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Primary prevention for worker health and safety: cleaner production and toxics use reduction in Massachusetts

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ABSTRACT

Worker health and safety and environmental protection are not always considered simultaneously when attempting to reduce or eliminate hazardous materials from our environment. Cleaner Production-Pollution Prevention (CPPP), as primary prevention, has the ability to shift worker health and safety strategies from control to prevention, where exposure prevention precedes exposure control. This paper evaluates the effect of Cleaner Production-Pollution Prevention in the form of toxics use reduction (TUR) on worker health and safety at three printed wire board facilities covered under the Massachusetts Toxics Use Reduction Act. In-depth case study analysis, including an assessment of each facility's health and safety status, explores the root causes of the worker health and safety changes attributable to the TUR interventions. By exploring the relationship between worker health and safety and environmental protection within the corporate structure; we can identify the factors driving companies to reduce toxics both inside and outside of their plants, as a single concern.

While traditionally there have been divergent paths of practice for worker health and safety and environmental protection, the two are closely connected. It is important, however, to consider the implications of risk transfer/shifting between the general and work environment. In order to avoid this risk shifting, worker health and safety perspectives and goals must be more clearly incorporated into the Cleaner Production-Pollution Prevention/TUR management system. This study opens a dialog around the effects of environmental intervention programs on worker health and safety. We realize now that while CPPP/TUR reduces exposure to toxic substances in the general environment, it also offers unique opportunities to reaffirm primary prevention principles in the work environment.

1. Introduction

It is established that Cleaner Production-Pollution Prevention (CPPP) is the method of choice in modern environmental management. CPPP activities are considered *primary* prevention in the public health sense (Ashford, 1997). This management system is based in technologies that prevent the *possibility* of harm from chemicals in industrial processes. *Secondary* prevention, on the other hand, only reduces the *probability* of harm from an industrial process. Traditional *occupational health* practice predominantly utilizes secondary and tertiary prevention strategies, including disease surveillance and medical treatment in public health, and "end-of-pipe" controls in exposure *reduction* (Moure-Eraso, 2006; Bennett, 1999).

This study focuses on aspects of the relationship between Cleaner Production-Pollution Prevention and worker health and safety. It evaluates the effects of pollution prevention intervention programs (toxics use reduction or TUR) on worker health and safety at three Massachusetts printed wire board manufacturing facilities. Most important, it focuses on *primary prevention* (in the form of CPPP) and how this model benefits both the environment *and* the worker. In addition, it provides useful feedback on what motivates companies to approach environmental and work environment compliance issues as a single concern.

1.1. Background

Worker health and safety and environmental protection are not always considered simultaneously when attempting to reduce or eliminate hazardous materials from our environment. Methods to decrease exposure to hazardous chemicals in the workplace often lead to increased exposure in the environment and to the

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community outside the workplace (for example, use of engineering controls such as local exhaust ventilation tends to shift the burden from the workplace to the ambient environment via contaminated filters or other pollution collection media) (Ellenbecker, 1996; Froines et al., 1995; Penny and Moure-Eraso, 1995; Quinn et al., 1998; Rosenberg et al., 2001). On the other hand, controls placed on emissions of hazardous chemicals into the environment often lead to increased exposure to the workers inside the plant (for example, the replacement of chlorinated brake cleaning solvents with n-hexane, a powerful neurotoxin, in the automotive mechanic industry) (Roelofs et al., 2000). There are government regulations in place that ensure a safe work environment or a safe outside environment; however, there is little integration of both approaches when considering the public's health as a whole. Cleaner Production-Pollution Prevention (CPPP), as primary prevention, has the ability to shift worker health and safety and environmental protection strategies from control to prevention, where exposure prevention precedes exposure control (Ashford et al., 1996).

Over the past 20 years, there has been a fundamental change in the legally prescribed methods for industrial environmental management from *end-of-pipe pollution control* to comprehensive *pollution prevention* interventions (Hirschhorn et al., 1993). Many U.S. industry associations resist these changes. Additionally, the move to cleaner production methods has been slow to take shape throughout industrial sectors. Nonetheless, the pollution prevention requirements of more recent federal and state laws and a new generation of environmental managers concerned about global pollution and warming are slowly bringing about improved industrial practices that embrace environmental sustainability. A way to develop the same fundamental change of methods in worker health and safety management, i.e., from *exposure control* to *exposure prevention,* needs to be explored (Jackson, 1993).

Historically, on the federal level, OSHA standards have focused on worker exposure and conditions inside the plant, while EPA standards have focused on releases to the environment outside of the facility and on "end-of-pipe" control methods (Colten and Skinner, 1996). Compliance with existing environmental regulations or anticipation of new environmental regulations may spur innovation towards more sustainable production processes and materials (Visser et al., 2008). Generally, however, this results in major expenditures which have little if any positive impact on worker exposure and in some cases may actually increase exposure from shifting toxics from one environmental medium to another (Froines et al., 1995). Ashford and Koch argue for the use of innovation forcing informational policies *in conjunction with* complementary regulatory mechanisms to ensure that *all* risks due to production, use, and disposal of chemical substances are considered. Worker health and safety usually are not an integral part of these policies (Koch and Ashford, 2006).

Through the Pollution Prevention Act, the EPA shifted its focus from end-of-pipe controls to reducing exposures at the front end of industrial processes by changing the raw material inputs through source reduction (USEPA, 1990). This has resulted in much greater regulatory involvement in the manufacturing process and it has moved EPA's purview inside the plant where its actions clearly have a much greater potential to have a positive impact on worker exposure. Unfortunately, this has not yet developed into an integrated approach to worker health and safety and environmental protection; resulting in unsystematic attempts to optimize *exposure prevention* (to both worker and community) (Armenti et al., 2003).

Part of the reason for this lies in the voluntary approach of the Pollution Prevention Act and its inability to mandate changes at the point of production. While not the focus of this paper, some researchers have discussed the potential of voluntary environmental strategies to promote efficiency within firms (Paton, 2001). Others have promoted the concept of voluntary environmental management tools to support continuous improvement in a firm, suggesting that consideration for worker health and safety be an integral component. For example, Veleva and Ellenbecker promote the use of indicators of sustainable production, used as a tool for promoting business sustainability. Among the core principles developed, indicators to protect workers include the minimization or elimination of physical, chemical, biological, and ergonomic hazards, organization to conserve and enhance the efficiency and creativity of employees, and the prioritization of security and well-being of all employees (Veleva and Ellenbecker, 2001). Other studies show improvement in cleaner production by integrating quality, environment and working conditions (Verschoor and Reijnders, 2000; Zwetsloot, 1995).

While the EPA's promotion of pollution prevention has required only voluntary participation from manufacturing facilities; on a more "local" level, occupational and environmental professionals in Massachusetts created the Toxics Use Reduction Act of 1989 (TURA) as a way of "forcing" manufacturing facilities to consider "reducing, avoiding, or eliminating" their use of toxic or hazardous substances (or byproducts) without "shifting risks between workers, consumers, or parts of the environment" (Massachusetts General Laws, 1989). According to the law, manufacturing facilities striving to improve environmental performance by implementing pollution prevention plans have the choice of adopting the following strategies: input substitution, process and product changes, improvements in operation and maintenance, materials recycling and resource conservation. Since pollution prevention strategies look at eliminating the root causes of pollution generation, rather than controlling releases to the environment, the impact on worker exposure and workplace conditions is fundamentally different from previous efforts at reducing the impact on the environment through control strategies which did not improve - and in many cases worsened - exposures inside the plant.

An obvious or potential outcome of TUR activities is reduced worker exposures to toxic substances. While few studies have evaluated outcomes specific to toxics use reduction in manufacturing plants, some have explored both worker health and safety and environmental risks associated with input substitution (Verschoor and Reijnders, 2001). Getzner evaluated clean technologies' impacts on employment using an empirical survey of companies in five European countries. He found "significant effects on qualifications (training) and significant improvements in the 'physical' working conditions (e.g. reduction in noise and air pollutants in the workplace)" (Getzner, 2002) Getzner also found that the "participation of employees in the decision-making and adoption process of clean technologies is decisive for improvements in the quality of the working environment" (Getzner, 2002). In similar research, Remmen and Lorentzen indicate an increase in environmental consciousness by providing a more active role for employees in the environmental activities of a company (Remmen and Lorentzen, 2000). Oschner found benefit to worker health and safety by including workers in decision-making around pollution prevention initiatives (Ochsner, 2001).

This study opens a dialog around the effects of CPPP/TUR programs on worker health and safety. Results indicate that, while CPPP/TUR reduces exposure to toxic substances in the general environment, it also offers unique opportunities to reaffirm primary prevention principles in occupational health.

2. Methodology

The study reported here evaluated the effect of CPPP in the form of toxics use reduction (TUR) on worker health and safety at three printed wire board facilities covered under TURA. In-depth case study analysis was used to identify specific TUR activities which had an impact on worker health and safety. The TUR interventions chosen by the three facilities mainly included input substitution or process change that resulted in less toxic substances replacing more toxic substances. These were primarily directed at environmental concerns. The worker health and safety impact of each TUR option was determined based on post-intervention evaluation of the work environment conditions in each plant. While this research primarily uses qualitative methods, it includes limited quantitative methods to evaluate the effectiveness of TUR intervention programs and to analyze the impact of these interventions on worker health and safety. Through the use of two tools, the OSHA Program Evaluation Profile (PEP), (OSHA, 1996), and the Pollution Prevention Options Analysis System (P2OASYS) (Tickner, 1997), quantifiable outcomes were obtained via a numerical scoring system.

The PEP survey identified a firm's degree of sophistication in managing worker health and safety programs. Each firm was evaluated one time with this tool. The PEP survey identified the three case studies as having similar health and safety cultures, commitment of resources, and management sophistication in worker health and safety. In order to test the impact of worker health and safety health changes of TUR interventions it was necessary to be sure that there was comparable "enlightenment" of the companies with regard to health and safety. The second survey instrument used was the Pollution Prevention Options Analysis System (P2OASYS) designed to perform both pre-intervention and post-intervention impact evaluation. The results of both surveys (PEP and P2OASYS) specifically aided in the determination of whether net gains in worker health and safety did take place after the TUR intervention.

An open-ended interview with key informants at the plants (Environmental Health and Safety, or EHS, Managers) was also used to explore how the TUR interventions brought about worker health and safety improvements. The key informant interviews allowed for a qualitative validation of the P2OASYS results. A thematic analysis followed collection of qualitative data.

2.1. Study population

Data was collected from three printed wire board facilities in Massachusetts. These plants are covered by TURA and were selected for the study from a list of several manufacturing facilities throughout the state. The companies chosen were not necessarily representative of the industry. However, each agreed to participate because of their experience with the Toxics Use Reduction Institute (TURI) and its Toxics Use Reduction Planner Program. Facilities ranged in size and structure. Each of the company's TUR activities was intended to have a positive impact on the company's environmental performance. In most cases, the strategy which was selected for reducing environmental impacts was input substitution or process change which resulted in the replacement of less toxic substances for more toxic substances. An outcome of these TUR activities "could have been" reduced worker exposure – although this was not the primary goal of their TUR program. While not every TUR intervention described in this study met the requirements of a "listed" chemical or process under TURA, each one was chosen to represent significant efforts in pollution prevention, which did lead to the reduction of toxics used and generated.

2.2. Survey instruments

2.2.1. OSHA PEP

The OSHA Program Evaluation Profile or PEP (OSHA, 1997), was originally designed by OSHA as an audit tool to assist compliance officers during general industry inspections to assess workplaces and their health and safety programs through a scoring system of six major categories and 15 subcategories. It was developed by representatives of OSHA's National Office and field staff in a cooperative effort with the National Council of Field Labor Locals (NCFLL) and is based on the Health and Safety Program Management Guidelines (Federal Register, January 26, 1989) (OSHA, 1996). It is considered to be an effective tool to measure good faith and to evaluate companies' worker health and safety programs (Rutenberg, 1997). The PEP evaluation form is also used by the OSHA consultation branch and is often left with the employer for their own use in evaluating the effectiveness of their worker health and safety programs.

2.2.2. PEP scoring

An overall score for the worksite is recorded as the average of six individual scores for six elements rounded to the nearest whole number. Each element is provided with five verbal descriptors of workplace characteristics representing five levels. The six elements to be scored in the PEP are:

- Management leadership and employment participation
- Workplace analysis
- Accident and record analysis
- Hazard control and prevention
- Emergency response
- Health and safety training

The researcher personally interviewed workers with questions based on the PEP survey (including all six elements) in order to achieve a more in-depth evaluation of the workers' perception of the health and safety status of the company. The employees were ensured that their responses would not be disclosed to management in any other format than the scored PEP form. The employees were chosen by the key informant (EHS Manager) at each facility, based on their work relationship with the TUR interventions, and/or for their ability to provide insightful responses regarding the operations and production processes of the plant. The experience of the researcher as an occupational health and safety expert/consultant was drawn upon to translate and apply this data.

The overall score (number) on the PEP constitutes the level at which the facility's health and safety program is scored. This level is an informal assessment of the program and does not represent a compliance judgment; that is, it does not determine whether an employer is in compliance with OSHA standards. Table 1 summarizes the levels.

2.2.3. P2OASYS

The second survey instrument used was the Pollution Prevention Options Analysis System (P2OASYS) designed to perform both pre-intervention and post-intervention impact evaluation. In order to measure the TUR intervention impact, this risk characteristics instrument derives a semi-quantitative evaluation of the changes after the TUR intervention (Edwards et al., 2005).

This instrument has 11 key elements or hazard categories with subsections for each element:

Acute human effects (10 elements)*
Chronic human effects (8 elements)*
Physical hazards (5 elements)*

Table 1
OSHA program evaluation profile (PEP) rankings.

Score	Level of safety and health program
5	Outstanding program
4	Superior program
3	Implemented program
2	Developmental program
1	No program

Aquatic hazards (5 elements)
Bioaccumulation (5 elements)
Atmospheric hazard (4 elements)
Disposal hazard (4 elements)
Chemical hazard (13 elements)*
Energy and resource use (3 elements)
Product hazard (3 elements)*
Exposure potential (1 element)*

These elements are measured as quantitative units (PEL's, LD_{50}, etc.) or qualitative units (evaluated as high, medium or low). They are integrated to give a numerical score from zero to 10. Six elements directly measuring worker health are identified in the list above with an asterisk. Depending on the certainty of the data, a percentage certainty factor can be used to weight results of a final score. Scores of elements related to worker health and safety can be calculated separately.

The P2OASYS surveys were conducted at each facility to assess both worker health and safety and environmental health parameters of the current technology or process (before the TUR intervention) compared with the alternative technology or process that was implemented (after the TUR intervention).

2.2.4. Open-ended survey/interview

The final survey instrument used was the open-ended interview conducted with the key informants (EHS Managers) at each facility. This interview was designed to investigate the companies' reasons behind the positive and/or negative impacts on worker health and safety of the TUR intervention, according to upper management. The interview identified the firm's perspective on the effects of the TUR intervention on worker health and safety, the limitations and potentials of the TUR intervention for this purpose, additional opportunities for improvement of the work environment, operational methods to achieve integration of TUR and worker health and safety in one intervention, identification of personnel that could help conduct the integrated intervention, and how to evaluate the performance of the integrated approach.

2.3. Case studies

The descriptions below are based on discussions with the key informants, as well as the researcher's observations during several visits and tours of each company. During these visits, evaluations were made according to both physical and chemical hazards in general and particularly those associated with each TUR project chosen. While these walkthroughs were not as comprehensive as an OSHA safety inspection, the researcher was able to observe firsthand the workings of the plants and the occupational health and safety status of some of the operations.

Two TUR interventions for each facility were chosen to evaluate in this study. These interventions meet the definition of toxics use reduction and pollution prevention. Typical TUR activities for printed wire board manufacturing include the following:

- Reduce drag out
- Reduce and substitute chemicals
- Reduce copper buildup on plating racks
- Reduce chemical losses from evaporation
- Conserve water
- Reduce sludge generated
- Materials recovery

(All three case facilities consistently implemented these general TUR options.)

2.3.1. Data analysis

The PEP instrument provides numerical scores (ranging from 1 to 5) that represent the degree of development of the worker health and safety function in each plant. For each plant the overall (PEP) score was calculated (scale 1–5). The same scores for the six key elements, described in Table 2 were also calculated. The overall score was tested as predictors of net gains in worker health and safety elements of the TUR evaluation survey P2OASYS.

The P2OASYS instrument provided, in addition to environmental impact data, a number of items related to workplace health and safety conditions (elements 1, 2, 3, 8, 10, and 11). The pre-intervention score for each of these elements was subtracted from the corresponding post-intervention score to generate a measure of impact of the intervention. A positive value was interpreted as an improvement and a negative value as worsened workplace conditions.

2.3.2. Study limitations

Observations of worker health and safety activities were limited to short controlled visits. Additional inspections of the operations where the TUR interventions took place were allowed at each plant on two more occasions, for a total of three visits per facility.

The OSHA PEP was used as a guide for the researcher to gather data on the employees' *perceptions* of the condition of their company's worker health and safety program. This information primarily aided in the evaluation process of linking TUR to worker health and safety. Ideally, the OSHA PEP could be used to analyze a company's health and safety status, both before and after a TUR or environmental intervention. This would require a longer duration of study and more data analysis to compare results.

Limitations with the P2OASYS rest in the difficulty of locating systematic, organized, efficient resources for toxicity data on chemicals. There are some very good databases on the Internet; however, most are restricted to providing data based on regulatory requirements under federal environmental and occupational regulations. It is cumbersome and difficult to interpret the quality of the data so that it can provide the information required in each element of the P2OASYS.

The open-ended interviews with each key informant could not be as detailed as originally planned. Due to time constraints on the key informants, the interviews were conducted by phone and lasted for 15 min to 1.5 h. While the researcher was able to ask all the questions of the questionnaire, there was limited time to discuss each answer in much detail.

3. Descriptions of the three facilities selected as case studies

3.1. Company # 1

This company was purchased in 1998 by a larger international PWB manufacturing firm. There were approximately 550 non-union employees in a 200,000 square foot facility manufacturing multi-layer circuit boards (approximately 9000 panels per week). Sales were over $2M annually. This facility was located in a zoned industrial area with houses approximately 600 feet away. It was kept very clean and free of debris in all working areas. Chemical fumes were present in the plant, but ventilation generally appeared to be in good working order. Most equipment was state of the art, and closed in or contained.

Despite the recent purchase of this facility by a larger PWB company, the environmental and safety personnel remained the same with the Environmental Health and Safety (EHS) manager placed organizationally directly under the Vice President of the company. The EHS manager (key informant) attempted to maintain the same atmosphere of the former owner by remaining proactive

Table 2
Outcomes of pollution prevention interventions with three survey instruments.

Survey type	Key elements	Before CPPP/TUR intervention	After CPPP/TUR intervention
OSHA PEP	Management leadership and employee participation		X
Evaluation	Workplace analysis		X
	Accident analysis		X
Semi-quantitative	Hazard prevention and control		X
	Emergency response		X
Scores: 1–5	Health and safety training		X
P2OASYS	Acute human effects[a]	X	X
	Chronic health effects[a]	X	X
Pollution Prevention Options Analysis System	Physical hazards[a]	X	X
	Aquatic hazards	X	X
	Bioaccumulation	X	X
	Atmospheric hazard	X	X
	Disposal hazard	X	X
Scores: low, medium, high (L, M, H)	Chemical hazard[a]	X	X
	Energy/resource use	X	X
	Product hazard[a]	X	X
	Exposure potential[a]	X	X
Open-ended survey	Positive effects of CPPP/TUR intervention on worker safety and health		X
	Barriers or limitations of CPPP/TUR interventions to positively impact worker safety and health		X
Key informants	Opportunities for improvement of worker safety and health		X
	Methods to achieve integration		X
	OHS/EHS team of personnel to promote integration		X
	Performance measures		X
	How to create successful OHS/EHS intervention program		X

[a] OHS emphasis.

with regard to environmental pollution reductions. He considered the company a "pioneer," on the cutting edge, not only in printed wire board manufacturing, but also in toxics use reduction. Prior to 1998, they participated in two of EPA's Design for the Environment Printed Wire Board Projects – alternatives to electroless copper for through-hole metalization and alternatives to tin/lead for final finishes (alternatives to hot air leveling). This facility was also ISO 14000 certified prior to June 1998. They utilized the assistance and services of TURI and the Massachusetts Office of Technical Assistance (OTA). Under the new ownership, the EHS manager was not sure how "innovative and safety driven" management would continue to be. It is his feeling that the current owners may be more "down to business" with the "profit/shareholder/customer satisfaction" mindset. Therefore, since it was still transitioning from old leadership to new, this one location is discussed as a single case in this study (as opposed to the entire company).

Pounds of toxics used peaked in 1993 (considered an "inefficient" year), however pounds of toxic chemicals required per layer-adjusted panel produced in 1996 decreased from 2.06 lb/panel to 1.43 lb/panel in 1998, a 30.6% reduction (data for 1999 was not available).

3.1.1. *TUR interventions*

The firm's TUR interventions chosen for this study were the elimination of chlorinated solvents (1,1,1 tricholoroethane) and the elimination of glycol ethers in outer layer resist processing and outer layer developing. 1,1,1 tricholoroethane was used to remove tape residue from circuit boards due to the tape that had to be applied prior to gold plating. This chemical was replaced with a terpene-based material with a more pleasant orange odor. The process machinery and work area needed little to no modification.

Significant reductions of glycol ether use have been achieved by converting to fully aqueous dry film at Outer Layer (O/L) resist coat/expose/develop/strip. Specifically, fully aqueous dry films were be developed with potassium carbonate versus glycol ethers and stripped with a sodium hydroxide/monoethanol amine/coline mixture versus glycol ethers.

3.2. *Company # 2*

This facility was one of three tech centers of a national PWB manufacturing facility with 10 facilities throughout the U.S. One of the other facilities in New England was to be ISO 14000 certified in May of 2000, with plans for all sites to be certified by year 2002.

This facility was located in an industrial park with other industries nearby. The non-union shop ran 5 shifts per week (first, second and third shifts on the weekdays). They were open 24 h a day, with manufacturing shifts available six days a week, and the Environmental Health & Safety department available 7 days/week. It was considered a prototype shop, not a "volume" shop, producing approximately 1500 multi-layer cores/day and shipping about 250/day. Being a lower volume shop and the prototype facility, their emissions did not go down every year, but they were involved in testing TUR projects for the other facilities. They specialized in military approved applications, and therefore followed the military specs for the product. They did have a goal of 5% reductions in toxics used and generated annually.

The key informant of this facility was also the EHS Manager. There was a separate safety specialist who reported to the EHS Manager. This person handled occupational safety issues such as workers' compensation, Hazard Communication, OSHA training, chemical maintenance, etc. This person was also part of the TUR team, which also included engineers, general management, some technicians, and waste treatment operators. This facility did air monitoring twice a year and as needed if a new process was introduced or an old process was changed. They also performed a comprehensive environmental health and safety audit twice a year. There is a list of 38 elements (or indicators), that made up this audit to confirm compliance and "beyond compliance" status at the facility. There was an in-house Emergency Response Team. All safety programs were in place and updated as needed. As stated in the Employee Health and Safety Policy, the employees were regarded as the company's "most valuable asset" and the prevention of industrial injuries and illnesses was the ultimate goal. There was no current formal safety incentive program; however there had been one in the past.

There was a "Chemical Approval Process" in place for all new chemicals and products that would be purchased for their manufacturing processes. A "team" of process engineers, the safety specialist and the EHS manager worked together to assess the hazards of each chemical being considered by obtaining information and data from the suppliers of each product via MSDS's, Tech Data Sheets, etc. This assessment included a review of toxicity, cost, and hazardous waste management requirements. This team could reject a new chemical/product for any "violations" of these criteria. There was currently a corporate policy not to introduce new chemical hazards into the workplace.

3.2.1. TUR interventions

The firm's TUR interventions chosen for this study were the installation of a new acid recycling and recovery technology for the solder strip line and the use of a plasma etchback system (replacing sulfuric acid system).

3.3. Company # 3

The last facility studied was a single, smaller facility that had been in business for over 30 years. There were approximately 130 non-union employees, about 70% of which had been there since the 1970s, and 30% of which were new, "transients" who often represented a larger employee turnover. The facility was approximately 63,000 square feet and was located in a large residential area. Three shifts operated daily. Annual sales were $12 + Million. Product was single/double sided, multi-layered, rigid printed circuit boards ("Masters", or panels, containing 1–1200 individual printed circuit boards). They manufactured both prototype and production volumes.

There was one EHS Manager (key informant) whose primary responsibility was environmental compliance with additional duties in occupational health. This person's background was environmental engineering. Individual health and safety programs appeared to be in place, however, there was no formal health and safety policy/program. Formal training in occupational safety awareness was sporadic, but was provided when each job warranted it (change in chemistry, process, etc). An outside consultant provided assistance on some worker health and safety issues. There were monthly safety meetings, but not attended by all employees (mostly new hires). There were informal inspections performed by the EHS Manager throughout the plant, as well as an informal chemical evaluation process when considering new products. The company was concerned about liability and seemed to adopt preventive approaches against injuries at the facility. It was company policy to consider occupational health before anything else when looking at TUR options. Air monitoring was done periodically (usually through the insurance carrier's audit 2–3 times per year), and hearing tests wee given to employees annually. There was an Emergency Response Team consisting of shift supervisors, maintenance personnel and operators.

The TUR planning team included managers, engineers, technicians and operators with solicitation for worker input. According to the EHS Manager, there was continuous environmental improvement through better maintenance throughout the plant, allowing for more efficient use of their chemicals (particularly less bath changing). They tried to conserve wherever possible in the plant and improve working conditions (i.e. installing new hoists over the baths to eliminate heavy lifting). One manager indicated that he believed the employees were the company's most important resource. The company was concerned about liability and seemed to adopt approaches to prevent harm to workers and the environment. Similar to the other study facilities, however, this company believed that they should not compromise quality in their processes, as they still had to meet customer needs.

3.3.1. TUR interventions

While this facility was involved in many TUR activities, the two interventions chosen do not fall under the criteria of the TUR Act. In their wastewater recycling process, they changed product from ferrous sulfate to polyferric in a flow-through system (wastewater treatment is not covered under TURA). This not only eliminated the use of ferrous sulfate (1994 saw usage at 34,050 pounds), but the new chemistry also reduced the amount of chemical needed to 1/16th of the ferrous sulfate. It also eliminated the need for extra reducing agents. The second intervention, while meeting the criteria for toxics use reduction, was occupationally driven. In the dry film development process, they replaced sodium carbonate with potassium carbonate.

3.4. OSHA PEP

Table 3 depicts final averaged OSHA PEP scores reported by managers and workers. Overall averages were then taken for each element for managers and workers based on a normal scale (not rounded).

4. Discussion

4.1. Analysis of overall scores

While the total averaged scores from Table 3 indicate that workers and managers are quite close in their perceptions of the health and safety status of their facilities, upon closer examination of the individual responses from the worker questionnaire, it is clear that some areas of the health and safety programs were lacking. We can make general comparisons between the scores of workers and managers; however, there may be bias on the part of the managers' scores, particularly since they scored the survey themselves. Management, in all three companies, was very aware (more educated) of the companies' policies around worker health

Table 3
Final averaged OSHA PEP scores reported by managers and workers of three Massachusetts companies.

Level of safety & health program	Averaged scores
Company # 1	
Managers	4
Workers	3.8
Average of managers and workers	3.9
Company # 2	
Managers	3.6
Workers	3.2
Average of managers and workers	3.4
Company # 3	
Managers	3.3
Workers	3
Average of managers and workers	3.2

and safety, and felt strongly that they had an effective program. These personnel were either directly involved with making these policies (EHS managers), or were engineers or administrative personnel, and not part of the hands-on floor operations. The workers, on the other hand, were very involved with production and floor operations, and could provide detailed information on their knowledge of health and safety programs according to their jobs and their immediate work environment. Thus, there were some obvious differences between managers' and workers' responses, simply because of the position they held in the company.

In our evaluation of the PEP scores, we found that all three facilities' average total score was 3–3.9 (including both managers and employees). According to the OSHA guidelines for the PEP survey, this indicates that each facility has *implemented* an OHS program. Average manager scores were consistently higher than worker scores. Company # 1 scores for both managers and workers were very close in all elements surveyed, thus resulting in the smallest difference between manager and worker scores (0.2).

It is more difficult to see a trend in the responses of the workers because of the varied work experiences of each respondent. We do see, however, that the workers' responses more routinely resulted in a lower score in most elements than those of the managers. Again, this is most likely due to the fact that it is the workers who are more affected by the requirements of the company health and safety program, and experience its limitations firsthand.

4.2. Detailed analysis by company

The average scores of each company (combined managers and workers), when compared to the other companies' scores, indicated that company # 1 scored the highest with an overall score of 3.9. Company # 2 scored the second highest with 3.6, and company # 3 scored the lowest with 3.2. As described in Section 4, companies # 1 and # 2 were the largest of the three facilities. There was an EHS manager who took the lead on TUR activities. Company # 3 was a smaller company with fewer personnel and resources to accommodate both environmental and worker health and safety concerns.

Company # 1: Forty-two percent (42%) of managers in company # 1 scored a 4. Sixty-eight percent (68%) of workers scored a 4. Two percent (2%) of both workers and managers scored a 2. Zero percent (0%) scored a 1. In this case the workers chose 4 in their responses more often than the managers. Greater than half of the total (managers and workers) responded with a score of 4, while only 2% of the responses scored a 2. These scores indicate that both managers and workers agree that the health and safety program at their facility is superior according to the OSHA PEP evaluation system.

The workers interviewed had been with company # 1 for over 12 years. Their jobs ranged from group leader of wet processes, technician in the plating area, waste treatment operator, and supervisor of the analytical lab. They were all somewhat familiar with OSHA standards and were comfortable bringing problems to their supervisors at any time. They all felt that management supported health and safety and met the needs of the employees. They also believed that the safety committee programs were effective in including worker concerns with management decision-making. Some thought the training sessions could be more interesting, however most found them to be helpful. They all generally agreed that toxics use reduction efforts led to a safer work environment for employees.

Company # 2: Twenty-nine percent (29%) of managers in company # 2 scored a 4, while the 24 percent of workers scored a 4. Twenty-seven percent (27%) of workers scored a 2, which was higher than the managers at 14%. Three percent (3%) of the workers scored a 1, with no managers scoring a 1. In this case, the percentage of responses for both managers and workers scoring a 4 was relatively close, however, more workers responded with a 2 and a 1 than the managers. Total responses (managers and workers) of 24 percent scoring a 4 and 20 percent scoring a 2 indicate that almost half of the responses were split between the categories of superior and developmental. However, with more workers responding in the 2 and 1 range, it appears that some aspects of the health and safety program were still developmental. As stated earlier, this variation could be due to the experience and perception of the workers, as production operators, and their "hands-on" dealings with health and safety issues in their area.

Employees interviewed held positions as process group leader, waste treatment operator, and chemical lab technicians. Most had been with the company for 1–5 years, with one individual having been there for 13 years. There was a general consensus that management attended to worker health and safety concerns; however, more as a "reactive" approach rather than proactive. Highly hazardous safety concerns were addressed quickly; however, some safety issues remained a problem. Three workers stated there was a chronic problem with the ventilation system in their area, and that it had still not been completely fixed. Most of the workers were not involved in the worker health and safety committee meetings, and those who were felt it was not very effective in changing things at the plant. According to these workers, their participation in decision-making around occupational and environmental issues was not encouraged. Workers did feel the company had a good emergency response program.

Most of the employees believed that while upper management verbally stressed that worker health and safety is important, they did not follow through with actions of support when needed, especially when production was involved. These workers felt that production was the most important issue to upper management and that it came before any other concerns. Two of the workers said they thought the EHS managers did a good job around occupational and environmental health and safety; however, they were not given adequate authority to override production decisions.

Company # 3: Thirty-six percent (36%) of managers in company # 3 scored a 4, while the 3 percent of workers scored a 4. Seventeen percent (17%) of managers scored a 2 and the 27 percent of workers scored a 2. Interestingly, 2 percent of the managers scored a 1 while zero percent of the workers scored a 1. While more of the managers' responses scored in the superior range, more of the workers' responses scored in the developmental range.

Interviewed employees worked as operators in the dry film and imaging production areas and in quality assurance. They had been with the company for 8 to 21 years. These employees were not very familiar with particular OSHA standards; however, they were aware of general hazard communication and personal protective equipment requirements. They were not aware of a formal written health and safety program. The general feeling was that management supported health and safety in the plant and that the opinions of the employees were considered when making decisions around occupational and environmental issues. All employees felt comfortable bringing up worker health and safety concerns with management. There seemed to be an awareness of toxics use reduction and that management wanted to eliminate toxic chemicals in the plant as much as possible.

One employee felt that worker health and safety concerns were not addressed until a serious incident occurred. Based on the experience of this individual, upper management did not have the "safety mindset" to consider safety first. This person also felt that requirements around personal protective equipment were not always met and that sometimes the supervisors did not comply either with these requirements.

4.3. P2OASYS

4.3.1. Overall scores

The second survey instrument, the Pollution Prevention Options Analysis System (P2OASYS) was used to perform both pre-and post-intervention TUR impact evaluation. This tool allowed us to measure the TUR intervention impact, by deriving a semi-quantitative evaluation of the changes after the TUR intervention.

Table 4 summarizes the results of each TUR intervention with a numerical score for the current technology (before TUR) compared to the alternative (after TUR). While the table below appears to indicate changes in chemistry only, details of the TUR intervention show there were some process changes as well that led to lower ergonomic hazard, lower worker exposure potential, and to reductions in energy use.

In each case below, the alternative, or the TUR option adopted, resulted in a lower score than the current technology, indicating that based on all elements measured by the P2OASYS, the alternative chosen was indeed less hazardous.

Company # 1 replaced glycol ethers with potassium carbonate in the dry film and outer layer development processes, resulting in a lower score for chronic human effects and physical hazards. These two differences in scores were weighted automatically and result in a lower score for the potassium carbonate. The importance of considering chronic human effects and physical hazards when looking at TUR alternatives is represented by the final score giving glycol ethers a 52 and potassium carbonate a 38.

For the second TUR intervention of switching from 1,1,1 trichloroethane to a terpene-based cleaner/degreaser, the terpene alternative scored lower in acute and chronic human effects, physical hazards, and disposal and chemical hazards. The final score was 63 for the 1,1,1 trichloroethane, and a 48 for the terpene.

Company # 2 replaced the old sulfuric acid/permanganate desmear with the plasma desmear, a complete process change. This resulted in a lower score for all elements of the P2OASYS. The second TUR project of installing a new solder strip system that recycled the used nitric acid also resulted in a lower score, particularly within the elements of physical hazard, disposal hazard, energy use, and exposure potential.

Company # 3 switched from using ferrous sulfate to polyferric sulfate in their waste treatment operations, which resulted in a lower score for both acute and chronic human effects, for physical and chemical hazards, and for exposure potential to workers. In the dry film development process, this company went to new system that replaced sodium carbonate with potassium carbonate. This resulted in a lower P2OASYS score in acute human effects, physical hazards, disposal hazard, and exposure potential.

In all three cases, the TUR alternative chosen resulted in lower hazard scores than the current technologies.

4.3.2. OHS elements

As already mentioned in our description of the P2OASYS, there are six elements that measure for changes in worker health and safety when considering TUR options. In all three companies, the scores for the worker health and safety elements of the P2OASYS were lower after the TUR intervention. While not all of these elements could be filled in for each process (current technology vs. alternative) due to lack of systematic technical and chemical databases for each process and/or chemical change, our results do show in each case that the TUR intervention led to a less hazardous work environment This indicates that the TUR intervention did have a positive impact on worker health and safety.

4.4. Open-ended questionnaire

The following points highlight the responses of the key informants (EHS Managers) of each facility regarding the causes of the occupational health changes attributable to the TUR interventions. By interviewing these individuals, we were able to realize the firms' perspective on the effects of the TUR intervention on occupational health, as well as discover the limitations and potential of the TUR intervention for this purpose. We are also able to gain insight regarding additional opportunities for improvement of the work environment; operational methods to achieve integration of TUR and worker health and safety in one intervention, identification of personnel that could help conduct the integrated intervention, and how to evaluate the performance of the integrated approach.

Company # 1

- TUR (reduction or elimination of chemicals) leads to less exposure to employees.
- The TUR option must include aspects of worker health and safety; there should be a check system for all chemical, process or equipment changes in plant to evaluate both environment and worker health and safety risks; all employees involved in the change should be included.
- An integrated approach can be measured by toxic chemical use, Industrial Hygiene monitoring, injury and illness reports, and employee feedback.
- A successful integrated approach must include consistent participation of all employees, from process engineers to operators on the floor. There must be top management support.

Company # 2

- Environment and worker health and safety are equally important; and therefore there is neither a positive nor negative impact of one over the other.
- Costs associated with each TUR option are important, where anticipation of *potential* problems must be considered (environmental and worker health impacts).
- A successful integrated approach must incorporate a system where the TUR option is evaluated by all employees affected by the change, including project managers, process and product engineers, department supervisors, operators, quality control,

Table 4
Final P2OASYS scores.

Pre/post TUR	Company # 1 PEP Ave 3.9		Company # 2 PEP Ave 3.4		Company # 3 PEP Ave 3.2	
Before TUR	Glycol ether	52	Sulfuric-permanganate	86	Ferrous sulfate	61
After TUR	Potassium Carbonate	38	Plasma Desmear	33	Polyferric sulfate	30
Difference		14		53		31
Before TUR	1,1,1 Trichloroethane	63	Old solder strip system	40	Sodium carbonate	50
After TUR	Terpene	48	New solder strip system	14	Potassium carbonate	28
Difference		15		34		38

purchasing, the controller, the business unit manager (GM), and even suppliers of the equipment.
- A company needs to be aggressive with Standard Operating Procedures that spell out internal requirements for evaluating TUR options.

Company # 3
- It is company policy that worker safety comes before TUR, that's why it's important to consider them both together and not separately. Some TUR options actually lead to increased risk to the employees and should not be considered.
- Generally TUR positively impacts worker health and safety, but cost is always a large part of the decision.
- An integrated approach can be measured by tracking toxics reductions, but more importantly, by talking to the operators and getting feedback on how the process is working.
- A successful integrated approach must be *preventive* in that both the environment and worker health and safety risks are considered up front, and all stakeholders are involved in the process (both management and employees).
- An integrated approach must include both environment and worker health and safety equally, i.e. not driven by one over the other. It must be preventive, not just reactive. TURA alone is not enough. It is driven by the pollutant and only in large amounts. Companies must act in good faith to reduce all risks but don't get credit for doing continuous improvements. A program needs to address the role a small business takes to go "beyond compliance."

5. Discussion/observations

The instruments used in our case study evaluation give us a context within which to evaluate, at the corporate level, the effect of environmental intervention programs on worker health and safety. In our analysis above, the methodology used provides a systematic, reasonable quantification of the change in worker health and safety attributable to CPPP/TUR.

The results of the OSHA PEP scores indicate the level of sophistication and the effectiveness of the health and safety program at each facility. The evaluation of each facility, including discussions with the key informants, as well as the workers' and managers' responses to the PEP survey, provide insight into the details of the health and safety program as it has been designed and implemented by management. The responses of the workers allow for additional analysis of the *effectiveness* of the company's program. The workers or operators on the plant floor are more affected by the daily safety requirements of their jobs and therefore provide a more detailed description of how the health and safety program applies to them.

By bringing in the P2OASYS survey, we began our analysis of the relationship between the environment and worker health and safety. We can evaluate how the sophistication of a company's worker health and safety program relates to the success of an environmental intervention program. In other words, is the success of an environmental intervention program contingent upon a superior health and safety program? In what way does the OSHA PEP predict positive impacts of TUR interventions on worker health and safety? Would the difference in P2OASYS scores be less dramatic in companies with lower PEP scores? Do high PEP scores and increased improvement in P2OASYS scores indicate greater integration of environmental protection and worker health and safety? To what extent does worker health and safety motivate TUR and what are the benefits to workers from TUR? What roles do individual personalities, corporate organization, and worker participation play in motivating companies to consider both environment and worker health and safety issues when adopting TUR options?

While the answers to some of these questions are broader than the scope of this research project, we are able to make some conclusions about these three firms based on the tools used and the information gathered from key informant interviews regarding the relationship between the environment and worker health and safety at the corporate level. We cannot say to what extent these conclusions can be generalized to industrial firms, especially those outside of Massachusetts.

- The higher the overall OSHA PEP score, the more sophisticated the company is around worker health and safety issues in general.
- Lower PEP scores and large differences between managers' scores and the workers' scores indicate multiple inefficiencies in the company's OHS program.
- The companies whose managers and workers both scored high in the PEP survey (scoring 4 or greater) were usually more "proactive" around environmental and worker health and safety issues and already adopt a preventive approach towards both concerns.
- Companies with higher PEP scores tend to have personnel with stronger backgrounds in worker health and safety and toxics use reduction.
- Companies with lower PEP scores seemed to lack the resources and skills needed to provide an effective worker health and safety program.
- Smaller companies may not have the resources to carry out the integration of environmental and worker health and safety concerns.
- Large differences in P2OASYS scores (before and after the TUR intervention) indicated a more successful reduction in hazard and exposure potential after the TUR option has been adopted.
- The P2OASYS demonstrated that chemical substitution and process change result in parallel reductions of both occupational and environmental hazards.
- TUR interventions were not usually driven by worker health and safety needs.
- In the cases discussed in this study, TUR had a positive impact on worker health and safety even though the focus of TUR was on the ambient environment, not the work environment.
- These three firms regarded TUR as a way to comply with hazardous waste regulations and to reduce costs associated with waste disposal.
- The requirement to consider toxics use reduction did not seem to encourage these companies to consider environmental and worker health and safety health concerns simultaneously.
- In these three firms, conscious integration of environment and worker health and safety is due to the foresight and preventive approach and philosophy of the company and its employees.

6. Conclusions/recommendations

We looked at three manufacturing facilities' compliance with the Massachusetts Toxics Use Reduction Act. We explored this model of primary prevention and how it relates to both environmental protection and worker health and safety. While the motive for most environmental interventions is waste reduction and resulting cost savings, we saw that CPPP/TUR had an impact on worker health and safety (whether intentional or not). Although this case study analysis is limited to three study cases, it has allowed us to create and utilize a sequential model including tools that support the process of integration. While traditionally there have been divergent paths of practice for worker health and safety and environmental protection, the two are closely connected. We have attempted to demonstrate this important link through the findings of our study. We conclude that the shift from end-of-pipe controls to pollution prevention must emerge as one integrated, holistic strategy to promote primary prevention of injuries, illnesses, and fatalities related to environmental pollution and unhealthy and unsafe work environment conditions. In this way, such measures would become part of a comprehensive public health model that promotes sustainable production and development.

The authors conclude that CPPP/TUR measures have the ability to shift environmental *and* worker health and safety strategies so that exposure prevention is a priority above exposure control. This shift would greatly advance the prevention of adverse environmental and public health outcomes related to industrial production.

This study continues the, so far limited but necessary, dialog around the effects of environmental intervention programs on worker health and safety. We have demonstrated that while CPPP/TUR reduces exposure to toxic substances in the ambient environment, it also offers unique opportunities to reaffirm primary prevention principles in worker health and safety.

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