Oregon 97242
(503) 236-4167

Kester Solder
515 East Touhy Ave
Des Plaines, IL 60018-2675
(312) 297-1600

London Chemical Company (LONCO)
P.O. Box 806
Bensenville, IL 60106
(312) 287-9477

4. Aqueous Cleaning Equipment

ECD
13626 South Freeman Road
Mulino, Oregon 97042
(503) 829-9108

Electrovert
4330 Beltway Place
Arlington, TX 76018
(817) 468-5171

[2]Note: This is not an exhaustive list of vendors.

Appendix 1 - Vendors (continued)

Hollis Automation, Inc.
15 Charron Ave.
Nashua, NH 03063

Ultronix
RD2 Box 100D
Coopersburg, PA 18036
(215) 965-8009

Westek
400 Rolyn Place
Arcadia, CA 91006
(818) 446-4444

5. Low Solids/"No-Clean" Assembly

Alpha Metals
600 Route 440
Jersey City, New Jersey 07304
(201) 434-7508

Cramco Inc.
P.O. Box 88500
Atlanta, Georgia 30338
(404) 475-6100

Hi-Grade Alloy Corporation
17425 South Laflin Street
P.O. Box 155
East Hazel Crest, Illinois 60429

Kester
515 East Touhy Ave
Des Plaines, IL 60018-2675
(312) 297-1600

Kester Solder Company of Canada, Ltd.
One Prince Charles Road, Bos 474
Branford, Ont N3T 5N9
(519) 753-3425

London Chemical Company (LONCO)
P.O. Box 806
Bensenville, IL 60106
(312) 287-9477

Multicore Canada Inc.
5730 Coopers Ave., Unit 21-22
Mississauga, Ont. L4Z 2E9
(416) 890-6955

6. Controlled Atmosphere Wave Soldering

OCS-SMT Automation Inc.
121 Montee De Liesse
St. Laurent, Quebec, Canada H4t 1S6
(514) 739-2076

Soltec
P.O. Box 143
4900 AC Oosterhout
Karolusstraat 20 The Netherlands
31-(0)1620-83000

7. Hydrocarbon/Surfactants

Alpha Metals
600 Route 440
Jersey City, NJ 07304
(201) 434-6778

Asahi Glass Co., Ltd.
1150, Hazawa-cho,
Kongawa-ku,221, Japan
045-381-1441

Brulin
2920 Dr. Andrew J. Brown Ave.
P.O. Box 270
Indianapolis, IN 46206
(317) 923-3211

Daikin Industries Ltd.
Chemical Division
1-1 Nishi Hitotsuya,
Settsu-shi
Osaka, 566, Japan
Osaka (06) 349-1778

DuPont Company
Electronics Department
Customer Service Center, B-15305
Wilmington, DE 19898
1-(800)-661-8450

Appendix 1 - Vendors (continued)

Fine Organics Corporation
205 Main Street
Lodi, NJ 07644
(201) 472-6800

Orange-Sol
P.O. Box 306
Chandler, AZ 85244
(602) 961-0975

Petroferm
5400 First Coast Highway
Fernadina Beach, FL 32034
(904) 261-8286

3D Inc.
2053 Plaza Drive
Benton, Harbor, MI 49022
(616) 925-5644

8. Hydrocarbon/Surfactant Equipment

Accel
1825 E. Plano Parkway
Plano, Texas 75074-8129
(214) 424-3525

Detrex Corporation
P.O. Box 501
Detroit, MI 48232
(313) 358-5800

ECD
13626 South Freeman Road
Mulino, Oregon 97042
(503) 829-9108

Electrovert
4330 Beltway Place
Arlington, TX 76018
(817) 468-5171

Ultronix
RD2 Box 100D
Coopersburg, PA 18036
(215) 965-8009

9. Water Recycling Equipment

Separation Technologists
32 Granger Ave.
Reading, MA 01867
(617) 942-0023

U.S. GOVERNMENT PRINTING OFFICE: 1990 0—944-802