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"THE COST OF CHANGING":

TOTAL COST ASSESSMENT OF SOLVENT ALTERNATIVES

Methods/Policy Report No. 6 1994

University of Massachusetts Lowell

"THE COST OF CHANGING":

TOTAL COST ASSESSMENT OF SOLVENT ALTERNATIVES

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The Toxics Use Reduction Institute is a multi-disciplinary research, education, and policy center established by the Massachusetts Toxics Use Reduction Act of 1989. The Institute sponsors and conducts research, organizes education and training programs, and provides technical support to governments to promote the reduction in the use of toxic chemicals or the generation of toxic chemical byproducts in industry and commerce. Further information can be obtained by writing the Toxics Use Reduction Institute, University of Massachusetts Lowell, One University Avenue, Lowell, Massachusetts 01854.

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EXECUTIVE SUMMARY

The purpose of this project was to find companies who had implemented toxics use reduction by changing their cleaning processes or who needed assistance in analyzing options, and to use total cost assessment to show the economic merits or detriments of the alternative. Efforts were made to find cases which represented various industries and company sizes.

Data from six case studies revealed the benefits of using a total cost assessment approach as well as interesting trends in the use of new cleaning technologies. The six examples came from companies of various size, product output, and use of solvents. Specifically there were three companies using chlorofluorocarbons (CFCs) for cleaning or parts drying, two companies using trichloroethylene (TCE) for cleaning and parts drying, and one using 1,1,1-trichloroethane (TCA) for cleaning. Company size ranged from 16 to over 200 employees. Parts cleaned included stamped copper stock, machined brass, copper and aluminum, plated precious metals, printed circuit boards, and galvanized steel.

The motivation for these companies to pursue solvent substitution varied among each company. Corporate environmental responsibility and image played the most significant role. The threat of enforcement actions and more stringent future regulations was seen as an additional driving force. All were concerned more with regulatory and image repercussions than the financial burden of a new cleaning process. Consequently none had specific net present values, cost benefit ratios, or hurdle rate goals in mind at the start of the projects.

The largest "regulatory" impact found was in the form of taxes on CFCs. The 800% increase in price of CFCs over the last four years has forced changeovers based on economic terms alone. The impact of state toxics use reduction laws, like the Massachusetts Toxics Use Reduction Act, is minimal in comparison to the federal taxes. In one case federal taxes represented 40% of the operating costs of using CFCs, whereas all costs to comply with TURA represented less than 2% of operating costs. The effect of the federal tax reaches smaller businesses and those who might lower their usage below a minimum threshold.

Chemical purchase and waste disposal costs, on average, accounted for 87% of the cost of running the operation. This average represents costs ranging from 68%, for removing asphaltic compounds from ceramic insulators, to 98% for drying parts spot-free using CFC's.

Of the alternatives analyzed in this project, half (four) of them had net operating cost savings in excess of 95%. Three more had cost savings greater than 75% and one had a cost savings of just 12% (Case 4a). Case 4a was used to demonstrate that total cost assessment can be used to find a maximum price per gallon for an alternative solvent to replace TCE in a parts drying operation.

1. INTRODUCTION

Continuing concern over the depletion of the stratospheric ozone layer and tightening restrictions on ozone depleting chemicals are driving manufacturers to find alternative cleaning technologies. Changing from a tried and true process to a new technology is not easy. The current array of claimed miracle solutions numbers in the hundreds. Careful evaluation and calculation of options can help sort out the most cost effective solution.

One element of any alternative options assessment is the evaluation of costs associated with each option. Anticipating additional problems such as impacts from new environmental regulations, new permits needed, additional paperwork, disposal issues, and product quality concerns can minimize the number and severity of surprises during this process. However, when comparing the costs between options many businesses do not include all the costs associated with a project. Many environmental costs are aggregated under "overhead" and not directly attributed to cleaning practices. Costs such as research and design for new processes, building modifications, worker training, time required for filing permits and filling out paperwork, waste disposal costs and maintenance costs all need to be considered.

The incorporation of all relevant costs associated with a project is known as total cost assessment. Total cost assessment is an innovative investment tool that imports less tangible costs of pollution prevention into the evaluation of investments. The method avoids lumping environmental costs in a single overhead by allocating costs directly to processes and products and expanding cost inventory. This project relates these overhead costs directly to the cleaning processes. Examples of such costs are filing paperwork time and disposal.

Costs are divided into capital costs and operating costs. Capital costs are related with the investments and appear once. The goal is to compare the annual operating costs with the investment in new cleaning systems to calculate the profitability of the investments.

The purpose of this project was to find companies who had implemented toxics use reduction by changing their cleaning processes or who needed assistance in analyzing options, and to use total cost assessment to show the economic merits or detriments of the alternative. Efforts were made to find cases which represented various industries and company sizes.

2. METHODOLOGY

The overall goal of the project was to obtain high quality financial data on several solvent substitution projects and to compare the costs of each before and after the substitute. The intended audience is professionals within industry and government either attempting a solvent substitution project or providing information and assistance in the search for an alternative. The research was conducted to explore the true costs associated with solvent substitution using total cost assessment methods.

Initially, the scope of the project entailed finding a representative example from each of three categories; large conveyorized degreasers, hand operated vapor dip tanks, and small wash tubs with spray wands similar to Safety Kleene units. These three types of technologies loosely represented the traditional standard cleaning operations of most industries. As research progressed, few willing industries could be found that fit strictly within the original project scope. The end result is a somewhat broader look into solvent substitution.

2.1. Data Collection

Cost data was discovered or derived from purchase orders, manifests for waste, chemical inventories, maintenance records, and catalog prices. Indirect costs were found through insurance premiums, labor rates, fees and taxes, and time required for compliance with applicable environmental regulations. The largest resource for contacts and leads on successful solvent projects came from the vendors of these new technologies. Additional source for information came from past case studies, current success stories available through state and federal agencies, and contacts at the Massachusetts Toxics Use Reduction Institute. All possible venues for information were explored in an effort to obtain accurate data representing typical cleaning operations.

Initially, it was hoped that three volunteer companies, willing to have their name in print and having complete records of their solvent substitution project could be found. Trends in the field of solvent substitution, concerns over too much publicity, corporate secrets, and a poor economic climate all contributed to the demise of this premise.

Several participating companies chose not to have their names attached to the study. These companies had already received publicity for their deeds and found responding to public inquiries a time consuming task detracting from the job of running a business. Others did not participate because top management felt that publicity over reducing toxics would have an over all negative effect on public perception of the company's product. The most common reason for companies not to participate was the lack of staff. Several unique projects could not be explored due to lay offs of 50 - 85% of the work force at these facilities.

One challenge to providing an accurate assessment of all the quantifiable costs associated with a project is data collection. Some firms simply did not have all the cost data necessary to compare the cost of options. For instance where cost data was missing from the firm, costs were secured from other sources, such as: vendors, distributors, suppliers, and waste haulers. In a few cases estimates by plant personnel were used and in others explanations for missing data are given in the chapter text. For example, the replacement of a hand operated vapor degreaser at one plant may not have records of the purchase price of the new unit, while a second plant may not have complete records of chemical costs for the old unit. This reflects the practices of real-time industry and underscores the importance of accuracy in cost tracking.

2.2. Cost Calculations and Terminology

This project used terms and methods commonly found in the financial analysis field in an attempt to standardize methodology and to limit the creation of new terms and potential for confusion. The following terms are used in this analysis and are briefly explained below.

Capital costs

These are all costs considered part of the implementation of a new project or system. In this case a new cleaning technology or chemistry. These include purchase of equipment, disposal of the old process, research and design of the new system, obtaining all necessary permits, and changes to the production process or building to accommodate the new system.

Operating cash flow

This refers to all regularly occurring costs or savings associated with the operation and maintenance of the cleaning systems. These include the costs of chemical purchases, waste management, regulatory compliance and annual permitting, system maintenance, production, and water, natural gas, steam, or electricity usage.

Incremental cash flow

This term refers to the difference in operating costs between the old cleaning system and the new. A more detailed financial analysis would call this category profits, which includes revenues not just expenses. Revenues from future systems were not estimated for this project, resulting in the use of this specific term.

Taxable income, income tax, after tax cash flow

These terms are used to figure the effect of income tax on the savings resulting from the pollution prevention projects. Taxable income is the operating cash flow minus the annual depreciation.

Income tax rates for corporations vary almost as much as personal income tax rates. Since most businesses are reluctant to state their income tax rate, a tax rate of 40% was used for all project evaluations.

The after tax cash flow refers to the amount of profit remaining after taxes have been paid.

Present Costs

Several of the solvent substitution projects were completed as far back as 1990. The advantage of using an older example is the abundance of data available on the replacement, its performance, and chemical usage. A disadvantage is that most equipment and chemical prices have increased faster than the national rate of inflation. To obtain accurate cost calculations current market prices for both chemicals and equipment were obtained. This was the easier than trying to locate prices for equipment and chemicals in the year after the changeover. For example, the price of CFC-113 has increased 852% in the past four years, far outstripping the average annual inflation rate of 2.7%/year.

Present value/net present value

Present value accounts for the effects of time on an investment opportunity. In this project most present values were calculated using the interest tables found in Appendix A. Net present value is calculated by subtracting capital costs from present costs.

Using the tables in Appendix A, the after tax cash flow can be easily multiplied by a single number to obtain a present value that results from an iterative process. While compound interest tables can be easily used for whole number interest rates for periods specified in the tables, fractions of percentage points and very long term calculations require the use of an algorithm. The algorithm used in this project was taken from *Engineering Economy*, by G.J. Thesen and W.J. Fabrycky (Englewood Cliffs, NJ: Prentice Hall Publishers, 1984). It converts actual dollars of the past or future into an equivalent amount at time t=0 (usually t=0 is the present day). The equation is given as:

$$P = F \times \frac{1}{(1+i)^n}$$

Where **P** is the unknown current dollar amount, **F** is the known past or future amount, **i** is the internal discount rate, and **n** is the number of years in the past or the future. The internal discount rate usually is a function of what business must pay to acquire capital (money) and what rate of return for a given level of risk it must earn on the investment to satisfy management and shareholders.

Benefit/cost ratio

The benefit/cost ratio is the net present value divided by the total capital cost. The higher the ratio the more profit per dollar invested.

Depreciation and Tax Cash Flows

Most investments in manufacturing equipment, pollution control technologies, and durable goods have a useful life. At the end of their useful life they may have a salvage value or they may be completely worthless. The Internal Revenue Service allows companies to depreciate the cost of their equipment over the lifetime of the equipment, with limitations to the amount of depreciation and number of years an item can be depreciated.

Depreciation refers to the process of allocating the costs of a machine across its entire lifetime to represent the loss of value as a result of using the machine. This analysis uses a straight line depreciation of all options because it is easy to use. Straight line depreciation simply divides the capital cost of the equipment by the number of years of expected lifetime minus any salvage value.

Depreciation is not a true cash flow in that no revenue transfers to the company. Depreciation is used to figure a tax decrease that in turn can be viewed as a cash flow. For example a company purchasing a $7,000 piece of equipment that has a seven year lifetime could depreciate $1,000/year on the item. However, the company does not actually receive $1,000. The true savings from depreciation comes from the avoided tax on income generated by the machine.

The following example illustrates the treatment of depreciation in this report:

Given an operation that costs $2,000/year to run and a new alternative that costs $1,000/year to run (operating costs) the difference (potential savings) between the two is $1,000 (incremental tax flow). If the lifetime of this new machine is 10 years and it costs $1,000 to purchase the annual depreciation would be $100. The annual depreciation is then subtracted from the incremental cash flow for a total taxable income of $900. The corporation's tax rate (40%) is applied to this balance and subtracted from taxable income ($900 - $360 = $540 net income). The annual depreciation is then added back in to eliminate its influence because it is not a true cash flow ($540 + $100 = $640 after tax cash flow).

The present value is computed by taking the after tax cash flow ($640) and multiplying it by the present value factor for the corporation's discount rate (10%) at 10 years ($640 * 6.1446 = $3,932). The net present value is obtained by subtracting the total operating costs ($3,932 - $1,000 = $2,932). A benefit to cost ratio can be developed by dividing the net present value by the total operating costs ($2,932/$1,000 = 2.93).

3. CASE STUDIES

This report includes six total cost assessment case studies that compared the costs of traditional to alternative cleaning technologies. In each case study the manufacturer had either already switched to an alternative cleaning process or was assisted in analyzing options. The six case studies include four firms from Massachusetts and one firm from out of state.

The first and second case studies were performed at the same manufacturer, which produces stamped insignia. The manufacturer used TCE until 1990 and has switched to aqueous-based cleaning.

The third case study was performed at a manufacturer of precision metal parts that switched from CFC's to aqueous-based cleaning in 1990. This case study evaluates the costs of the CFC cleaning system and three aqueous-based cleaning scenarios. Each aqueous-based scenario includes an alkaline cleaner with a different wastewater treatment/disposal process: off-site disposal, discharge to sewer, and ultra-filtration.

The fourth case study evaluates two options for Hi-Tec Plating, a manufacturer of electronic components (plated precious metals) that uses TCE and a water displacer. The financial evaluation of the first option was used to find a maximum price for an alternative cleaning solvent.

The fifth case study was performed at K & M Electronics, a manufacturer of electronic equipment (printed circuit boards). It evaluates the switch from CFC-113 to HCFC-141b and from HCFC-141b to a terpene alternative.

Finally, the sixth case study was performed at Lapp Insulators of Sandersville, Georgia. This company manufactures ceramic insulators and switched to a non-ozone depleting solvent in 1990.

Each case study includes text and tables on the costs associated with traditional and alternative cleaning technologies. Each case study is sub-divided into six sections:

Background information	An introduction of the manufacturer and the cleaning systems used.
Initial costs	Costs to find a suitable cleaning system. Initial costs are associated with the initial decision to look for an alternative cleaning system.
Chemicals and wastes	Costs associated with the purchase of chemicals, and the treatment and disposal of wastes.

Production and maintenance	A description of the changes in productivity and maintenance.
Options cost analysis worksheet	A worksheet that analyses the financial impact of the different cleaning alternatives using financial indicators.
Project outcome	A brief discussion of the results of the financial analysis and the most significant costs.

The options cost analysis worksheets contain a lot of information in a small space. The following abbreviations and short-hand terms are used to save space.

Increm. C.F.	Incremental cash flow. This category appears as the far right column in some Options Worksheets. It provides a quick reference for the cost difference of each category. Standard accounting practice was used to show costs in parentheses ($400) and savings without $400.
Total Annual Oper. C.F.	Total annual operating cash flow. Refers to the total annual amount of operating costs for a cleaning system.
Fees	Refers to any taxes, levies or monies collected by federal or state agencies for the use of a particular technology or chemical. For example, the state of Massachusetts charges a fee for the use of all SARA 313 listed chemicals used above a given threshold.
Gas/Steam	Refers to the use of natural gas or steam to heat a process tank, does not include heating of the building.
0	Use of a zero in the tables means there is no cost in this category associated with the project.
same	Refers to relative amounts in two categories which are equal. Limits of available data in specific cases forced conclusions that this category would not significantly effect the end analysis. Explanations for each use are given in case text.
NA	Not Applicable. This abbreviation appears whenever data was not needed for the cost comparison. Some technologies do not need gas or steam for heating, while others would not need water. For these cases NA would appear under the utilities category for water, gas or steam.

3.1. Case One

Case Summary:	Stamped Insignia
Substrate:	Stamped copper stock
Soils:	Stamping oils
Current Process:	TCE vapor degreaser
Alternative:	Alkaline aqueous
Outcome:	18K/year savings

Background

This nationally recognized manufacturer specializes in name plates and badges for federal, state, and local law enforcement departments. Products are stamped from copper stock, deburred, cleaned, plated, dried, and buffed. A light stamping oil must be cleaned off prior to the plating operations. Part configuration is basically flat, having some small crevices and ornamentation. Two case studies resulted from working with this firm: the first is a traditional cleaning application and the second a use of CFCs to dry parts to a spot-free quality.

The plant manager had previous experience in solvent substitution at a similar facility, which allowed him to quickly narrow alternatives. Alternatives under initial consideration were aqueous systems using ultrasonics, aqueous systems using large automated basket washers, drop-in replacements of hydrocarbon blends, and terpene based chemistries followed by water rinses. The decision to go to aqueous instead of a hydrocarbon came as a desire to limit future liabilities. The company's discount rate is 10% and the labor rate $16/hour. The new projects both have a lifetime of 10 years.

Initial Costs

In 1990, the company switched from vapor degreasing to aqueous cleaning in keeping with a strong tradition of corporate environmental responsibility. The vapor degreaser was 10 years old when replaced with an aqueous system using air agitation and counter current rinsing. The unit was custom built by Greco Bros. for $7,200 in 1991. This custom system has since become a product line at Greco and sells for $9,000[1]. No additional changes to the processes or building were necessary, however, labor associated with disconnecting the old vapor degreaser and connecting a water line for the new system has been included. The old vapor degreaser was cleaned out and sold as scrap for $48.

[1] Price figure from 12/93 interview of Greco sales staff.

Chemicals and Wastes

The company's 1989 usage of TCE (trichloroethylene) was 25,492 pounds. TCE sold for $.48/pound in 1989, or $5.80/gallon. The current market price for TCE is $1.08/pound or $12.50/gallon[2]. If the company was still using TCE today they would be spending $27,531/year on purchases. Disposal of waste TCE depends on the percent TCE per drum, ranging from $165 to $325/drum. Current annual disposal costs would be $1,320/year for eight drums[3]. This is up from the 1989 level of $880/year for the same method of disposal, solvent reclamation.

The new system uses an alkaline aqueous chemistry from Hubbard Hall. Chemical usage for the system averages one half gallon of make up per week. This is significantly less usage than the 10 - 20 gallons/week of TCE previously used. The new solution is added at strength from the drum. Cost per gallon for the new chemical is slightly higher than TCE's current market price ($12.95/gallon of new cleaner versus $12.50/gallon for TCE). However, the aqueous chemicals remain in use much longer than the TCE.

Regulatory Impacts

Usage levels of TCE required the company to file both SARA 313 form R and TURA form S. The TCE use fee under the Toxic Use Reduction Act was $1100/year. In addition to the TURA fee, the associated paperwork took 15 hours for both forms and another 3-4 hours for permits associated with the chemical use. The chemicals used in the aqueous system do not trigger any regulatory thresholds.

Production and Maintenance

Maintenance on the old system was significantly less than the new unit, requiring a clean out once every 6 months (7 hours/year) versus monthly cleaning on the new unit (36 hrs/yr). Copper filings are cleaned from the bottom of the tank every month and sold to the local scrap dealer. The in-line filters are changed every 6 months and discarded as solid waste.

The running rinses consume 60 gallons of water per day, 15,000 gallons per year, or roughly $7/year. Compared to water used in the plating and grinding areas this is a nominal impact. The company used in-plant steam to heat both the old and new systems. Pump size and horsepower was also similar between the two parts cleaners. Since both systems were/are run for a single 8 hour shift the cost difference for steam heat and electricity were considered marginal.

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[2] 12/93 Ashland Chemical Co. market price quote.

[3] East Coast Environmental Services price quotes 12/93.

Table 1. Case One Total Cost Assessment Worksheet: Capital Costs

	TCE degreaser	Alkaline wash
Capital Costs		
Equipment Purchase	NA	($9,000)
Disposal of Old Process	NA	$48
Research and Design	NA	0
Initial Permits	NA	0
Building/Process Changes	NA	($432)
Total Capital Costs	NA	($9384)

Project Outcome

Current annual cost for running the old degreaser would be $30,377. Total annual savings from the new system are $17,972 after taxes (after tax cash flow). The net present value on this project is $101,047. This means the investment in an alternative to TCE is returning over $10 for every dollar invested.

Notice that the old degreaser was disposed of at a profit. The company assisted in the clean out of the system, while the scrap dealer furnished the transportation and labor to remove the unit. Copper filings from the cleaned parts accumulate at the bottom of the new cleaning tank. These filings are also sold as scrap, but are thrown together with other copper scrap from the stamping operation. The price for this waste stream could not be estimated by plant personnel.

The company had not consulted with their insurance agent at the time of the interview, but was interested in pursuing premium decreases due to fewer toxics being on site. The company is saving $1,400/year on avoided paperwork and fees, and has maintained regulatory compliance by eliminating regulated substances.

Production costs have not increased as a result of this project. Original operator practices were to leave racks or baskets of parts hanging in the vapor degreaser and do another task. The new system allows them to operate in the same way. Maintenance on the new system is higher due to more frequent filter changes and clean outs.

Table 2. Case One Total Cost Assessment Worksheet: Operating Cash Flows

		TCE degreaser	Alkaline wash	Increm. C.F.
Operating Cash Flows				
Chemical Purchases		($27,531)	($444)	$27,087
Waste Mgmt.	Chemicals	0	0	0
	Testing	0	0	0
	Disposal	($1,320)	0	$1,320
Safety Training/Equipment		($20)	($20)	0
Insurance		NA	no change	0
Fees (i.e. TURA)		($1,100)	0	$1,100
Filing Paperwork time		($240)	0	$240
Annual Permitting		($54)	0	$54
Production Costs	% Inc./Dec.	0	0	0
	Hours/year	0	0	0
Maintenance	Time	($112)	($576)	($464)
	Materials	0	0	0
Utilities	Water	NA	($7)	($7)
	Electricity	same	same	0
	Gas/Steam.	same	same	0
Total Annual Oper. C. F.		($30,377)	($1,047)	$29,330

Table 3. Case One Total Cost Assessment Worksheet: Cash Flow Summary

	TCE degreaser	Alkaline wash
Cash Flow Summary		
Total Operating Costs	($30,377)	($1,047)
Incremental Cash Flow	NA	$29,330
- Depreciation	NA	($938)
Taxable Income	NA	$28,391
Income Tax (40%)		($11,356)
Net Income	NA	$17,034
+ Depreciation	NA	$938
After Tax Cash Flow	NA	$17,972
Present Value (6.1446)	NA	$110,431
Total Capital Cost	NA	($9,384)
Net Present Value	NA	$101,047
Benefit/Cost Ratio	NA	10.77

3.2. Case Two

Case Summary:	Stamped Insignia
Substrate:	Stamped copper stock
Soils:	Rinse water
Current Process:	CFC vapor degreaser
Alternative:	Hot air dryer
Outcome:	61K/year savings

Background

In a separate project the same manufacturer as in Case One decided to eliminate their use of CFC-113 (chlorofluorocarbon-113) as a drying agent for finished product. Parts coming out of the precious metal plating lines must be spotless and without residue. The company previously used a water displacer followed by cleaning in CFC-113 to remove the displacer and flash dry the part.

Through a suggestion from one of the shop workers the company purchased a forced hot air dryer and changed the final rinse tank in the plating line to a four stage de-ionized (DI) water rinse. Parts are taken from the DI rinse, blown off with compressed air and placed in the drying cabinet. Water for the rinse tanks comes from other shop processes and is de-ionized with ion exchange columns.

Initial Costs

The drying cabinet's current market price is $9,100 and the purchase and installation price of the DI rinse water system for the plating line is $2,300. All power hook-ups, piping for steam, and installation was done by the facility. The old vapor degreaser was taken away as scrap, but at no salvage value.

Chemicals and Wastes

In 1989 the company was using 11,550 pounds of Freon TF ($10,280/year or roughly $0.89/pound). Current market prices for CFCs are $8.57/pound with all taxes included. At these prices the company would have spent $98,980 in 1993 to dry their parts with CFC-113. Records were not available on the cost of waste disposal for the CFC-113 degreaser.

Regulatory Impacts

Freon TF is considered a Massachusetts TURA chemical and the level of use triggered filing requirements. An annual use fee of $1,100 plus associated time for filling out paperwork are the main regulatory costs. The new system uses only heat and air blown by fan into the cabinet.

Production and Maintenance

Operator practices are similar to those at the parts cleaning line where racks and barrels are left to dry and the operator moves on to another task yielding no increase in production costs. The old degreaser required clean outs and inspections regularly amounting to $464/year in maintenance costs. The new drying booth has been running for three years with no major repairs or maintenance. The ion exchange units that provide DI water for final rinses also provide water for other plating operations and could not be isolated as separate costs.

Heat for the drying closet is provided by steam lines running around the outside of the cabinet. An electric fan circulates the air in the cabinet. Electrical use is estimated to have decreased because the old system had electric heating coils and a pump versus a small electric fan for the hot air dryer.

Table 4. Case Two Total Cost Assessment Worksheet: Capital Costs

	CFC Dryer	Hot Air Dryer
Capital Costs		
Equipment Purchase	NA	($9,100)
Disposal of Old Process	NA	scrapped
Research and Design	NA	0
Initial Permits	NA	0
Building/Process Changes	NA	($2,300)
Total Capital Costs	NA	($11,400)

Project Outcome

This projects cost analysis looks particularly favorable given the current level of federal taxes on CFCs. Taxes account for 41% of the purchase price of the chemical. Because of this the project is saving the company almost $61,000 (after taxes) per year in CFC-113 purchase cost, fees and paperwork. The project is returning over $31 for every dollar invested.

Part quality is comparable to parts dried using CFC-113. Drying time for parts is roughly the same and does not require workers to hold the racked parts over the vapor degreaser tank. The company achieved a return on their investment in less than 3 months. The success of this project and the TCE replacement has prompted the company to explore other pollution prevention projects.

Table 5. Case Two Total Cost Assessment Worksheet: Operating Cash Flows

		CFC dryer	Hot Air dryer	Increm. C.F.
Operating Cash Flows				
Chemical Purchases		($98,980)	0	$98,980
Waste Mgmt.	Chemicals	0	0	0
	Testing	0	0	0
	Disposal	no record	0	0
Safety Training/Equipment		($20)	0	$20
Insurance		no record	no change	NA
Fees (i.e. TURA)		($1,100)	0	$1,100
Filing Paperwork time		($240)	0	$240
Annual Permitting		0	0	0
Production Costs	% Inc./Dec.	0	nominal	0
	$/year	0	0	0
Maintenance	Time	($256)	($48)	$208
	Materials	0	0	0
Utilities	Water	0	nominal	0
	Electricity	no record	NA	NA
	Gas/Steam.	same	same	0
Total Ann. Oper. C.F.		($100,596)	($48)	$100,548

Table 6. Case Two Total Cost Assessment Worksheet: Cash Flow Summary

	CFC Dryer	Hot Air Dryer
Cash Flow Summary		
Total Ann. Oper. C.F.	($100,596)	($48)
Incremental Cash Flow	0	$100,548
- Depreciation	NA	($1,140)
Taxable Income	NA	$99,408
Income Tax (40%)	NA	($39,763)
Net Income	NA	$59,644
+ Depreciation	NA	$1,140
After Tax Cash Flow	NA	$60,784
Present Value (6.1446)	NA	$373,493
Total Capital Costs	NA	($11,400)
Net Present Value	NA	$362,093
Benefit/Cost Ratio	NA	31.76

3.3. Case Three

Case Summary:	Precision Components
Substrate:	S.Steel, Brass, Alum.
Soils:	Machine tool oils
Current Process:	CFC vapor degreaser
Alternative:	Alkaline aqueous
Outcome:	17K/year savings

Background

Operations at this 16 employee manufacturer of precision metal parts consist of milling, tapping, reaming, and close tolerance lathe work. Most of their parts are small in size, large in quantity. The machine tools run on either straight petroleum oil or water based coolant.

In 1990 they switched from CFC-113 vapor degreasing to an aqueous solution with a hot water rinse. Parts are machined brass, aluminum, stainless, or cast metals and often have threaded holes and recesses. Soils are either petroleum based threading and cutting lubricants or water based machine tool coolants.

The company evaluated four options: continued use of CFC-113, use an alkaline cleaner and send all waste cleaner off-site as a hazardous waste, use an alkaline cleaner and discharge the waste to the sewer, and use the alkaline cleaner and recycle it through a small ultra-filtration unit. Costs for each of these options are presented in as much detail as was available.

Initial Costs

In 1989, the old vapor degreaser used 2,673 pounds of Freon TF (tradename for CFC-113). Current market prices for CFC-113 are \$5.05/pound + \$3.52/pound in federal taxes. This brings the total to \$8.57/pound or almost \$6,000/55 gallon drum[4]. CFC-113 use at current market rates would cost the company \$22,907 annually. Off-site disposal of 668 pounds cost \$150 that year. Current costs for a similar quantity of waste CFCs would be \$365/drum.[5] The company purchased a Bowden aqueous cleaning system in 1990. The unit consists of two separate tanks, one wash and one rinse. The two tanks would cost \$11,400 today[6].

[4]Market price from Hubbard Hall, 12/93.

[5]East Coast Environmental, 12/93.

[6]Bowden Industries retail price 12/93.

The company president made the decision to purchase an ultrafiltration unit to recycle the waste waters. A strong commitment to the environment coupled with a desire to reduce regulatory burdens out weighed the additional $4,000 cost (current market price). The old vapor degreaser is still on site, in storage. Both the cleaning tanks and the ultrafilter are depreciated over an 8 year lifetime. Labor at the facility runs $20/hour and the discount rate was estimated at 10%.

Chemicals and Wastes

Chemical purchase costs for the new system are about $75/year. The unit has only used one 55 gallon drum in the first two years of operation. Each drum costs $150.

Sludge from the ultrafilter must be sent off-site at a cost of $71.50/year. Having the ultrafilter on-site for recycling the cleaner also allows them to run their water soluble machine coolant through the ultrafilter and reuse the water. The coolants had accounted for 30 - 60 % of the total hazardous waste disposal costs of the company (oily waste waters are considered hazardous wastes in Massachusetts).

Occasionally the ultrafilter produces more water than the cleaning system and the water based machine tools can use. This is discharged to the sewer. The company has sampled this effluent to provide a record in the event of future environmental action or a change in the sewer authority's effluent limits.

Regulatory Impacts

This facility does not use enough chemicals to break the thresholds for filing under Form R or Massachusetts Form S (TURA). By replacing their CFC degreaser they have eliminated the risk of future regulations that might effect smaller businesses. The insurance policy for the facility did not include toxics as a factor in estimates of coverage cost.

Production and Maintenance

The company found processing time takes longer with the new system. The extra time required is not billable time, that is the parts can be left in the washer and the worker can move on to some other task. It effectively cleans only 80% of the parts. The remaining 20% require hand cleaning, mostly due to blind holes. These 20% are not part of regular production runs. No data was available on the time involved in cleaning these parts. However, it can be inferred that the lack of concern by the plant manager and president means the actual extra time is nominal.

The old degreaser required cleaning 3 - 4 times per year at 4 hours each cleaning. Electricity costs for the old and new systems are about the same: the vapor degreaser had a heater and chiller and the aqueous system has a heater and a mechanical agitator. Maintenance on the new unit runs as follows: daily check of the pH and top off with water (roughly 1/2 hour/week, or 25 hours/year), drain, filter, and return to tank the cleaner every two months (3 hours/operation or 18 hours/year).

Three Options

Sending the waste cleaner off-site

An annual laboratory testing fee of $400 was included to assure the waste hauler of the exact specifications of the wastes leaving the facility. Disposal costs were figured as follows: the facility has roughly 150 gallons of coolant in machine sumps and replaces it once per year. Disposal of waste coolants average $100/drum ($300/year). Alkaline cleaning solutions average $35/drum with the cleaning tank emptied 6 times/year ($210/year). Paperwork connected with testing and manifesting the waste was figured at one hour every 3 months at $20/hour. It is important to note the facility would change hazardous waste status under this option from a Very Small Quantity generator to a Small Quantity Generator.

Discharging the wastes to the sewer

A $300 laboratory test fee was included for each batch dump to the sewer (3x for coolant and cleaner + 3x cleaner alone = $600). While not specifically required by law, the facility is located next door to the water treatment plant and this action was deemed a show of good faith and possible protection against future legal actions. Acid would need to be maintained on site to balance the pH of the wastes before discharge (Cost of 1/2 carboy of acid/year). A half hour of paperwork is connected with this option for each test and discharge (0.5 * 6 * $20/hour = $60).

Recycling the wastes

The company purchased a small ultra-filtration unit and currently recycles both its waste cleaner and machine tool coolants. The decision to recycle was motivated by the companies environmental philosophy and desire to limit its liability. There is additional maintenance connected with the ultra-filter (1/2 hour/filtering run) and the concentrate must still be manifested off-site. Having the equipment available to recycle the coolants reduced the need to dispose of fouled coolant. The companies conserves its well water supply by re-using the filtered water for make up of new coolant and cleaner.

Project Outcome

Many companies face this choice when looking for a solvent substitute. Changing to an aqueous or semi aqueous cleaning process requires a careful evaluation of the alternatives. Often times the costs for disposing or treating an additional waste stream are not considered and can have a significant impact on the profitability of the project. In this case all three alternatives result in annual after tax savings to the firm of $16,000 to $17,000.

Notice that choosing the option with the highest annual cost savings may not be the most profitable. Making a decision in this case requires normalizing each option's net present value. Since the third option (using an ultrafilter to recycle waste waters) has a different initial investment from the other two, the net present values must be adjusted by the initial investment, yielding the benefit/cost ratio. The benefit/cost ratio states that the higher ratio is the more desirable investment. Following this rule would mean shipping the spent cleaner and coolants off-site as hazardous waste. Off-site disposal is more profitable in this instance even though it requires more paperwork and testing than using the ultrafilter.

The company chose to recycle before it knew that sending waste off-site would result in greater profit. The company's commitment to environmental protection and pollution prevention influenced the decision. This facility still saves over $17,000/year.

Table 7. Case Three Total Cost Assessment Worksheet: Capital Costs

	CFC degreaser	Alk. & offsite	Alk. & disch.	Alk. & UF
Capital Costs				
Equipment Purchase	NA	($11,400)	($11,400)	($15,400)
Disposal of Old Process	NA	in storage	in storage	in storage
Research and Design	NA	0	0	0
Initial Permits	NA	0	0	0
Building/Process Changes	NA	0	0	0
Total Capital Costs	NA	($11,400)	($11,400)	($15,400)

Table 8. Case Three Total Cost Assessment Worksheet: Operating Cash Flow

		CFC degreaser	Alk. & offsite	Alk. & disch.	Alk. & UF
Operating Cash Flow					
Chemical Purchases		($27,907)	($75)	($75)	($75)
Waste Mgmt.	Chemicals	0	0	($38)	0
	Testing	0	($400)	($1,800)	0
	Disposal	($365)	($210)	0	($229)
Safety Training/Equipment		($20)	($20)	($20)	($20)
Insurance		NA	NA	NA	NA
Fees (i.e. TURA)		NA	NA	NA	NA
Filing Paperwork time		($15)	($80)	($60)	($15)
Annual Permitting		0	0	0	0
Production Costs	% Inc./Dec.	0	nominal	nominal	nominal
	$/year	not avail.	not avail.	not avail.	not avail.
Maintenance	Time	($320)	($860)	($860)	($900)
	Materials	0	0	0	0
Utilities	Water	0	nominal	nominal	nominal
	Electricity	same.	same.	same.	same.
	Gas/Steam.	0	0	0	0
Total Ann. Oper. C.F.		($28,627)	($1,645)	($2,853)	($1,239)

Table 9. Case Three Total Cost Assessment Worksheet: Cash Flow Summary

	CFC degreaser	Alk. & offsite	Alk. & disch.	Alk. & UF
Cash Flow Summary				
Total Ann. Oper. C. F.	($28,627)	($1,645)	($2,853)	($1239)
Incremental Cash Flow	0	$26,982	$25,774	$27,288
- Depreciation	NA	($1,140)	($1,140)	($1,540)
Taxable Income	NA	$25,842	$24,634	$25,748
Income Tax (40%)	NA	($10,337)	($9,854)	($10,299)
Net Income	NA	$15,505	$14,780	$15,449
+ Depreciation	NA	$1,140	$1,140	$1,540
After Tax Cash Flow	NA	$16,645	$15,920	$17,323
Present Value (5.3349)	NA	$88,799	$84,931	$92,416
Total Capital Costs	NA	($11,400)	($11,400)	($15,400)
Net Present Value	NA	$77,399	$73,531	$77,016
Benefit/Cost Ratio	NA	6.79	6.45	5.00

3.4. Case Four

Case Summary: Electronic Components	
Substrate:	Plated precious metals
Soils:	Water marks from rinses
Current Process:	TCE vapor degreaser
Alternative:	A drop-in or hot air
Outcome:	in progress

Background

Hi-Tec Plating of Everett, Massachusetts is a precious metals job shop specializing in electrical component plating for corrosion resistance and conductivity. Low volumes of small parts are plated using hand racks. After plating parts are rinsed in DI water, displaced of water, and cleaned with trichloroethylene (TCE). After cleaning the parts dry in a drying closet and are packaged for shipping.

The analysis calculates the maximum price per gallon for a profitable direct solvent substitute. This is accomplished by working numbers backward from a net present value slightly greater than zero. The first column in the cost worksheet ("TCE & Displ.") lists costs for the current system of drying parts using a water displacer and a TCE degreaser. The second column in the worksheet ("TCE alone") calculates the annual costs of using TCE, and serves as a reference to estimate how much could be spent on finding a direct replacement of TCE. This alternative would still be preceded by the water displacer.

The third column in the worksheet ("Direct Sub.") is an alternative that would replace both TCE and the water displacer. Costs are estimates based upon other successful direct substitutions of TCE. Savings from this alternative come from the avoided costs of not using both the displacer and the TCE.

The fourth column in the worksheet ("Hot Air Dry") calculates the costs of a technology change that could eliminate all chemical use for drying parts. The Project Outcome section of this case study discusses the price per gallon of a direct substitute if it were to compete financially with this alternative.

Potential alternatives that could work as a drop in would include terpenes, alcohols, glycol ethers, and non-chlorinated hydrocarbon blends. Factors that narrow the options are flammability, acute and chronic toxicity, the need to have minimal residuals left on parts, and waste disposal issues.

Initial Costs

The current vapor degreaser is four to five years old. Estimates of research needed were used in this evaluation because a suitable replacement for the process has not been found. Two alternatives illustrating both ends of the spectrum were selected and developed using industry average costs and data from other case studies.

The first option directly replaces TCE. Initial costs in this instance would be minimal and largely under the research and development category. Hi-Tec has already gathered data on potential alternatives and is currently evaluating chemistries. Time required to evaluate four options, test cleanliness and treatability of wastes was estimated to be 40 hours each (40hrs * 4 options * $20/hour). A drop-in alternative is assumed here with few modifications needed to the existing system.

The second option explores the possibility of eliminating the need for TCE and a water displacer by using hot, counter current, de-ionized water rinses, compressed air blow-off of parts and drying in a forced hot air closet. Research costs for this option were estimated at one week of testing part cleanliness (40 hours * $20/ hour). Initial equipment costs for this option were taken from a similar successful change over from CFCs to hot air drying. Modifications are made to the end of the plating line to reduce drag out from the final rinse and blow off as much water as possible. These modifications cost $800 for piping, nozzles and blowers. The drying closet is outfitted with hot air blowers at an additional cost of $10,000[7]. Process alterations consist of modifying the final rinse tanks on the plating lines which already have DI water sources.

The labor rate is $20/hour and the discount rate is 10%. The drop-in alternative was given a four year lifetime based on uncertainty of changes in regulations, developments of better technologies, and unknown health effects of many current alternates. The hot air dryer was evaluated using a standard seven year lifetime.

Chemicals and Wastes

Hi-Tec Plating currently uses $6,000/year in water displacer and $16,000/year of TCE. Their usage of TCE (14,895 pounds, or 23 drums) requires them to file a Form S for the Massachusetts Toxics Use Reduction Act ($1,100/year) and spend 5 hours/month on paperwork and 2 hours maintenance on the system ($1,200/year and $480/year respectively).

Disposal costs are 5 drums of water displacer every two months (@ $120/drum), and 2 drums of TCE waste every two months (@ $150/drum). Total disposal costs are $3,600/year on the water displacer and $1,800/year on the TCE. A direct substitution of TCE and the displacer would most likely result in some waste generated unless recycling equipment is considered. For this example waste disposal costs were kept the same to retain a conservative cost estimate.

[7] Equipment costs based upon similar successful solvent substitutions.

Under the options being considered only the "Hot Air Dry" eliminates the need to purchase chemicals. More complete rinsing of parts in each plating line would result in additional metals going to the waste water treatment plant. These were discounted in this calculation.

Regulatory Impacts

One to two hours per month are spent training workers on safety for the cleaning operation ($480/year). Replacing the TCE with either a non-listed alternative or hot air drying would have the same short term effect regarding compliance under TURA. The facility would still need to file a TURA plan because of other operations.

The calculations did not make assumptions about the probability of a non-listed chemical being added to the TURA lists, however, that is a potential risk. Time required to file paper work (18 hours/year = $360) was reduced to the TCE costs under the "drop in" option because fewer types of waste would be generated and the company would not file under TURA or SARA.

In the Hot Air Dry option the line workers are re-trained ($40/year in worker training) and a worker quality incentive program is implemented on the plating line budgeted at $500/year.

Production and Maintenance

Maintenance of the current system was figured to be an hour per month. This includes draining off water from the water displacer tank, upkeep on the vapor degreaser, and chemical re-fills. Alternatives would most likely require a similar amount of time, either in equipment or chemicals. Likewise, utilities were kept the same. Either option would require some electricity: a drop-in replacement may require a heater or mechanical agitation and the hot air dryer would have an electric blower/heater.

Project Outcome

The calculations reveal that Hi-Tech Plating has the potential to save substantial capital in pursuing either option. In the first example the chemical is not listed on the TURA lists and may or may not have the same disposal requirements of TCE. TCE's 1993 market price is $12.89/gallon. The new alternative, provided it replaced the need for a water displacer could cost as much as $16.20/gallon and still allow the company to break even. For a direct substitute to compete financially with the hot air dry option, assuming the same quantity of chemical use as current with TCE, the price per gallon would need to stay at $8.43 over the seven year lifetime.

The hot air dryer saves the company more money per year than is spent on purchasing TCE and the water displacer over its lifetime. The payback for this option is less than one year (6.7 months) and is less vulnerable to long term changes in environmental regulations, illustrating a higher initial investment with greater long term benefit.

Table 10. Case Four Total Cost Assessment Worksheet: Capital Costs

	TCE & Displ.	TCE alone	Direct Sub.	Hot Air Dry
Capital Costs				
Equipment Purchase	NA	NA	0	($10,000)
Disposal of Old Process	NA	NA	0	0
Research and Design	NA	NA	($3,200)	($800)
Initial Permits	NA	NA	NA	NA
Building/Process changes	NA	NA	0	$800
Total Capital Costs	NA	NA	($3,200)	($11,600)

Table 11. Case Four Total Cost Assessment Worksheet: Operating Cash Flows

		TCE & Displ.	TCE alone	Direct Sub	Hot Air Dry
Operating Cash Flows					
Chemical Purchases		($22,000)	($16,000)	($20,124)	0
Waste Mgmt.	Treat. Chem.	0	0	0	0
	Testing	0	0	0	0
	Disposal	($5,400)	($1,600)	($5,400)	0
Safety Training/Equipment		($480)	($480)	($480)	($540)
Insurance		NA	NA	NA	NA
Fees (i.e. TURA)		($1,100)	($1,100)	0	0
Filing Paperwork time		($1,200)	($360)	($360)	0
Annual Permitting		NA	NA	NA	NA
Maintenance	Time	($480)	($480)	($480)	($480)
	Materials	0	0	0	0
Production	% Inc./Dec.	NA	NA	same	same
	$/year	NA	NA	same	same
Utilities	Water	NA	NA	NA	NA
	Electricity	same	same	same	same
	Gas/Steam.	NA	NA	NA	NA
Total Ann. Oper. C.F.		($30,660)	($20,020)	($26,844)	($1,020)

Table 12. Case Four Total Cost Assessment Worksheet: Cash Flow Summary

	TCE & Displ.	TCE alone	Direct Sub.	Hot Air Dry
Cash Flow Summary				
Total Ann. Oper. Cash Flow	($30,660)	($20,020)	($26,844)	($1,020)
Incremental Cash Flow	0	0	$3,816	$29,640
- Depreciation	NA	NA	($800)	($1,657)
Taxable Income	NA	NA	$3,016	$27,983
Income Tax (40%)	NA	NA	($1,206)	($11,193)
Net Income	NA	NA	$1,810	$16,790
+ Depreciation	NA	NA	$800	$1,657
After Tax Cash Flow	NA	NA	$1,010	$18,447
PV: 4yr=3.1699, 7yr=4.8684	NA	NA	$3,202	$89,807
Total Capital Costs	NA	NA	($3,200)	($11,600)
Net Present Value	NA	NA	$2	$78,207
Benefit/Cost Ratio	NA	NA	0	6.74

3.5. Case Five

Case Summary:	Electronic Equipment
Substrate:	Printed circuit boards
Soils:	Solder and flux
Current Process:	CFC vapor degreaser
Alternative:	HCFCs/Ultrasonics
Outcome:	78-84K/year savings

Background

K & M Electronics of West Springfield, Massachusetts is a medium sized manufacturer of military and civilian electronic equipment. Products include power supplies for night vision goggles for military use, channel electron multipliers, and high ohmic resistors. The circuit boards for these products are manufactured outside the facility but components are soldered and assembled in house. Due to the high voltages and low currents of these types of electronic devices, soil contamination must be kept at a minimum or result in product failure.

The company began looking for alternatives to Freon in early 1992. They purchased an ultrasonic cleaner from Ultrasound Fabricators Inc. (UFI) and began searching for replacement solvents. In the interim the corporate directive came down to eliminate usage of CFC-113. HCFC-141b was quickly brought in as a drop-in replacement for the CFC-113 and used in customized bench-top vapor degreasers manufactured in-house.

This case study looks at costs for changing from CFC-113 to HCFC-141b, and from HCFC-141b to a terpene alternative. The interim use of HCFCs has become more prevalent now that labeling laws have gone into effect.

Initial Costs

The custom built bench top degreasers took two engineers, six months to design and develop the solid state controls (6 months * 4 weeks * 40 hours * 2 people * $25/hour = $48,000). Manufacturing the units required 60 hours per unit @ $8.50/hour * 18 units = $9,180. The existing solvent distillation system was also modified to recycle HCFCs ($453 in 1993 dollars). No permits or building changes were required for the switch to HCFCs.

The UFI system consists of a single immersion tank with ultrasonics followed by heated 3 stage counter current rinse tanks with ultrasonics in the final rinse, and a forced hot air dryer. Initial cost for the unit was $25,525 in 1993 dollars. The new UFI unit required raising the suspended ceiling and new water and discharge lines ($1,009).

The company figures two years on HCFCs while they find a suitable chemistry for their ultrasonic unit. Estimates on research required are 1/4 of a full time employee for one year ($15/hour * 500 hours). The UFI unit is given a 7 year lifetime. Labor rates are for maintenance ($15) and paperwork ($25). The discount rate is 10%.

Chemicals and Wastes

K & M had been using CFC-113 in a vapor degreaser to remove flux and soils from printed circuit board assemblies. Year to year usage of CFC-113 varied due to contracts and the recession. Between 1990 and 1992 K & M used an average of 14,043 pounds of CFC-113 annually. These quantities tripped the requirements to comply with the Massachusetts Toxics Use Reduction Act. Current market price for CFC is $8.57/pound, up from $5.0/pound in 1992. K & M currently purchases 1,000 pounds/month of HCFC-141b (12,000 pounds/year * $3.15/pound). Disposal costs for the CFC and HCFC run the same at $150/year.

Current market prices for terpenes range from $12 - $15/gallon. If the 8 gallon UFI sump under heavy use required changing every month, it would mean 96 gallons of use and waste, or $1,400/year in chemical costs and approximately $330 in disposal costs.

Regulatory Impacts

The company estimates filing paperwork related to the use of CFCs is 16 hours per year * $25/hour. K & M's only TURA reportable chemical was CFC 113. Because of the change to HCFC 141b, the company will not have to develop a TURA plan. Estimates of time required to develop TUR plans average around 4 weeks of intensive work by a team of several employees. Not having to develop a plan results in approximately $8,000 of savings (2 persons * 40 hours/week * 4 weeks * $25/hour). This savings was distributed over the lifetime of the alternatives (2 years for the HCFC and 7 years for the UFI) and appears as a negative cost in the Paperwork category.

Worker health and safety training attributable to CFCs cost $50 every year. Safety training for the HCFC consisted of writing a new cleaning procedure and circulating a memo. The amount of training needed for the new UFI unit is unknown. K & M has not yet consulted their insurance agent regarding premium reductions for reduced use of toxic chemicals.

Toxic Use Reduction fees for CFC use were $1,100 for the CFC plus $8,600 for the facility. Use of the HCFCs saves K & M $9,700/year under TURA, as is likely with the solvent for the UFI system.

Production and Maintenance

Maintenance on the old CFC degreaser was 4 hours every 6 moths or 8 hours/year. Electrical usage was estimated using a standard vapor degreaser specification on file: Detrex Corp's Challenger Series 2D 20 -ER (230V 60Amp).

The current bench top systems allow workers to clean their own parts without waiting and eliminates the need for a vapor degreaser operator. This results in a savings in production costs. Initially the individual HCFC degreasers required replacement valves every two months. The engineering team resolved this issue and the replacements are considered a one time maintenance cost and have been added to the "Equipment Purchase" category under this option (2 valve replacements/machine every two months * 15 machines * $6/valve and taking 15 minutes for each valve).

The bench top units come in three sizes, each with a different electrical demand: twelve 1.1 gallon units at 300 watts each; two 2.55 gallon units at 500 watts each; and four 5 gallon units at 700 watts each. The cost of electricity is $0.05/KWhr. Total electrical demand for these machines running eight hours/day, 250 days/year is $740. Each unit is drained at the end of the day so the machines need not run continuously to limit evaporative losses. This is estimated to take 2 minutes/machine each day and costs the company $1,875/year.

Filters for the UFI system need to be replaced in the following frequency: $44 and $100 type every month and $5 type every week. The UFI unit's electrical demand is 240v @ 36 amps, or $1,209/year. Water use is nominal due to the de-ionized rinses which continually recirculate from the tanks to the DI columns and back. The columns have not yet been recharged, so no cost data was available.

Project Outcome

The calculations show $163,348 annual operating costs for the CFC vapor degreaser. Switching to bench top style units, manufactured in-house and equipped with HCFCs saved the company $84,120/year. While this may appear to be a significant cost savings, 34% of that savings comes from eliminating the one worker who operated the vapor degreaser. K & M staff claim productivity may have increased because assembly workers can clean parts at their convenience without waiting. They also state that chemical use per part is probably higher because of the difficulty of getting all the workers to raise and lower their parts at a correct rate, empty and refill their bench top units carefully, and keep them covered when not in use.

It would be tempting to keep using HCFCs until the price rises to the level that CFCs were in 1993. The company would continue to save money and perhaps continue to avoid having to comply with TURA. Yet, rising concern for the ozone layer and provisions under TURA allowing the Department of Environmental Protection to add chemicals to the list could develop into an early phaseout of HCFCs. K & M would also be missing out on an investment opportunity that returns 10 times more money per dollar invested. The ultrasonics option can save them an additional $30,000/year if workers could be trained to schedule their use of the ultrasonic unit.

Table 13. Case Five Total Cost Assessment Worksheet: Capital Costs

	CFC degrease	HCFC degreaser	Ultrasonics
Capital Costs			
Equipment Purchase	NA	($9,810)	($25,525)
Disposal of Old Process	NA	in storage	in storage
Research and Design	NA	($48,000)	($7,500)
Initial Permits	NA	0	0
Building/Process changes	NA	($440)	($1,009)
Total Capital Costs	NA	($58,250)	($34,034)

Table 14. Case Five Total Cost Assessment Worksheet: Operating Cash Flow

		CFC degrease	HCFC degreaser	Ultrasonics
Operating Cash Flow				
Chemical Purchases		($120,348)	($37,800)	($1,400)
Waste Mgmt.	Treat. Chem.	0	0	0
	Testing	0	0	0
	Disposal	($150)	($150)	($330)
Safety Training/Equipment		($50)	nominal	($50)
Insurance		NA	NA	NA
Fees (i.e. TURA)		($9,700)	0	0
Filing Paperwork time		($400)	$1,950	$742
Annual Permitting		NA	NA	NA
Maintenance	Time	($120)	($1,875)	($108)
	Materials	0	0	($1978)
Production Costs	% Inc./Dec.	0	0	0
	$/year	($30,000)	0	($30,000)
Utilities	Water	0	0	nominal
	Electricity	($2,580)	($740)	($1,209)
	Gas/Steam.	0	0	0
Total Ann. Oper. C.F.		($163,348)	($42,515)	($34,333)

Table 15. Case Five Total Cost Assessment Worksheet: Cash Flow Summary

	CFC degreaser	HCFC degreaser	Ultrasonics
Cash Flow Summary			
Total Ann. Oper. Cash Flow	(\$163,348)	(\$42,515)	(\$35,817)
Incremental Cash Flow	0	\$120,783	\$127,531
- Depreciation	NA	(\$29,125)	(\$4,862)
Taxable Income	NA	\$91,658	\$122,669
Income Tax (40%)	NA	(\$36,663)	(\$49,068)
Net Income	NA	\$54,995	\$73,601
+ Depreciation	NA	\$29,125	\$4,862
After Tax Cash Flow	NA	\$84,120	\$78,463
PV: 2yr=1.7355, 7yr=4.8684	NA	\$145,990	\$381,989
Total Capital Cost	NA	(\$58,250)	(\$34,034)
Net Present Value	NA	\$87,740	\$347,995
Benefit/Cost Ratio	NA	1.51	10.02

3.6. Case Six

Case Summary:	Ceramic Insulators
Substrate:	Galvanized steel and ceramics
Soils:	Asphaltic compounds
Old Process:	TCA vapor degreaser
Alternative:	Terpene/Mineral spirits
Outcome:	102K/year savings

Background

Lapp Insulators of Sandersville, Georgia employs 162 people as a manufacturer of porcelain insulators for high voltage power lines. The insulators attach the high voltage lines to transmission towers. Mounting onto the tower requires a galvanized steel casing. The porcelain component is seated in cement and inserted into the casing. An asphaltic compound is used to protect the galvanized steel from the corrosive effects of the cement. Previously, 1,1,1-trichloroethane (TCA) was used to remove excess asphalt from the insulators. The company also used trichloroethylene to thin the asphalt prior to application to the casings. Solvent contaminated waste from both these operations had to be shipped off as hazardous material.

Initial Costs

The search for a non-ozone depleting solvent began in 1990 with the assistance of Ashland Chemical. Several alternatives were tried, most of which worked as solvents but had limited additional uses. Ashland brought Environmental Solvents Corporation on board and found cleaner KNI-2000, a terpene based alternative, that successfully cleaned the parts. KNI 2000 was then thinned to 50% strength with mineral spirits to provide a faster drying time. Environmental Solvents Corp worked with Lapp Insulators at no charge until the final chemistry worked. Estimates of facility staff involvement in research over the three years are about one-quarter of an full time employee per year. Total labor research cost to Lapp is estimated at $21,000 total ($14/hour * 1/4 * 2,000 hours * 3 years). Lapp built three new cleaning tanks in-house for a cost of $5,000. Lapp is currently looking for a buyer for its old vapor degreaser. The new system did not require additional building changes or permits. Depreciation for the new unit was figured at 10 years with a 10% cost of capital. Labor for maintenance and production is $14/hour.

Chemicals and Wastes

The company had been purchasing 10 drums of TCA month, and sending 3 to 5 drums/month of waste off-site for incineration. Given a current market price of $16.70/gallon for TCA

($920/drum)[8] Lapp would be spending $110,220 in 1993 to use TCA. Incineration of TCA is $400/drum.

Lapp currently uses 18 drums/year of both KNI-2000 and mineral spirits. KNI-2000 is $14/gallon, lasts longer in the tank due to its lower vapor pressure, and is blended 50% with mineral spirits costing $2.64/gallon. Total chemical purchases for KNI-2000 and mineral spirits are $13,860 and $2,613 respectively. The KNI-2000 and the mineral spirits are only 3 degrees apart in boiling temperature. Lapp borrowed a solvent distillation unit from their Leroy, New York, plant and distills the spent cleaner. Lapp produces near-virgin cleaner through this process and uses the sludge residue, being mostly asphalt, as part of their coating. They currently accumulate only 6 drums/year of unusable waste (instead of 48) and are able to dispose of it at a lower per drum cost.

Regulatory Impacts

The production manager at Lapp figures worker health and safety training takes roughly the same amount of time due to the number of chemicals used at the facility. The company's insurance policy will come up for review in February of 1994 and Lapp will be presenting its successful project in hopes of lowering the premium for the Sandersville plant. Unlike Massachusetts, Georgia does not currently have a Toxics Use Reduction Act or impose fees on companies based upon their chemical use. This reduces paperwork connected with manifesting wastes to six hours/year ($84/year).

Lapp Insulators corporate office in Leroy handles all environmental compliance duties and engineering tasks for the satellite plants. The $25,000 cost associated with permitting the old system and filing compliance documents reflect the expenses of flying an engineer from the corporate office to Georgia at least four or more times per year to check on the environmental status of the Sandersville plant.

Production and Maintenance

One of the largest savings achieved through this project was the reduction in time required to clean the insulators. According to the plant manager vapor degreasing used to require 1 and 1/2 hours of cleaning time, running continuously 250 days/year. With the terpene/mineral spirits system it takes only 10 minutes. This works out to an 88% reduction in cleaning time and a resulting savings of almost $25,000.

The TCA required standard maintenance to keep the thermostats, pumps, heaters and sumps in working condition. The terpene alternative is used at room temperature, as a cold dip tank. This saves $100/month in maintenance costs. Since the new cleaner is used as a cold dip tank without agitation or heat there are no electricity, steam, or water costs associated with it.

[8] Market price quote, Ashland Chemical, 12/93.

Project Outcome

The calculations above reveal phenomenal savings for Lapp Insulators. Given the relatively low initial investment the savings will return that investment to the company 23 times over the 10 year life span. Even the relatively high cost of researching an alternative could not offset the savings from not using TCA.

Lapp has since discovered the terpene/mineral spirits blend can be used to thin the asphalt prior to spraying the steel casings. This will entirely replace their traditional solvent, TCA. Lapp Insulator's other facilities are watching these developments closely and expect to follow suit in the near future.

Table 16. Case Six Total Cost Assessment Worksheet: Capital Costs

	TCA	Terpene & MS
Capital Costs		
Equipment Purchase	NA	($5,000)
Disposal of Old Process	NA	in storage
Research and Design	NA	($21,000)
Initial Permits	NA	0
Building/Process changes	NA	0
Total Capital Costs	NA	($26,000)

Table 17. Case Six Total Cost Assessment Worksheet: Operating Cash Flows

		TCA	Terpene & MS
Operating Cash Flows			
Chemical Purchases		($110,220)	($16,473)
Waste Mgmt.	Treat. Chem.	0	0
	Testing	0	0
	Disposal	($19,200)	($1,200)
Safety Training/Equipment		same	same
Insurance		NA	NA
Fees (i.e. TURA)		NA	NA
Filing Paperwork time		see below	($84)
Annual Permitting		($25,000)	0
Production Costs	% Inc./Dec.	0	88% dec.
	$/year	($28,000)	($3,408)
Maintenance	Time	($1,200)	0
	Materials	0	0
Utilities	Water	0	0
	Electricity	($5,000)	0
	Gas/Steam.	0	0
Total Ann. Oper. Cash Flow		($188,620)	($21,165)

Table 18. Case Six Total Cost Assessment Worksheet: Cash Flow Summary

	TCA	Terpene & MS
Cash Flow Summary		
Total Ann. Oper. Cash Flow	($188,620)	($21,165)
Incremental Cash Flow	0	$167,455
- Depreciation	NA	($2,600)
Taxable Income	NA	$164,855
Income Tax (40%)	NA	($65,942)
Net Income	NA	$98,913
+ Depreciation	NA	$2,600
After Tax Cash Flow	NA	$101,513
Present Value (6.1446)	NA	$623,757
Total Capital Cost	NA	($26,000)
Net Present Value	NA	$597,757
Benefit/Cost Ratio	NA	22.99

4. CONCLUSION

The motivation for these companies to pursue solvent substitution varies among each company. Corporate environmental responsibility and image played the most significant role. The threat of enforcement actions and more stringent future regulations was seen as an additional driving force. All were more concerned with regulatory and image repercussions than the financial burden of a new cleaning process. Consequently none had specific net present values, benefit/cost ratio, or hurdle rate goals in mind at the start of the projects.

In three of the six cases the motivation for change came from a corporate directive to stop using CFCs and chlorinated solvents. Of these three, all were privately owned, two having 100 - 200 employees and the third having fewer than 20 employees. All stated that public image played an important role. The public availability of TRI data for solvent usage allowed these companies to become potential targets of local activist groups. One of the two mid-sized companies stated that the potential cost savings were also a motivator.

Cost savings, worker exposure, and reducing regulatory burden were drivers for a fourth company. Eliminating the solvent reduced the amount of paperwork required to comply with the Massachusetts Toxics Use Reduction Act and TRI reporting.

Regulatory enforcement provided the incentive for the fifth company. Allowable air emissions limits forced this company to find a less volatile alternative. The resulting cost savings inspired the plant manger to pursue additional solvent substitution projects (see the "Avoided Costs" section for more detail).

Disposal of Old Degreasers

Disposing of the old cleaning system was an issue that most industries asked about. There were no known vapor degreaser reclaiming centers. Most facilities surveyed were retaining the old degreaser, or attempting to sell it. It appeared that finding storage space for the old equipment was easier than trying to find a buyer. As the market for vapor degreasing continues to shrink, finding buyers for used equipment will become more difficult. A large manufacturer having multiple vapor degreasers could be faced with the cost of having the units removed.

Disposal of CFCs

In the past many chemical producers and distributors offered recycling services to their clients for chlorinated solvents. The used solvent would be picked up, reprocessed at the chemical plant, and returned or re-sold to another client. With the market shift away from CFCs and other chlorinated solvents, chemical distributors have found a tighter market to sell recycled product. As a result it is often more expensive to have a chemical dealer take back the CFCs than to pay to dispose of them another way. The most common method is to blend CFCs with other fuel sources and "F-type wastes" in cement kilns. Proper blending keeps the chlorine content of the fuel to legal limits. As more and more industries move away from chlorinated solvents, the market to sell reclaimed solvent will also continue to shrink, forcing more burning of waste solvents.

Research and Design Costs

One of the most difficult costs to track for the project was time associated with finding new alternatives. Most figures are the estimates of people involved in finding the alternatives. Nobody had records of exactly how much time had been spent. The search in five of the cases was performed as time could be found, in between other duties associated with running a factory. Tasks such as testing part quality, contacting vendors, and estimating costs were split among several individuals.

Building and Process Changes

Four of the six projects required some level of alteration to the buildings. The changes ranged from bringing in a new water line to raising the suspended ceiling above the new cleaning unit. Several of the projects used in-house skills and labor to fabricate tanks and equipment for the cleaning system.

Chemical Purchases

Three factors make this category the largest cost saver. First, the prices of chlorinated solvents and CFCs have risen dramatically in the past two to three years. TCE's going rate in 1989 was $3.95/gallon. Today's market rate is over $12.80/gallon. TCA has risen from $5.20/gallon in 1991 to $16.71/gallon in 1993. CFC's have experienced over an 800% increase in price from 1990 to 1993. Federal taxes on these chemicals account for roughly 40% of the market price.

Second, alternative chemistries such as alkaline aqueous and terpenes have been more expensive than chlorinated solvents in the past, but are now often less expensive. Federal taxes and larger numbers of alternatives on the market have reduced the relative expense of these alternatives. For example, terpenes are currently selling around $12/gallon. In 1990 or 1991 this would have been considered expensive. Today, in comparison to CFCs and TCA there is a cost savings.

Third, most alternatives are not used at full strength, further lowering the in-tank costs. For example, alkaline aqueous chemistries are often diluted at least 50%, effectively halving the cost of using them. Lower evaporation rates also decrease fugitive emissions, further reducing quantities used.

Table 19 illustrates the significance of each cost category as a percentage of total cost. For these six case studies chemical purchases and waste disposal accounted for 87% of the cost of running the operation. In Case 6, using TCA to remove asphaltic compounds from ceramic insulators, chemicals and waste made up 68% of the cost with production and regulatory compliance being the next highest. In Case 2, using CFCs to dry parts spot-free, chemical usage was 98% of the cost of the operation.

Table 20 illustrates the significance of each cost category. The maintenance costs increase from solvent substitution. Some cost categories differ significantly between case studies. In some case studies chemical purchases are a small percentage of the operating costs, whereas in other case studies chemical purchases are the largest percentage.

Table 21 illustrates the percent decreases in each cost category as a result of solvent substitution. Percentages in parentheses are cost increases due to solvent substitution. Almost all cost increases occur in the maintenance category. Two reasons account for this. First, the relative costs of system maintenance are small and therefore any cost increase will have a larger percentage impact. For example a $1 increase on a $10 item is only 10%, but the same increase on a $1 item is 100%. As was seen in the preceding table, maintenance costs are a small percentage of the total operating costs, ranging from 0.4% to 18% of total costs.

Second, it appears that traditional petroleum based solvents have a wider acceptable operating range, and can go for longer periods of time without maintenance. Alternatives in this project needed monitoring of pH, more frequent tank clean-outs, and replacements of filters. In Case 5a the maintenance costs were connected to the servicing of 18 bench top degreasers versus one vapor degreaser, amounting to $1,875/year versus $120/year. In Case 5b the 1700% increase in maintenance costs comes from the labor involved in changing the in-line bag and canister filters as well as the cost of those filters. Labor for this task is $108/year at $15/hour, and materials are $1,978/year.

Table 19. Breakdown of Costs for Traditional Cleaning Systems by Case Study (%)

Category	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Ave.
Chemical Purchases	90.6	98.4	97.5	71.8	73.7	58.4	81.7
Waste Disposal	4.4	0	1.3	17.6	0.1	10.2	5.6
Safety Training/ Equipment	0	0	0	1.55	0	0	0.3
Regulatory Compliance	4.6	1.3	0.1	7.5	6.2	13.3	5.5
Production	0	0	0	0	0.1	14.8	2.5
Maintenance	0.4	0.3	1.1	1.55	18.3	0.6	3.7
Utilities	0	0	0	0	1.6	2.6	0.7

Table 20. Breakdown of Costs for Alternative Cleaning Systems by Case Study (%)

Category	Case 1	Case 2	Case 3	4a.	4b.	5a.	5b.	Case 6	Ave.
Chemical Purchases	42.4	0	6.1	75	0	88.9	3.9	77.8	36.8
Waste Disposal	0	0	18.5	20.1	0	0.4	0.9	5.7	5.7
Safety Training/ Equipment	1.9	0	1.6	1.8	52.9	0	0.1	0	7.3
Regulatory Compliance	0	0	1.2	1.3	0	4.6	2.1	0.4	1.2
Production	0	0	0	0	0	0	83.8	16.1	12.5
Maintenance	55	100	72.6	1.8	47.1	4.4	5.8	0	35.8
Utilities	0.7	0	0	0	0	1.7	3.4	0	0.7

Table 21. Percent Change in Operating Costs from Solvent Substitution

Category	Case 1	Case 2	Case 3	4a.	4b.	5a.	5b.	Case 6
Chemical Purchases	98.0	100.	99.0	8.5	100.0	68.6	98.8	85.0
Waste Disposal	100.0	None	37.0	0	100.0	None	(220)	93.7
Reg. Compliance	98.0	100.	None	30.0	100.0	80.7	92.7	99.0
Production	None	None	None	None	None	100.0	None	87.8
Maintenance	(414.0)	81.0	(181.0)	None	None	(1500)	(1700)	100.0
Utilities	(700.0)	None	None	None	None	71.4	53.2	100.0
Overall % Decrease	96.5	99.0	95.7	12.0	96.7	74.0	78.1	88.7

There were also some increases in the utilities category. In particular, Case 1 had a 700% increase in use of water. Taken out of context this would be extremely alarming. In fact, the percent increase in water use was infinite since the old system did not use any water. Placing the usage in context with other costs reveals water use is only 0.6% of the total operating costs of that system.

The facility in Case 1 is also an electroplating company where $7 annual water use is offset by the daily use of the plating lines.

The last cost increase seen in these cases came from a change over to terpene cleaner from CFCs in a circuit board assembly operation. The 220% increase in waste disposal costs results from the difference in how spent cleaners are treated. Previously spent CFCs were recycled with only a small fraction disposed of as hazardous waste. It is unknown at this point if the new alternative will be recyclable in the same way. The exercise therefore included a cost for shipping all waste terpenes off-site as hazardous waste.

Of the eight alternatives analyzed in this project, half (four) of them had net operating cost savings in excess of 95%. Three more had cost savings greater than 75% and one had a cost savings of just 12% (Case 4a). Case 4a demonstrates that total cost assessment can be used to find a maximum price per gallon for an alternative solvent to replace TCE in a parts drying operation. By holding waste disposal, maintenance, production, and utility costs the same, the cost reductions achieved from reduced regulatory burden were applied directly to reducing per gallon chemical costs. The suggested alternative for 4a was a "drop-in" replacement that also eliminates the need for the water displacer preceding the TCE degreaser. Many factors could change this number.

It might cost more or less to dispose of the new drop in alternate. Future regulations could lead to higher prices, fees or taxes. The other suggested option for 4a was further modification of the final rinses on the plating lines, followed by hot air drying. Total operational cost savings for this option is 96%.

Regulations as Motivators

Case 5 illustrates the hidden value of total cost assessment. The facility's only Massachusetts Toxics Use Reduction Act (TURA) regulated chemical was CFC-113. By eliminating the chemical they were able to save money on the filing fees, chemical fees, and associated paperwork. They also avoided having to develop a TURA plan, saving an estimated additional $8,000 for 1994. TURA plans are also required to be updated every two years.

As mentioned before the largest cost saving category is chemical purchases, not regulatory compliance. Eliminating the need to file forms has certain intangible benefits such as reduced stress and concern, yet the overall financial impact is small. Specifically, the effect of the Massachusetts TUR Act as a driver for solvent substitution is also small. None of the four Massachusetts companies considered TURA a prime driver for substituting a solvent. While one company did eliminate the need to file a TUR plan, the prime motivation came from a corporate directive having no knowledge of TURA.

The largest "regulatory" impact has come in the form of taxes on CFCs. The 800% increase in price of CFCs over the last four years has forced changeovers based on economic terms alone. For example;

A company of over 10 employees that uses more than 10,000 pounds of CFCs per year must file under the TURA act. The Act also levies a use fee of $1,100/chemical. Add in the cost of paper work at $20/hour (16 hours/year).' Also spread the cost of developing a TURA plan across the remaining years before a CFC phaseout in the year 2000 ($8,000/7 years = $1,143/year) and the total "burden" for using CFCs under TURA is $2,643/year.

The current market price of CFCs is $5.05/pound plus $3.52 in federal taxes. In total, the impact of TURA fees is $2,643 for 10,000 pounds, while the federal tax is $35,200 for the same quantity. The federal tax also has an impact at any level of use where as the TUR law only impacts uses above 10,000 pounds and in some cases 25,000 pounds. The effect of the federal tax reaches the smaller business, and those who might try merely to lower their usage below the 10,000 pound threshold.

Health and Safety Costs

Worker health and safety costs directly related to solvent use were difficult to locate. All companies involved conducted health and safety training for their workers and combined eduction on all chemicals into a single training day. Line workers were trained individually if they were the only operator of the degreaser. Instruction on safe use of the degreasers and solvents required less than an hour. Relative to other operating costs this category is very small, accounting for between 0.02% and 1.5% of total operating costs.

Production Costs

There is often a misconception that a new cleaning process necessarily takes longer than the current process. The calculations of these cases show either no significant increase or a decrease in production costs. The replacement systems handled parts in similar ways as the older systems. Use of the new systems required minimal re-training of the line operators. In several cases the existing degreasers had no hang-bars to rest parts, requiring operators to hold the parts in the vapor zone. The newer systems allowed for this or some variation, leaving the operators free to perform another task while the parts were cleaning. This offset any extended cleaning time required.

Employment, Profit and Case 5

Case 5 detailed the savings resulting from changing to individual bench top degreasers, using HCFC 141b, from a single larger unit that used CFC 113. This saved time by eliminating the degreaser operator. Each assembly person requiring clean parts had a degreaser right next to them. The trade off in this situation is less control over chemical use. It is more difficult keeping 18 units running properly, and the operators using them properly, than having just one degreaser. In the new scenario using ultrasonics, the salary of an operator was included in the labor costs. The company still achieved savings, due mostly to smaller usages of cheaper chemicals.

Notice that the interim solution actually saves more money per year than the terpene/ultrasonic alternative. If both projects are given a similar lifetime (7 years) the terpene alternative looks much better. The benefit/cost ratio of the HCFC degreasers rises to around 6 but does not surpass the ultrasonics' 10.0. Subtracting the $30,000 allotted for a salary of a degreaser operator in the ultrasonics option raises the after tax cash flow to over $100,000/year and the benefit/cost ratio to 12.8. This means the profits from the short term use of the HCFCs come mostly from tax savings due to the depreciation of the capital costs.

Over Cleaning

In several cases previous use of chlorinated solvents and CFCs was replaced with simple alkaline soap solutions. One company president even admitted that his company used to use soap and water to clean their parts years ago. The advent of petroleum solvents has led to a form of overkill in cleaning processes. It is akin to being sold a V-8 engine when all that was needed was a motor scooter. Water based machine tool lubricants have further reduced the need for an aggressive cleaner. The net effect is satisfactory cleaning with relatively simple soap solutions. Issues of blind holes, threads, and complex geometries can be met with heated solutions, air and mechanical agitation or ultrasonics. Discretion is advised in selecting a solvent substitute to avoid another case of cleaning overkill.

Use of Terpenes

The initial scope of work included finding an example of chlorinated solvents replaced with terpenes in a metal fabricating/machining application. None of the metal fabricating and tool companies contacted were using terpenes. Interviews with vendors of terpene chemistries offered these reasons.

There has been a time lag between industry sectors around regulatory impacts. The electronics industry used CFC-113 for almost 90% of its cleaning needs. Terpenes have been on the market for many years. When the public outcry on ozone layer depletion grew, the industry grabbed for what was available, terpenes. This was not the case in the metal fabricating/machine tool industries. Here most cleaning was done with TCA, which was not added to the Montreal Protocol until much later. The delay in switching has allowed more options to develop and be tested.

A second theory focuses on circuit board manufacturers using terpenes more extensively because the cost of their product supports a more complex cleaning operation. Additionally their solders often contain lead, which can not be dumped down the drain. In most metal intensive operations the soils and substrates can be sufficiently cleaned without damage using simple water based solutions. In some instances there is no real need to clean between production processes. Electroplaters and many machine shops have waste water treatment systems in place, and can accept additional aqueous waste waters.

As the research progressed interesting trends were discovered in the field of solvent substitution. The predominant theme was to keep the cleaning processes as simple as possible. In every case the alternative ended up saving the company money; savings ranging from $3,000 annually to almost $100,000 annually. Each of the cases had a positive net present value and benefit/cost ratio. This means that each of the investments was financially beneficial for the companies in this study. The net present value of the Hi-Tech Plating in the fourth case study is not applicable because it was used to determine the maximum price for an alternative cleaning solvent.

Table 22. Breakdown of Net Present Value and Benefit/Cost Ratio for Alternative Cleaning Systems by Case Study

Case Study		Net Present Value	Benefit/Cost Ratio
Case 1		$110,437	10.77
Case 2		$362,093	31.76
Case 3	Alk. & offsite	$77,399	6.79
	Alk. & disch.	$73,531	6.45
	Alk. & UF	$77,016	5.00
Case 4	Hot Air Dry	$78,207	6.74
	Direct Sub.	NA	NA
Case 5	HCFC degreaser	$87,740	1.51
	Ultrasonics	$347,995	10.02
Case 6		$597,757	22.99

The effects of federal and state regulation have contributed to the timelines and choice of alternative cleaners used by these industries. Many industries contributed time, data and experiences, several had more than one project to evaluate. It is hoped that this report offers insights to firms on how to apply the total cost assessment methodology and of the benefits that frequently result from implementing pollution prevention project.

Appendix A

Table B. Present Value of \$1: $\frac{1}{(1+k)^n}$

Period	1%	3%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%	20%	24%	28%
1	.9901	.9709	.9524	.9434	.9346	.9259	.9174	.9091	.9009	.8929	.8850	.8772	.8696	.8621	.8547	.8475	.8403	.8333	.8065	.7813
2	.9803	.9426	.9070	.8900	.8734	.8573	.8417	.8264	.8116	.7972	.7831	.7695	.7561	.7432	.7305	.7182	.7062	.6944	.6504	.6104
3	.9706	.9151	.8638	.8396	.8163	.7938	.7722	.7513	.7312	.7118	.6930	.6750	.6575	.6407	.6244	.6086	.5934	.5787	.5245	.4768
4	.9610	.8885	.8227	.7921	.7629	.7350	.7084	.6830	.6587	.6355	.6133	.5921	.5718	.5523	.5336	.5158	.4987	.4823	.4230	.3725
5	.9515	.8626	.7835	.7473	.7130	.6806	.6499	.6209	.5934	.5674	.5428	.5194	.4972	.4761	.4561	.4371	.4190	.4019	.3411	.2910
6	9420	8375	.7462	7050	.6663	.6302	.5963	.5645	.5346	.5066	.4803	.4556	.4323	.4104	.3898	.3704	.3521	.3349	2751	.2274
7	9327	8131	7107	6651	.6627	.5835	.5470	5132	.4187	.4523	.4251	.3996	.3759	3538	.3332	.3139	2959	.2791	2218	.1776
8	9235	7894	6768	6274	5820	5403	.5019	4665	4339	.4039	.3762	.3506	.3269	3050	.2848	.2660	.2487	.2326	1789	.1388
9	9143	7664	6446	5919	5439	5002	.4604	4241	.3909	3606	3329	3075	2843	.2630	.2434	.2255	2090	.1938	.1443	.1084
10	9053	7441	.6139	5584	.5083	4632	.4224	.3855	.3522	.3220	.2946	2697	.2472	.2267	2080	.1911	.1756	.1615	.1164	.0847
11	.8963	.7224	.5847	.5268	.4751	.4289	.3875	.3505	.3173	.2875	.2607	.2366	.2149	.1954	.1778	.1619	.1476	.1348	.0938	.0662
12	.8874	.7014	.5568	.4970	.4440	.3971	.3555	.3186	.2858	.2567	.2307	.2076	.1869	.1685	.1520	.1372	.1240	.1122	.0757	.0517
13	.8787	.6810	.5303	.4688	.4150	.3677	.3262	.2897	.2575	.2292	.2042	.1821	.1625	.1452	.1299	.1163	.1042	.0935	.0610	.0404
14	.8700	.6611	.5051	.4423	.3878	.3405	.2992	.2633	.2320	.2046	.1807	.1597	.1413	.1252	.1110	.0985	.0876	.0779	.0492	.0316
15	.8613	.6419	.4810	.4173	.3624	.3152	.2745	.2394	.2090	.1827	.1599	.1401	.1229	.1079	.0949	.0835	.0736	.0649	.0397	.0247
16	8528	.6232	.4581	.3936	.3387	2919	.2519	.2176	.1883	.1631	.1415	.1229	.1069	.0930	.0811	.0708	.0618	.0541	.0320	.0193
17	8444	6050	.4363	.3714	3166	.2703	.2311	1978	.1696	.1456	.1252	.1078	.0929	.0802	.0693	.0600	.0520	.0451	.0258	.0150
18	8360	5874	4155	.3503	2959	2502	.2120	1799	1528	.1300	.1108	.0946	.0808	.0691	.0592	.0508	.0437	.0376	.0208	.0118
19	8277	5703	3957	3305	2765	.2317	.1945	1635	.1377	1161	.0981	.0829	.0703	.0596	.0506	.0431	.0367	.0313	.0168	.0092
20	8195	5537	.3769	3118	.2584	.2145	.1784	1486	.1240	.1037	.0868	.0728	.0611	.0514	.0433	.0365	.0308	.0261	.0135	.0072
25	.7798	.4776	.2953	.2330	.1842	.1460	.1160	.0923	.0736	[illegible]	.0471	[illegible]	[illegible]	[illegible]	.0197	.0160	.0129	.0105	[illegible]	.0021
30	.7419	.4120	.2314	.1741	.1314	.0994	.0754	.0573	.0437	.0334	.0256	.0196	.0151	.0116	.0090	.0070	.0054	.0042	.0016	.0006
40	.6717	.3066	.1420	.0972	.0668	.0460	.0318	.0221	.0154	.0107	.0075	.0053	.0037	.0026	.0019	.0013	.0010	.0007	.0002	.0001
50	[illegible]	.2281	.0872	.0543	.0339	.0213	.0134	.0085	.0054	.0035	.0022	.0014	.0009	.0006	.0004	.0003	.0002	.0001	[illegible]	[illegible]
60	.5504	.1697	.0535	.0303	.0173	.0099	.0057	.0033	.0019	.0011	.0007	.0004	.0002	.0001	.0001	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*The factor is zero to four decimal places.

Table D. Present Value of an Annuity of \$1 for n Periods: $\left[\sum_{t=1}^{n} \frac{1}{(1+k)^t} \right]$

Number of payments	1%	3%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	16%	17%	18%	19%	20%	24%
1	0.9901	0.9709	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8850	0.8772	0.8696	0.8621	0.8547	0.8475	0.8403	0.8333	0.8065
2	1.9704	1.9135	1.8594	1.8334	1.8080	1.7833	1.7591	1.7355	1.7125	1.6901	1.6681	1.6467	1.6257	1.6052	1.5852	1.5656	1.5465	1.5278	1.4568
3	2.9410	2.8286	2.7232	2.6730	2.6243	2.5771	2.5313	2.4869	2.4437	2.4018	2.3612	2.3216	2.2832	2.2459	2.2096	2.1743	2.1399	2.1065	1.9813
4	3.9020	3.7171	3.5460	3.4651	3.3872	3.3121	3.2397	3.1699	3.1024	3.0373	2.9745	2.9137	2.8550	2.7982	2.7432	2.6901	2.6386	2.5887	2.4043
5	4.8534	4.5797	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908	3.6959	3.6048	3.5172	3.4331	3.3522	3.2743	3.1993	3.1272	3.0576	2.9906	2.7454
6	5.7955	5.4172	5.0757	4.9173	4.7665	4.6229	4.4859	4.3553	4.2305	4.1114	3.9976	3.8887	3.7845	3.6847	3.5892	3.4976	3.4098	3.3255	3.0205
7	6.7282	6.2303	5.7864	5.5824	5.3893	5.2064	5.0330	4.8684	4.7122	4.5638	4.4226	4.2883	4.1604	4.0386	3.9224	3.8115	3.7057	3.6046	3.2423
8	7.6517	7.0197	6.4632	6.2098	5.9713	5.7466	5.5348	5.3349	5.1461	4.9676	4.7988	4.6389	4.4873	4.3436	4.2072	4.0776	3.9544	3.8372	3.4212
9	8.5660	7.7861	7.1078	6.8017	6.5152	6.2469	5.9952	5.7590	5.5370	5.3282	5.1317	4.9464	4.7716	4.6065	4.4506	4.3030	4.1633	4.0310	3.5655
10	9.4713	8.5302	7.7217	7.3601	7.0236	6.7101	6.4177	6.1446	5.8992	5.6502	5.4262	5.2161	5.0188	4.8332	4.6586	4.4941	4.3389	4.1925	3.6819
11	10.3676	9.2526	8.3064	7.8869	7.4987	7.1390	6.8052	6.4951	6.2065	5.9377	5.6869	5.4527	5.2337	5.0286	4.8364	4.6560	4.4865	4.3271	3.7757
12	11.2551	9.9540	8.8633	8.3838	7.9427	7.5361	7.1607	6.8137	6.4924	6.1944	5.9176	5.6603	5.4206	5.1971	4.9884	4.7932	4.6105	4.4392	3.8514
13	12.1337	10.6350	9.3936	8.8527	8.3577	7.9038	7.4869	7.1034	6.7499	6.4235	6.1218	5.8424	5.5831	5.3423	5.1183	4.9095	4.7147	4.5327	3.9124
14	13.0037	11.2961	9.8986	9.2950	8.7455	8.2442	7.7862	7.3667	6.9819	6.6282	6.3025	6.0021	5.7245	5.4675	5.2293	5.0081	4.8023	4.6106	3.9616
15	13.8651	11.9379	10.3797	9.7122	9.1079	8.5595	8.0607	7.6061	7.1909	6.8109	6.4624	6.1422	5.8474	5.5755	5.3242	5.0916	4.8759	4.6755	4.0013
16	14.7179	12.5611	10.8378	10.1059	9.4466	8.8514	8.3126	7.8237	7.3792	6.9740	6.6039	6.2651	5.9542	5.6685	5.4053	5.1624	4.9377	4.7296	4.0333
17	15.5623	13.1661	11.2741	10.4773	9.7632	9.1216	8.5436	8.0216	7.5488	7.2497	6.7291	5.4674	6.0472	5.1280	5.4746	5.2223	4.9897	4.7746	4.0591
18	16.3983	13.7535	11.6896	10.8276	10.0591	9.3719	8.7556	8.2014	7.7016	7.1196	6.8399	6.3729	6.1280	5.7487	5.5339	5.2732	5.0333	4.8122	4.0799
19	17.2260	14.3238	12.0853	11.1581	10.3356	9.6036	8.9501	8.3649	7.8393	7.3658	6.9380	6.5504	6.1982	5.8775	5.5845	5.3162	5.0700	4.8435	4.0967
20	18.0456	14.8775	12.4622	11.4699	10.5940	9.8181	9.1285	8.5136	7.9633	7.4694	7.0248	6.6231	6.2593	5.9288	5.6278	5.3527	5.1009	4.8696	4.1103
25	22.0232	17.4131	14.0939	12.7834	11.6536	10.6748	9.8226	9.0770	8.4217	7.8431	7.3300	6.8729	6.4641	6.0971	5.7662	5.4669	5.1951	4.9476	4.1474
30	25.8077	19.6004	15.3725	13.7648	12.4090	11.2578	10.2737	9.4269	8.6938	8.0552	7.4957	7.0027	6.5660	6.1772	5.8294	5.5168	5.2347	4.9789	4.1601
40	[illegible]	[illegible]	[illegible]	15.0463	13.3317	11.9246	10.7574	9.7791	8.9511	8.2438	7.6344	7.1050	6.6418	6.2335	5.8713	5.5482	5.2582	4.9966	4.1659
50	39.1961	25.7298	18.2559	15.7619	13.8007	12.2335	10.9617	9.9148	9.0417	8.3045	7.6752	7.1327	6.6605	6.2463	5.8801	5.5541	5.2623	4.9995	4.1666
60	44.9550	27.6756	18.9293	16.1614	14.0392	12.3766	11.0480	9.9672	9.0736	8.3240	7.6873	7.1401	6.6651	6.2492	5.8819	5.5553	5.2630	4.9999	4.1667

APPENDIX B. LIST OF PARTICIPATING VENDORS

Mikro Industrial Finishing
Turbo parts washers and
ultrasonics.

170 West Main St.
Vernon, CT 06066
203-875-6357
Mark Kressner

Environmental Solvents Corp.
Re-Entry brand terpene based
cleaners.

70 Walnut St.
Natick, MA 01760
(508) 653-7655
Steve Collier

Petroferm
BioAct EC-7 terpene cleaner

5415 First Coast Highway
Fernandina Beach, FL 32034
(904) 261-8286
Craig Hood

Brulin Corp.
Glycol Ethers, terpene based
alternatives and aqueous.

P.O. Box 270
Indianapolis, IN 46205
317-923-3211 x3290
Janet Salisbury

V&A Cleaning Systems, Inc.
Immersion tanks, rotary washers,
ultrasonics cleaning systems

P.O. Box 555
Rindge, NH 03461
(603) 899-6490
Skip Marsh